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INMATEH – AGRICULTURAL ENGINEERING

MAY - AUGUST

Editorial

The National Institute of Research-Development for Machines and Installations designed to Agriculture and Food Industry - INMA Bucharest has the oldest and most prestigious research activity in the field of agricultural machinery and mechanizing technologies in Romania.

Short History

- In 1927, the first research **Center for Agricultural Machinery** in Agricultural Research Institute of Romania - ICAR (Establishing Law was published in O.D. no. 97/05.05.1927) was established;
- In 1930, was founded **The Testing Department of Agricultural Machinery and Tools** by transforming Agricultural Research Centre of ICAR - that founded the science of methodologies and experimental techniques in the field (Decision no. 2000/1930 of ICAR Manager - GHEORGHE IONESCU ŞIŞEŞTI);
- In 1952, was established the Research Institute for Mechanization and Electrification of Agriculture - ICMA Băneasa, by transforming the Department of Agricultural Machines and Tools Testing;
- In 1979, the Research Institute of Scientific and Technological Engineering for Agricultural Machinery and Tools – ICSITMUA was founded - subordinated to Ministry of Machine Building Industry - MICM, by unifying ICMA subordinated to MAA with ICPMA subordinated to MICM;
- In 1996 the National Institute of Research-Development for Machines and Installations designed to Agriculture and Food Industry – INMA was founded – according to G.D. no.1308/25.11.1996, by reorganizing ICSITMUA, G.D no. 1308/1996 coordinated by the Ministry of Education and Research G.D. no. 823/2004;
- In 2008 INMA has been accredited to carry out research and developing activities financed from public funds under G.D. no. 551/2007, Decision of the National Authority for Scientific Research - ANCS no. 9634/2008.

As a result of widening the spectrum of communication, dissemination and implementation of scientific research results, in 2000 was founded the institute magazine, issued under the name of SCIENTIFIC PAPERS **(INMATEH)**, ISSN 1583 – 1019.

Starting with volume 30, no. 1/2010, the magazine changed its name to **INMATEH - Agricultural Engineering**, appearing both in print format (ISSN 2068 - 4215), and online (ISSN online: 2068 - 2239). The magazine is bilingual, being published in Romanian and English, with a rhythm of three issues / year: January-April, May-August, September-December and is recognized by CNCSIS – with B^+ category. Published articles are from the field of AGRICULTURAL ENGINEERING: technologies and technical equipment for agriculture and food industry, ecological agriculture, renewable energy, machinery testing, environment, transport in agriculture etc. and are evaluated by specialists inside the country and abroad, in mentioned domains.

Technical level and performance processes, technology and machinery for agriculture and food industry increasing, according to national requirements and European and international regulations , as well as exploitation of renewable resources in terms of efficiency, life, health and environment protection represent referential elements for the magazine „**INMATEH - Agricultural Engineering**".

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CUPRINS / *CONTENT*

		Pag.
1.	**EXPERIMENTAL RESEARCHES ON WORKING QUALITATIVE INDEXES OF A DEEP LOOSENING EQUIPMENT/** ***CERCETĂRI EXPERIMENTALE PRIVIND INDICII CALITATIVI DE LUCRU AI UNUI ECHIPAMENT DE AFÂNAT SOLUL ÎN PROFUNZIME*** **PhD. Stud. Eng. David Al.[1)], Prof. PhD. Eng. Voicu Gh.[2)], PhD. Eng. Marin E.[1)], Lect. PhD. Eng. Dutu M.[2)], Eng. Gheorghe G.[2)]** [1)]INMA Bucharest / Romania; [2)]University POLITEHNICA Bucharest / Romania	5
2.	**OPTIMAL DESIGN AND DYNAMIC ANALYSIS OF SNOWPLOW DECELERATOR FOR AGRICULTURAL GREENHOUSES /** ***农业大棚扫雪机减速器优化设计及动态特性分析*** **Ph.D. Xiangyang JIN [1)], Ph.D. Eng. Hongling KANG [2)] , B.S. Yiming SUN [1)]** [1)] School of Light Industry, Harbin University of Commerce, Harbin / China; [2)] Department of Mechanical Engineering, Keimyung College of Technology, Daegu /Republic of Korea	13
3.	**DESIGN OF A LOW-COST SYSTEM WITH BUILT-IN-GPS AGRICULTURAL MACHINERY /** ***种基于嵌入式的低成本农业机械 GPS 导航定位系统设计*** **Assoc. Prof. Ms. Lin Hanhui[1)], Assoc. Prof. Ph.D. Cai Ken[2)], Eng. Zeng Zhaofeng[3)]** [1)] Center for Educational Technology, Guangdong University of Finance and Economics, Guangzhou / China; [2)] School of Information Science and Technology, Zhongkai University of Agriculture and Engineering, Guangzhou / China; [3)] Department of Mathematics and Computer Science, California State University, East Bay/ U.S.A	25
4.	**RESEARCH ON SAVING IRRIGATION CONTROL SYSTEM BASED ON THINGS /** ***基于物联网的节水灌溉控制系统研究*** **M.E. Lect. Xiaoying Yang, M.E.. Lect. Wanli Zhang, M.E..Prof. Qixiang Song** College of Information Engineering, Suzhou University, Suzhou, China	37
5.	**STUDY ON THE SOIL MOISTURE MOVEMENT UNDER INFILTRATION IRRIGATION /** ***渗灌条件下土壤水分运移规律研究*** **Prof. Ph.D. Stud. Agr. Feng Yao-zu[1,2)], As. Ms. Agr. Wang Zhi-guo[2)], Prof. Ph. D. Sci. Zhou Jian-bin[1*)], Ph.D. Agr. Yu Dan-lin[3)]** [1)] College of Resources and Environment, Northwest A&F University, Yangling / China, [2)] Institute of Fertilizer and Agricultural Water Conservation, Xinjiang Academy of Agricultural Sciences, Urumqi / China, [3)] Department of Earth & Environmental Studies, Montclair State University, New Jersey / U.S.A.	47
6.	**MATHEMATICAL MODEL CHARACTERIZING THE ANGLE OF SPRAYING JET OF SPRAYERS DESIGNED TO FIELD CROPS /** ***MODEL MATEMATIC DE CARACTERIZARE A UNGHIULUI JETULUI DE PULVERIZARE A MASINILOR DE STROPIT CULTURILE CAMP*** **PhD. Stud. Eng. Niţu (Roşu) M.[1)], PhD. Eng. Vlăduţ V.[1)], PhD. Stud. Eng. Matache M.[1)], PhD. Eng. Vlad C.[2)]** [1)]INMA Bucharest / Romania; [2)]ICEADR / Romania	59
7.	**ORGANIC PLANT AND ANIMAL WASTE MANAGEMENT SYSTEM /** ***SISTEM ECOLOGIC DE GESTIONARE A DEŞEURILOR VEGETALE ŞI ANIMALE*** **PhD. Eng. Ciuperca R., PhD. Stud. Eng. Lazar G., PhD.Eng.Popa L., PhD. Eng. Nedelcu A., PhD. Stud. Ştefan V., PhD. Stud. Eng. Zaica A, PhD. Stud. Eng. Petcu A.** INMA Bucharest / Romania	69
8.	**THE INFLUENCE OF PHYSICAL CHARACTERISTICS OF SOLID ORGANIC FERTILIZERS ON QUALITY OF LAND SPREADING /** ***INFLUENŢA CARACTERISTICILOR FIZICE ALE ÎNGRĂŞĂMINTELOR ORGANICE SOLIDE ASUPRA CALITĂŢII LUCRĂRII DE ÎMPRĂŞTIERE*** **PhD.Stud. Eng.Ştefan (Popa) V., PhD.Eng. Ciupercă R., PhD.Eng. Popa L., PhD. Eng.Nedelcu A., PhD. Stud. Eng. Lazăr G., PhD.Stud. Eng. Petcu A.S., PhD.Stud. . Eng. Zaica A.** INMA Bucharest / Romania	77
9.	**SYSTEM DESIGN AND IMPLEMENTATION OF A NOVEL ROBOT FOR APPLE HARVEST /** ***一种新型苹果采摘机器人系统设计与实现*** **Lect. Ph.D Haifeng Luo[1)] , Lect. Ph.D Guowu Wei[2)]** [1)]The Technology School of Beijing Forest University, Beijing / China; [2)] University of Salford, Manchester/ United Kingdom	85
10.	**THEORETICAL REASONING OF THE COUPLANT EQUIPMENT DRUM POSITION RESPECTIVE TO THE CUT PLANTS /** ***ОБҐРУНТУВАННЯ ПОЛОЖЕННЯ БАРАБАНУ КОНТАКТНОГО ПРИСТРОЮ ВІДНОСНО ЗРІЗУ СТЕБЛА РОСЛИНИ*** **Ass. Ph.D. Eng. Bundza O.Z., Prof. Ph.D. Eng. Kravets S. V., Prof. Ph.D. Eng. Nalobina O.O., Assoc.Prof. Ph.D. Eng. Nikitin V.G.** National University of Water Management and Nature Resources Use, Soborna str., 11, Rivne / Ukraine	95

11. **RESEARCH RESULTS OF HARVESTING HAULM REMNANTS OF ROOT CROPS /** 101
РЕЗУЛЬТАТИ ДОСЛІДЖЕННЯ ОБРІЗУВАННЯ ЗАЛИШКІВ ГИЧКИ КОРЕНЕПЛОДІВ
MSC Eng. Storozhuk I.M.[1)], MSC Eng. Pankiv V.R.[2)]
[1)]National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony 15, Kiev/ Ukraine
[2)] Ternopil Ivan Pul'uj National Technical University, Ruska str., 56, Ternopil/ Ukraine

12. **RESEARCHES ON QUALITY OF LAVENDER SCREENING PROCESS /** 109
CERCETĂRI PRIVIND CALITATEA PROCESULUI DE SORTARE LA LEVĂNŢICĂ *(Lavandula angustifolia L)*
Ph.D. Stud. Biol. Pruteanu. A.[1)], Prof. Ph.D. Eng. David L.[2)], Ph.D. Eng. Vladuţ V. [1)], Ph.D. Stud. Eng. Matache M.[1)], Ph.D. Stud. Eng. Muscalu A.[1)], Ph.D. Eng. Danciu A.[1)]
[1)] INMA Bucharest/Romania
[2)]Polytechnic University of Bucharest, Faculty of Biotechnical Systems Engineering / Romania

13. **ANALYSIS OF A CONVECTIVE DRYING PROCESS OF PLUMS /** 115
ANALIZA PROCESULUI DE DESHIDRATARE CONVECTIVĂ A PRUNELOR
PhD. Stud. Eng. Ingeaua M.[1)], Prof. PhD. Eng. Prisecaru T.[1)], Prof. PhD. Eng. Pirna I.[2)], PhD. Eng. Sorică C.[2)]
[1)] University Politehnica of Bucharest / Romania; [2)] INMA Bucharest / Romania

14. **EXPERIMENTAL ASPECTS REGARDING SEED SEPARATION WITH MECHANICAL SEPARATING MACHINES WITH DRUMS /** 125
ASPECTE EXPERIMENTALE PRIVIND SEPARAREA SEMINŢELOR LA MAŞINILE DE SEPARARE MAGNETICĂ PE TAMBURI
[1, 2)]Ph.D. Stud. Eng. Ciobanu V., [2)] Prof. Ph.D. Eng. Căsăndroiu T., [1, 2)]Ph.D. Stud. Eng. Persu C., [1)] Ph.D. Eng.Păun A., [1)] Ph.D. Eng. Muraru V.
[1)]INMA Bucharest / Romania
[2)] Politehnica University of Bucharest, Faculty of Biotechnical Systems Engineering / Romania

15. **DEVELOPMENT AND INVESTIGATION OF RECIPROCATING SCREW WITH FLEXIBLE HELICAL SURFACE/** 133
РОЗРОБКА ТА ДОСЛІДЖЕННЯ ШНЕКА З ЕЛАСТИЧНОЮ ГВИНТОВОЮ ПОВЕРХНЕЮ
Prof. Ph.D. Eng. Hevko R.B., Eng. Zalutskyi S.Z., Prof. Ph.D. Eng. Tkachenko I.G., Ph.D. Eng. Klendiy O.M.
Ternopil National Economical University, Lvivska Str., 11, Ternopil / Ukraine

16. **ANALYSIS OF LASER-CLADDING REPAIR PERFORMANCE OF WORN UNIVERSAL JOINT SURFACES IN AGRICULTURAL VEHICLES /** 139
农用车十字轴磨损表面的激光熔覆修复性能分析
Ph.D. Stud. Che Lei 1), Prof. Ph.D. Sun Wenlei 1), Lect. Ph.D. Chao Yongsheng 1), Ph.D. Stud. Huang Yong 1), Prof. Ph.D. Weng Yuting2)
[1)] School of Mechanical Engineering, Xinjiang University, Urumqi / China;
[2)] Industrial Engineering Department, SMENT-Chile, Las Condes-158, Santiago / Chile

17. **ESTIMATION OF SOIL'S SORPTION CAPACITY TO HEAVY METALS IN ALGERIAN MEGACITIES: CASE OF ALGIERS AND ANNABA /** 147
ESTIMATION DE LA CAPACITE DE SORPTION DU SOL AUX METAUX LOURDS DANS LES MEGAPOLES ALGERIENNES: CAS D'ALGER ET ANNABA
Ph.D. Stud. Benselhoub A.[1)], Prof. PhD. Kharytonov M.[1)], Prof. PhD. Bounouala M.[2)], Ph.D. Stud. Chaabia R.[2)], Ph.D. Stud. Badjoudj S.[2)]
[1)] Department of Ecology and Environment Protection, State Agrarian and Economic University, Dnipropetrovsk / Ukraine. [2)] Laboratory of Mining Resources valorization and Environment, Mining Department, Badji Mokhtar University, Annaba / Algeria

18. **ANALYSIS OF PROFITABILITY OF IMPLEMENTING THE MISCANTHUS ENERGETIC CROP TECHNOLOGY FOR RHIZOMES CAPITALIZATION /** 155
ANALIZA RENTABILITĂŢII IMPLEMENTĂRII TEHNOLOGIEI DE CULTURĂ A PLANTEI ENERGETICE MISCANTHUS ÎN VEDEREA VALORIFICĂRII RIZOMILOR
PhD. Stud. Eng. Sorică E.
University Politehnica of Bucharest / Romania

19. **COMPREHENSIVE EVALUATION MODEL OF AGRICULTURAL DROUGHT DISASTER RISK /** 165
农业干旱灾害风险综合评估模型
Prof. LI Yanbin, M.E. LI Jia, ASS. Prof. You Feng, ASS. Prof. Zhang Zezhong
North China University of Water Conservancy and Hydroelectric Power, 450011, Zhengzhou, China

20. **HARVESTING SCHEDULING OPERATIONS FOR THE MACHINERY OWNERS UNDER MULTI-FARMLAND, MULTI-TYPE SITUATION WITH TIME WINDOW - AN EMPIRICAL STUDY ARISING IN AGRICULTURAL CONTEXTS IN CHINA /** 175
基于时间窗的多农机点、多农田作业点、 多机型的混合农机资源调度问题研究
Lect. Ph.D. Xiaoning Zhu[1)], Lect. Ph.D. Rui Yan[2)], M. Ec. Hongli Wang[1)]
[1)] School of Economic and Management, University of Science and Technology Beijing, Beijing / China
[2)] School of Economic and Management, Beijing Information Science & Technology University, Beijing / China

EXPERIMENTAL RESEARCHES ON WORKING QUALITATIVE INDEXES OF A DEEP LOOSENING EQUIPMENT
/
CERCETĂRI EXPERIMENTALE PRIVIND INDICII CALITATIVI DE LUCRU AI UNUI ECHIPAMENT DE AFÂNAT SOLUL ÎN PROFUNZIME

PhD. Stud. Eng. David Al.[1)], Prof. PhD. Eng. Voicu Gh.[2)], PhD. Eng. Marin E.[1)], Lect. PhD. Eng. Dutu M.[2)], Eng. Gheorghe G.[2)]
[1)]INMA Bucharest / Romania; [2)]University POLITEHNICA Bucharest / Romania
Tel:0720569365.; E-mail: Somy_alex_07@yahoo.com

Abstract: *The paper presents the results of experimental tests of deep soil loosening machine EAA – 220 in order to determine the following qualitative indexes: soil loosening degree, working depth, working width and soil levelling degree. Experimental tests were performed at INMA Bucharest (during 2012, 2013 and 2014) where the average humidity of soil was u = 29.9% and average resistance necessary to penetrate the soil of 2840.5 kPa.*

Keywords*: loosening degree, levelling degree, loosening equipment.*

INTRODUCTION

Soil compaction consists in diminishing its apparent porosity and density. This phenomenon is determined by natural causes (impact of rain droplets, humidity, tensions of soil water) or because of the action of agricultural machines' running parts (artificial compaction).

Through compaction, the soil is less permeable to water draining on soil surface, determining soil erosion. Soil aeration both reduces and increases soil mechanical resistance, negatively influencing plants development.

Soil damaging caused by compaction is explained by agricultural machines and tractors mass increase and inappropriate crop rotation. Main factors of soil artificial compaction are:

- Soil type;
- humidity;
- form and area of contact surface;
- type of running part
- tyre pressure
- number of passes

- **Influence of soil type on compaction**

Because of pressures exerted, the soil is subject to deformations, mostly generated by movement of pores between the mineral skeleton' particles, and, if the pores are saturated with water, the settlement depends on the manner in which the liquid is evaporated. [14]

Following the researches achieved by Ellies, (2000) it has found out that, in coarse texture soil the predominant direction of tensions propagation is vertical, while in fine texture soil they propagates towards all directions. At the same time, within a well-structured soil (aggregated soil), compaction determined by external load has not manifested at great depth, [6].

- **Influence of humidity on compaction**

In farming, especially the humidity is the most important factor for soil compacting potential. Humidity determines the manner in which the soil deforms under the action of running parts, [6]. Complete dry soil, between particles of which the friction is present, can support high external

Abstract: *În lucrare se prezinta rezultatele incercarilor experimentale ale masinii de afânare adânca a solului EAA – 220 în vederea determinării următorilor indici calitativi: gradul de afânare al solului, adâncimea de lucru, lătimea de lucru si gradul de nivelare al solului. Încercările experimentale s-au efectuat la INMA Bucuresti (in anii 2012,2013 si 2014) unde umiditatea medie a solului a fost u = 29,9% iar rezistenta medie necesară penetrării solului de 2840,5 kPa.*

Cuvinte cheie: *grad de afânare, grad de nivelare, echipament de afânare.*

INTRODUCERE

Compactarea solului consta in micsorarea porozitatii si densitatii aparente a acestuia. Acest fenomen se produce datorita unor cauza naturale (impactul cu picaturile de ploaie, umezirea, tensiunile interne ale apei din sol) sau datorita actiunii organelor de rulare ale masinilor agricole (compactarea artificiala).

Prin compactare solul este mai putin permeabil pentru apa care se scurge pe suprafata solului producand eroziunea acestuia. Aerarea solului si reduce si creste rezistenta mecanica a acestuia influentand in mod negative dezvoltarea plantelor.

Degradarea solului prin compactare se datoreaza cresterii masei masinilor agricole si tractoarelor si rotatiei necorespunzatoare a culturilor. Principalii factori ai compactarii artificiale a solului sunt:

- tipul solului;
- umiditatea;
- forma si aria suprafetei de contact;
- tipul organului de rulare
- presiunea din pneu
- numarul de treceri.

- **Influenţa tipului de sol asupra compactării**

Datorită presiunilor exercitate asupra sa, solul suferă deformaţii generate în cea mai mare parte de micşorarea porilor dintre particulele scheletului mineral, iar dacă porii sunt saturaţi cu apă, tasarea este condiţionată de modul în care se produce evacuarea lichidului [14]

Din cercetările realizate de Ellies ş.a., (2000) s-a descoperit că în solul cu textură grosieră, direcţia predominantă de propagare a tensiunilor este verticală, iar în solul cu textură mai fină tensiunile se propagă multidirecţional. De asemenea, într-un sol bine structurat (sol agregat), compactarea provocată de sarcina exterioară nu s-a manifestat la adâncime mare, [6].

- **Influenţa umidităţii asupra compactării**

Îndeosebi în agricultură, umiditatea este cel mai important factor pentru potenţialul de compactare al solului. Umiditatea determină modul în care solul se deformează sub acţiunea organelor de rulare, [6]. Solul

loads and contact pressures, being almost impossible to compact. As soil moisture increases, water acts as a particles binder favoring particles agglomeration and thus, soil is easily compacted. [4; 8;10; 12].

- **Influence of shape and area of contact surface on soil artificial compaction**

  Area of contact surface between the running part and soil greatly influences the manner of propagation of soil tensions. Increase of contact surface does not necessarily determine the diminishing of soil tension, but limits the propagation of high tensions in depth, respectively extends them to horizons close to soil surface [1].
- **Influence of running part type on soil artificial compaction**

  Tensions applied on soil by farming wheeled machines or machines endowed with tyres, are dynamic, the soil stress time is short, and arable soil is usually unsaturated and structured, [10].

Tensions under the running parts of agricultural vehicles were measured and presented in many specialty studies, performed in laboratory, in ground channels but also in field (Kirby and Zoz, 1997). Tensions in contact spot generally vary from approx. 50 kPa (under the tracks and double or large tyres), to 300 kPa or even more (under narrow tyres of heavy vehicles such as cotton harvesting machines) (Kirby and Blunden, 1992), [11].

- **Influence of tyre pressure on soil artificial compaction**

Tyre pressure determines the tyre rigidity, which has a significant influence on contact surface between soil and tyre, as well as pressure distribution in contact surface. As for the agricultural soil, because of tyre higher pressures, small contact surfaces form, soil damages much more and tensions are transmitted deeper into the soil; therefore, it is necessary to remedy the negative effects of tensions transmission at great depth (e.g.: deep loosening requires a high energy consumption [1].

Perdok and Tijink (1990) and Wood and Burt (1987) have performed tests in ground channels with tyres of 18.4-38, both in rigid soils and ploughed soils. In order to vary the pressure on soil, dynamic loads of 10 and 20 kN and tyre pressures between 110 and 140 kPa, have been used. These studies have demonstrated that tyre pressure determines the size of horizontal components of forces located in contact spot center between soil and tyre, as well as dynamic load distribution on this surface contour, [3].

- **Influence of number of passes on soil artificial compaction**

Number of passes influences the extent of soil stress. Generally, light-weight tractors involve an increase number of passes on soil, thus intensifying compaction of vegetal soil, excepting the case when the contact pressure with soil is substantially reduced, [8]. In light soils, or when the tensions are high enough, both severity and depth of compaction increase along with agricultural vehicle passes (Kirby and al.., 1997a). At first pass of the wheel, soil settles much more in comparison with the subsequent passes compaction (Cooper et al., 1969; Soane, 1980), [2, 11], this reaction of soil being connected to the initial level of compaction and deep compaction distribution, [2].

complet uscat, între particulele căruia există frecare, poate susţine sarcini exterioare mari şi presiuni de contact mari, fiind aproape imposibil de compactat. Pe măsură ce creşte umiditatea solului, apa acţionează ca liant între particule favorizând aglomerarea acestora, iar solul se va compacta mai uşor, [4; 8;10; 12].

- **Influenţa formei şi ariei suprafeţei de contact asupra compactării artificiale a solului**

Aria suprafeţei de contact dintre organul de rulare şi sol are o influenţă majoră asupra modului de propagare a tensiunilor în sol. Creşterea suprafeţei de contact nu conduce neapărat la scăderea intensităţii tensiunii din sol, ci la limitarea propagării tensiunilor mari în adâncime, respectiv la extinderea acestora în orizonturi din apropierea suprafaţei solului [1].

- **Influenţa tipului organului de rulare asupra compactării artificiale a solului**

Tensiunile aplicate pe sol de către maşinile agricole pe pneuri sau pe şenile sunt dinamice, timpul de solicitare a solului de către organele de rulare este scurt, iar solurile arabile sunt de obicei nesaturate şi structurate, [10].

Tensiunile sub organele de rulare ale vehiculelor agricole au fost măsurate şi prezentate în multe studii de specialitate, realizate în laborator în canale de sol, dar şi în câmp (Kirby şi Zoz, 1997). Tensiunile în pata de contact variază, în general, de la aproximativ 50 kPa (sub şenile şi pneuri late sau duble), la 300 kPa sau mai mult (sub pneuri înguste ale vehiculelor grele, precum maşinile de recoltat bumbac) (Kirby şi Blunden, 1992), [11].

- **Influenţa presiunii din pneu asupra compactării artificiale a solului**

Presiunea din pneu determină rigiditatea pneului, care are o influenţă semnificativă asupra suprafeţei de contact dintre sol şi pneu, precum şi asupra distribuţiei presiunii în suprafaţa de contact. În cazul solului agricol, datorită presiunilor mai mari în pneuri se formează suprafeţe de contact mai mici, solul se deformează mai mult, iar tensiunile se transmit mai adânc în sol, din acest motiv fiind necesare lucrări de remediere a efectelor negative ale transmiterii tensiunilor pe adâncimi mari (ex: afânarea adâncă necesită un consum mare de energie), [1].

Perdok şi Tijink (1990) şi Wood şi Burt (1987) au efectuat teste în canale de sol cu anvelope 18.4-38, atât pe soluri rigide cât şi pe soluri arate. Pentru a varia presiunea pe sol s-au folosit sarcini dinamice de 10 şi 20 kN şi presiuni în pneu între 110 şi 140 kPa. Aceste studii au demonstrat că presiunea din pneu determină mărimea componentelor orizontale ale forţelor în centrul suprafeţei de contact dintre sol şi pneu, precum şi distribuţia greutăţii dinamice pe conturul acestei suprafeţe, [3].

- **Influenţa numărului de treceri asupra compactării artificiale a solului**

Numărul de treceri influenţează numărul solicitărilor asupra solului. În general, utilizarea tractoarelor uşoare implică un număr crescut de treceri pe sol, intensificând astfel compactarea stratului de sol vegetal, cu excepţia cazului în care presiunea de contact cu solul este redusă substanţial, [8]. În solurile suficient de slabe, sau atunci când tensiunile sunt suficient de mari, atât severitatea cât şi adâncimea la care se manifestă compactarea cresc cu numărul de treceri ale vehiculului agricol (Kirby ş.a., 1997a). La prima trecere a roţii, solul se compactează mai mult comparativ cu următoarele treceri (Cooper ş.a., 1969; Soane, 1980), [2, 11], această reacţie a solului fiind legată de nivelul iniţial de compactare şi de distribuţia compactării în adâncime, [2].

MATERIAL AND METHOD

Experimental researches for determining the qualitative working indices have been performed using an aggregate made of soil deep loosening equipment EAA 220 and a tractor New Holland T6070 (fig. 1a), respectively Agrotron L720 Deutz-Fahr (fig. 1b).

Soil deep loosening equipment [13] for which were determined the qualitative working indices requires driving power sources (tractors) of 140-220 HP (103-163 kW), being endowed with two working parts, with 1.9 m distance between them.

Main constructive and functional parameters, characterizing the loosening part are:

- angle formed by the share with the supporting plan: 0.696 rad;
- dimensions of share (L x l): 500 x 100 mm;
- shape of share blade: rectangular;
- frequency of oscillations: adjustable by the rotation of tractor's PTO, between: 8.6 – 10.7 Hz;
- amplitude of share edge oscillations: 18 mm.

MATERIAL ŞI METODĂ

Cercetările experimentale pentru determinarea indicilor calitativi de lucru s-au realizat utilizând un agregat format din echipamentul de afânare adânca a solului - EAA 220 şi un tractor New Holland T6070 (fig. 1a), respectiv Agrotron L720 Deutz-Fahr (fig. 1b).

Echipamentul de afânare adâncă a solului [13] pentru care s-a urmărit determinarea indicilor calitativi de lucru, necesită pentru acţionare surse energetice (tractoare) cu puteri cuprinse între 140-220 CP (103-163 kW), acesta fiind prevăzut cu două organe active de lucru, cu distanţa dintre ele de 1,9 m.

Principalii parametri constructivi şi funcţionali, care caracterizează organul activ de afânare sunt:

- unghiul format de brăzdar cu planul de sprijin: 0.696 rad;
- dimensiunile brăzdarului (L x l): 500 x 100 mm;
- forma tăişului brăzdarului: rectangulara;
- frecvenţa oscilaţiilor: reglabilă prin turatia arborelui prizei de putere a tractorului, între: 8,6 – 10,7 Hz;
- amplitudinea oscilaţiilor vîrfului brazdarului: 18 mm.

Fig. 1 – Equipment designed to soil deep loosening- EAA 220 in aggregate with
a) New Holland T6070 tractor; b) Agrotron L 720 Deutz - Fahr tractor

During the tests the following parameters were varied:

- working depth: 0.5, 0.6 and 0.7 m;
- working speed: 0.192 – 1.25 m/s (0.69 – 4.5 km/h);
- frequency of share edge oscillation: f=8.6 – 10.7 Hz.

the following values being determined:

- soil loosening degree;
- soil levelling degree;
- working depth;
- share working width.

Determination of working depth [14] has been made by a furrow measuring device, by measuring the distance between unploughed field surface and furrow made by the working part. Subsequently, based on measurements, the average working depth was calculated, namely, a_m

În timpul experimentărilor au fost variaţi următorii parametri:

- adâncimea de lucru: 0,5, 0,6 şi 0,7 m;
- viteza de lucru: 0,192 – 1,25 m/s (0,69 – 4,5 km/h);
- frecvenţa oscitaţiei brăzdarului: f=8,6 – 10,7 Hz.

determinându-se următoarele mărimi:

- gradul de afânare al solului;
- gradul de nivelare al solului;
- adâncimea de lucru;
- lătimea de lucru a unui brăzdar.

Determinarea adâncimii de lucru [14] s-a realizat cu ajutorul unui brazdometru, prin măsurarea distanţei dintre suprafaţa câmpului nearat şi fundul de brazdă lăsat de organul de lucru. Pe baza măsurătorilor s-a calculat ulterior adâncimea medie de lucru, a_m:

$$a_{dm} = \frac{\sum_{1}^{n} a_{di}}{n} \quad (1)$$

where:

a_{di} – working depth experimentally measured;
n – number of measurements performed.

unde:

a_{di} - adâncimea de lucru măsurată exprimatal;
n - numărul măsurătorilor efectuate.

For verification, the working depth was measured by gauge tape, after manually removing the soil dislocated by share (fig. 2).

Pentru verificare, adâncimea de lucru s-a măsurat si cu ruleta, dupa indepartarea manuala a solului dislocat de brazdar (fig. 2).

Fig. 2 – Determination of working depth by gauge tape

Determination of the working width was measured by gauge tape the distance from each peg marking the displaced soil limits after being manually removed (fig. 3). Thus, using the working widths previously measured in different points of furrow, the average working width has been calculated, L_m:

Determinarea lăţimii de lucru s-a realizat prin măsurarea cu ruleta a distanţei de la fiecare ţăruş de marcare a limitelor solului dislocat după ce acesta a fost indepartat manual (fig. 3). Astfel, utilizând lăţimile de lucru efective măsurate anterior în diferite puncte ale brazdei, s-a calculat lăţimea medie de lucru, L_m:

$$L_m = \frac{\sum_{1}^{n} L_i}{n} \quad (2)$$

where:

L_i – working width measured;

n – number of measurements performed.

Determination of loosening and levelling degree of soil was made by measuring the coordinates of different points reported to a reference system consisting of a rule placed horizontally on two pegs above the field, perpendicularly oriented towards the machine's forward direction.

The loosening degree and levelling degree (fig.4) were determined by measuring the distances between the rule and field, from 10 to 10cm, before and after the passing of loosening equipment.

în care:

L_i - lăţimea de lucru măsurată;

n - numărul măsurătorilor efectuate.

Determinarea gradului de afânare şi a gradului de nivelare a solului s-a realizat prin măsurarea coordonatelor diferitelor puncte faţă de un sistem de referinţă constând într-o riglă aşezată orizontal deasupra câmpului pe doi ţăruşi, orientată perpendicular pe direcţia de înaintare a maşinii.

Determinarea gradului de afânare şi a gradului de nivelare a solului (fig. 4) s-a realizat măsurând distanţele dintre riglă şi câmp, din 10 în 10 cm, înainte si după trecerea echipamentului de afânare.

Fig. 3 – Determination of working width

Fig. 4 – Determination of soil loosening degree

Soil levelling degree is given by the relation:

Gradul de nivelare a solului este dat de relaţia:

$$G_{ns} = \frac{\sum_{i=1}^{i=n} h_{1i} - h_{2i}}{\sum_{i=1}^{n} h_{1i}} .100 \ [\%] \quad (3)$$

where:
h_{1i} – measured height of field levelling before the machine passing;
h_{2i} - measured height of field unevenness after the machine passing;
n – number of measurements performed.
And soil loosening degree:

în care:
h_{1i} - înălţimea măsurată a denivelării terenului înainte de trecerea maşinii;
h_{2i} - înălţimea măsurată a denivelării terenului după trecerea maşinii;
n - numărul măsurătorilor efectuate.
iar gradul de afânare a solului:

$$G_{as} = \frac{\sum_{i=1}^{i=n} h_{3i} - h_{1i}}{\frac{h_{3i}}{n}} 100 \ [\%] \quad (4)$$

where:
h_{3i} – dimension measured in the same point from the rule to the bottom of the furrow let by the machine.

în care:
h_{3i} - dimensiunea măsurată în acelaşi punct de la riglă la fundul brazdei lucrate de maşină.

RESULTS

For determining the soil levelling degree and loosening degree, 31 tests have been performed, the results for 15 and 26 tests being shown below.

Soil leveling degree resulted after its loosening by equipment EAA 220 is shown in table 1 and graphic representing the distances h_1, h_2 si h_3 measured at test 26 is shown in figure 5 and, respectively for test 15 in figure 6.

REZULTATE

Pentru determinarea gradului de nivelare si gradului de afânare a solului s-au realizat o serie de 31 de probe, fiind prezentate mai jos rezultatele pentru proba 15 si proba 26, considerate a fi reprezentative.

Gradul de nivelare a solului rezultat după afânarea acestuia cu echipamentul EAA 220 este prezentat în tabelul 1 iar reprezentarea grafica a distantelor h_1, h_2 si h_3 masurate la proba 26 este prezentata in figura 5 si pentru proba 15 in figura 6.

Table 1

Soil unevenness height

Measuring distance	Test 26			Test 15		
	h_1 [cm]	h_2 [cm]	h_3 [cm]	h_1 [cm]	h_2 [cm]	h_3 [cm]
10	68	68	68	61.5	61.5	61.5
20	67	67	67	61	61	61
30	66	66	66	62	62	62
40	65	65	65	60	60	60
50	64	64	64	62	62	62
60	63.5	61	72	62	52	80
70	64	59	78	64	50	100
80	63.5	55	85	65	50	110
90	65	54	95	66	52	120
100	65	52	110	65	51	123
110	65	52	130	63	52	115
120	66.5	53	132	62.5	51	95
130	69	52	120	60	55	85
140	70	55	112	60	60	60
150	69.5	61	86	61	61	61
160	69	63	80	63	63	63
170	65	65	65	61	61	61
180	63.5	63.5	63,5	63	63	63
190	66	66	66	62	62	62
200	65	65	65	63	63	63

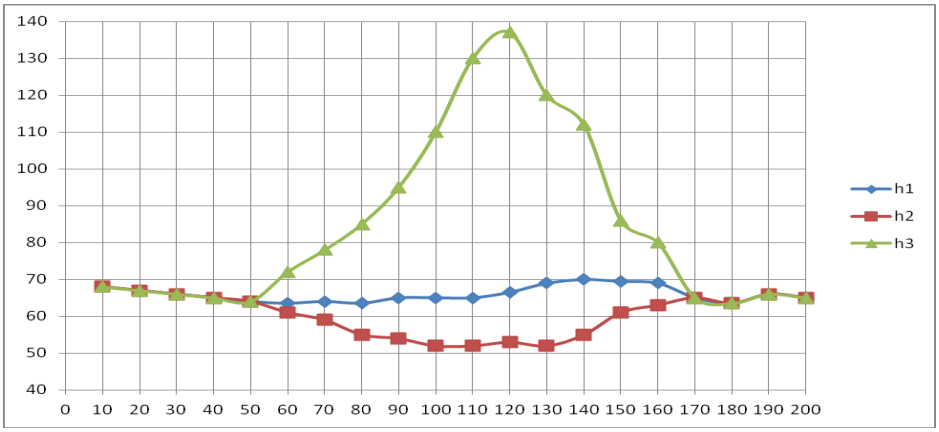

Fig. 5 - Distances h1, h2 and h3 measured at test 26(working depth of 0.7m) for determining the soil levelling and looosening degree

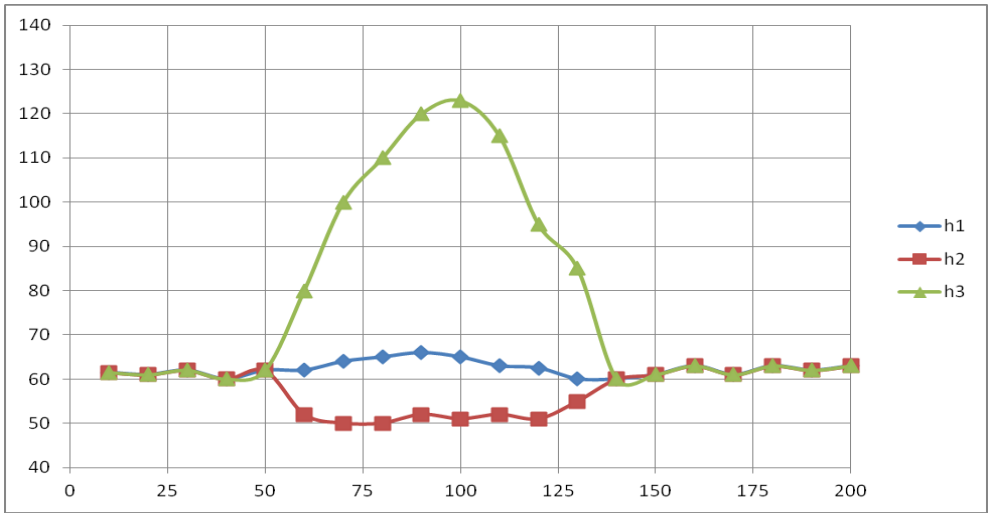

Fig. 6 - Distances h1, h2 and h3 mesured at test 15 (working depth of 0.6m) for determining the soil levelling and looosening degree

In table 2 are presented the following values: loosening degree, leveling degree, working depth and working width.

In tabelul 2 sunt prezentate: gradul de afânare, gradul de nivelare a solului, adincimea si latimea de lucru.

Table2

Qualitative indexes of soil loosening machine

Den. no.	Test	Depth [m]	Speed [m/s]	Frequency [Hz]	a_d [m]	L [m]	G_{as} [%]	G_{ns} [%]
1	5	0.5	0.192	8.6	0.485	0.8	11.98	5.8
2	6		0.2	8.6	0.52	0.9	11.2	5.65
3	7		0.195	8.6	0.495	0.7	10.98	5.41
Average values					***0.5***	***0.8***	***11.38***	***5.62***
4	12	0.6	0.694	9.3	0.59	0.8	15.8	7.75
5	13		0.736	10.16	0.61	1	15.8	8.4
6	14		0.758	8.6	0.57	0.8	14	8.2
7	15		1.25	9.2	0.58	0.9	15.02	7.4
8	17		1.064	9.8	0.61	0.9	15.1	7.04
9	20		0.72	9.116	0.59	0.9	14.8	8.6
Average values					***0.59***	***0.88***	***15.086***	***7.89***
10	24	0.7	1.028	8.61	0.71	1.1	19.62	10.68
11	25		1.028	8.61	0.7	1.2	17.4	10.78
12	26		0.772	8.61	0.705	1.2	17.01	8.46
13	27		0.861	9.667	0.71	1.2	20.3	9.16
14	28		0.994	10.67	0.705	1.2	22.57	11.24
15	30		0.794	10.7	0.71	1.1	19.71	8.6
Average values					***0.706***	***1.16***	***19.43***	***9.82***

CONCLUSIONS

- Variation of working depth, experimentally determined, in comparison with set depth, was of 0.16 – 0.66%. Average working width of deep soil loosening machine is maximum for the maximum working depth (1.16m for 0.7m depth) and diminishes along with depth, being of 0.8m for a working depth of 0.5m;
- The soil average degree depends on the working depth, being 5.62% for a working depth of 0.5m and 9.82% for 0.7 working depth;

CONCLUSIONS

- Variatia adâncimii de lucru determinata experimental, fata de adâncimea reglata, a fost de 0.16 – 0.66%. Latimea medie de lucru a masinii de afânare adânca a solului are valoarea maxima pentru adâncimea maxima de lucru (1,16m pentru adâncimea de 0.7m) si scade odata cu scaderea adâncimii fiind de 0.8m pentru adâncimea de lucru de 0.5m;
- Gradul mediu de nivelare a solului depinde de adâncimea de lucru fiind de 5.62% la o adâncime de 0.5 m, respectiv 9.82% la adâncimea 0.7 m;

- Average loosening degree of soil is of maximum 20.44% for 0.7m working depth.

It can be noticed that the levelling degree and loosening degree, both depend on working depth, having maximum values for 0.7m working depth.

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- Gradul mediu de afânare al solului are valoarea maxima 20.44% pentru adâncimea de lucru de 0.7m.

Se observă că atât gradul de nivelare cât şi gradul de afânare a solului depind de adâncimea de lucru având valorile maxime pentru adâncimea de 0.7m.

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[16] *** STAS 6926/3-78 - *Măsurarea dimensiunilor exterioare.*

OPTIMAL DESIGN AND DYNAMIC ANALYSIS OF SNOWPLOW DECELERATOR FOR AGRICULTURAL GREENHOUSES
/
农业大棚扫雪机减速器优化设计及动态特性分析

Ph.D. Xiangyang JIN [1], Ph.D. Eng. Hongling KANG [2] , B.S. Yiming SUN [1]
[1] School of Light Industry, Harbin University of Commerce, Harbin / China;
[2] Department of Mechanical Engineering, Keimyung College of Technology, Daegu /Republic of Korea
Tel:0451-84865182; E-mail: jinxiangyang@126.com

Abstract: *A decelerator with high efficiency used in a snowplow for agricultural greenhouses was designed. Firstly, some decelerator types which can be used in snowplow were analyzed and a closed epi-cyclic gear, which has the effect of power-splitting, was used as the drivetrain of the deceleration system. A combination of the Ant Colony Algorithm and the Interior Point Penalty Function was adopted for the optimal design of the decelerator. Specifically, a structure that can be compensated has been designed to make sure the sealing security of the decelerator. To satisfy with the large torque of the decelerator, the finite element analysis (FEA) was performed for optimizing the key components of the decelerator. According to the FEA results, the decelerator was restructured to reach the optimum state. In addition, a virtual prototype model of the decelerator was established to make interference detection and motion simulation by using Pro/E software. As a result, the model was adjusted and checked by the above calculus, the interference was detected and removed. This paper offers the theoretical foundation to the mechanism designing and the simulation for the snowplow.*

Keywords: *Snowplow; Ant Colony Algorithm; Finite element analysis; Interference detection*

INTRODUCTION

The heavy snow in winter is a serious disaster for the greenhouse. If not being promptly cleaned up, the deep snow will affect the growth of vegetable. Therefore, one of the urgent affairs currently is to find a way, which is more efficient, simply structured and with low cost [4], to clean the snow before covering the greenhouse with plastic films.

At present, there are four common snow removing methods including the artificial snow cleaning, the chemical deicing salt, the thermal deicing, and the mechanical deicing [3, 6, 7]. The artificial snow cleaning method has low efficiency and bad work environment. The chemical deicing salt pollutes the soil. The thermal deicing is an energy-consumed method with high cost. The mechanical deicing has been enjoyed in the widest application for having advantages of high sweeping efficiency and no pollution from chemicals. Snowplow for greenhouse has small size, required transmission power and transmission ratio is large, traditional bulky decelerator can not meet the requirement of snow cleaning equipment for greenhouse' use [1, 5, 9]. Therefore, this paper designed a new kind of decelerator for the greenhouse snowplow, which has the higher transmission power and smaller size.

The driving types of the snowplow decelerator were studied to select the best type. The improved Ant Colony Algorithm was adopted to build an optimum model. The

摘要：*设计出一种高效农业大棚扫雪机用减速器。首先对能实现同轴减速的传动类型进行计算和分析,采用具有功率分流作用的封闭周转轮系作为减速系统的传动型式，将蚁群算法和内点惩罚函数法结合，对减速器进行优化设计。专门设计可补偿式结构来保证减速器的密封安全。为了满足减速器各元件在大扭矩作用下的强度要求,对减速器关键元件进行有限元分析，并根据分析结果对减速器结构进行调整以达到最优状态。利用 Pro/E 软件建立减速器的虚拟样机模型，进行干涉检测和运动仿真，根据仿真结果对减速器虚拟样机进行调整，去除干涉，并与理论计算进行验证。为农业大棚减速系统结构设计和计算机仿真提供理论依据。*

关键词: *扫雪机; 蚁群算法; 有限元分析; 干涉检测*

引言

冬季的暴风雪对农业大棚的危害巨大，如果不及时清理，积雪就会影响蔬菜的生长。因此，当务之急，是寻找一种高效、结构简单、低成本的大棚清雪方法[4]，在覆膜之前能将大棚积雪清理干净。

目前，有四种常用的清雪方法，包括人工清雪法、化学溶解法、热熔法、机械清雪法[3,6,7]。人工清雪法效率低，工作环境恶劣。化学溶解法溶解冰雪虽然很有效，但有明显不足，就是污染土壤。热熔法比化学熔解法快，但能耗高，限制了其应用。机械清雪法效率高，无污染，应用日益广泛。大棚清雪设备体积小，要求传递的功率和传动比大，传统减速器体积大，不能满足大棚清雪设备的使用要求[1,5,9]。本文为大棚清雪设备设计了一种新型减速器，传动效率高，节省空间。

本文对扫雪机械的减速器的传动类型进行分析，选择最佳传动方式，对新型减速器的结构进行了创新设计，并进行了理论计算，采用改进的蚁群算法建立了寻优模型，给

result was compared with those of traditional optimization design methods. Next, the key components of the decelerator were checked and optimized by using the finite element analysis (FEA). The calculation to the important transmission part of the snowplow was checked. The 3D models of every part and components in the snowplow were created. The models were used for the virtual assembly to simulate the motion of the decelerators.

MATERIALS AND METHODS

Design of the drive scheme for the deceleration system

For a decelerator, it is crucial to design a speed-reducing and torque-increasing device. This device matches the rotational speed of the combustion engine to the speed of the output shaft, and gives solution to the connection between the engine with a high speed and low torque and the shaft with a low speed and high torque. Figure 1 shows the appearance of the snowplow decelerator for the agricultural greenhouse. Considering the small installation space of the decelerator as well as the large drive power and ratio, a reasonable selection of the driving type for the decelerator is a key step to design the snowplow. According to the mechanical drive theory, drive types can be used in snowplow such as the fixed axis gear, the harmonic gear, the NGW-type planetary gear, the N- and NN-type planetary gear with few teeth difference.

出寻优结果，并与传统优化设计方法进行比较。采用有限元分析对减速器关键部件进行校核，根据校核结果进一步优化结构设计。建立三维实体模型和虚拟装配，对减速器进行运动仿真研究。

材料与方法

减速系统传动方案设计

减速器设计的关键是能够设计使内燃机转速与输出轴转速相匹配的减速增矩装置，解决内燃机转速高、扭矩小，与输出轴转速低、扭矩大之间的连接。农业大棚清雪车外形如图 1 所示，由于减速器的安装空间小，需要传递的功率和传动比大，因此合理选择减速器传动类型是设计扫雪机械的关键步骤。从机械传动的理论来讲，扫雪机械可以采用定轴轮系、谐波齿轮传动、NGW 型行星轮系、N 型少齿差行星轮系及 NN 型少齿差行星轮系等传动方式。

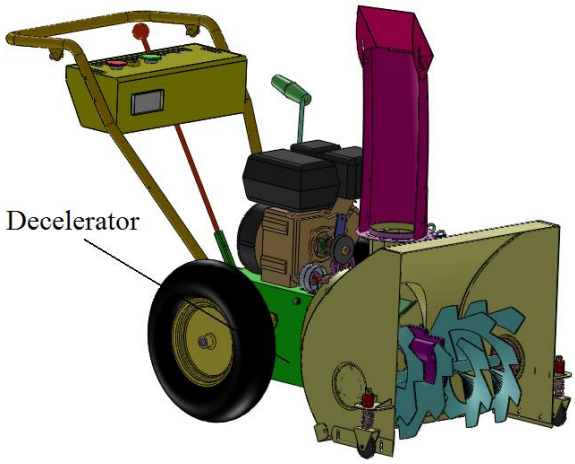


Fig.1 - Appearance figure of snowplow's decelerator for agricultural greenhouse

The fixed axis gear and the harmonic gear cannot meet the requirements for being constrained by the outer diameters. The NGW-type planetary gear, as shown in figure 2, has a drive ratio which is greater than 10. In such a structure, the power from the first-stage gear to the second-stage gear is the same as the input power. As the increasing of stages, the forces on post-stage gears become larger. And under the restriction of gear materials, this driving type is hard to meet the torque requirements [8].

由于其外径尺寸的限制，定轴轮系、谐波齿轮传动不能满足要求。NGW 型行星轮系传动比在 10 以上，结构简图如图 2 所示，由于该结构中第一级传递给第二级的功率与输入功率一样大，随着级数的增多，后一级所受的力逐渐增大，受齿轮材料的限制很难达到预定的扭矩要求[8]。

The driving of N-type planetary gear is as shown in figure 3. To get a large driving ratio, modified inside-engaged gears must be adopted for driving. However, the calculation and machining of such gears turn to be complex. Meanwhile, a larger modification coefficient of the gear pair corresponds to a larger angle of engagement, which will increase the radial force. Further, the output unit has strict requirements for the machining accuracy, and the working life will be shortened because of the high speed of bearings of the rotating arm.

The NN-type driving device consists of two pairs of inside-engaged gears by which the function of the deceleration and output can be achieved, and the gear shaft or internal gear is directly used as the output unit. Figure 4 shows its driving diagram. This type has a high driving ratio but low efficiency. And, when the rotating arm rotates at a high velocity, the noise caused by the rotation, is difficult to be completely eliminated even by balancing weight.

The closed epi-cyclic gear train is a combination of a 2-DOF differential gear mechanism and a 1-DOF stand planetary gear mechanism. Figure 5 shows its driving diagram. The input power can be split apart as a direct output-power after being transferred to the differential gears. Meanwhile, the differential gear mechanism can transfer its part power to the stand planetary gear mechanism. The transferred power is outputted together with the power of the differential mechanism. By considering small pipe diameters and splitting the power to make the gears of stage 2 to suffer a smaller torque, such a mechanism system is appropriate to the large torque output of a snowplow decelerator.

N 型行星轮系的传动比是靠一对内啮合齿轮的齿数差实现的，其传动简图如图 3 所示。该轮系要实现大的传动比必须采用变位的内啮合齿轮传动，这样轮系的计算、加工变得复杂了，同时齿轮采用较大的变位系数，传动啮合角也较大，使其径向力增大。另外，其输出机构对制造精度要求较高，转臂轴承的转速较高，使其使用寿命缩短。

NN 型传动装置由两对内啮合齿轮副组成，共同完成减速与输出任务，由齿轮轴或内齿轮直接输出，传动简图如图 4 所示。该类型传动的传动比较大，但是效率不高。且当转臂的角速度很大时，在其运转中会产生一定的噪声，即使采用平衡重量也难于完全消除。

封闭周转轮系是由一个二自由度的差动齿轮机构与一个单自由度的准行星齿轮机构封闭组合而成的，其传动简图如图 5 所示。输入功率传递给差动齿轮机构后可以进行分流，一方面直接输出功率，同时，差动齿轮机构又将部分功率传给单自由度的准行星齿轮机构，且经其变换后的输出功率与前者的输出功率一起进行输出。该机构在满足小尺寸管径的情况下，将功率分流，使得第二级齿轮机构承受较小的扭矩，适合扫雪机减速器的大扭矩输出要求。

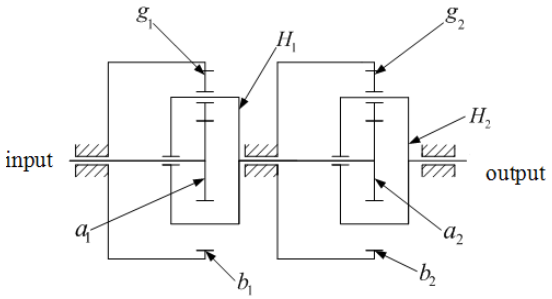


Fig.2 - Driving diagram of the NGW type planetary gear

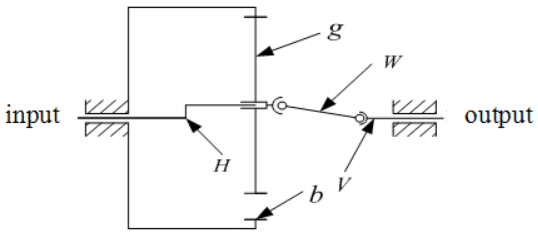


Fig.3 - Driving diagram of the N type planetary gear

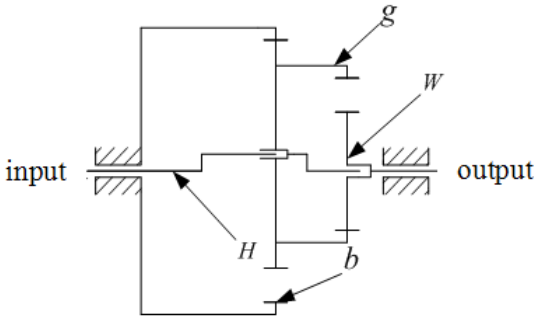


Fig.4 - Driving diagram of NN type planetary gear

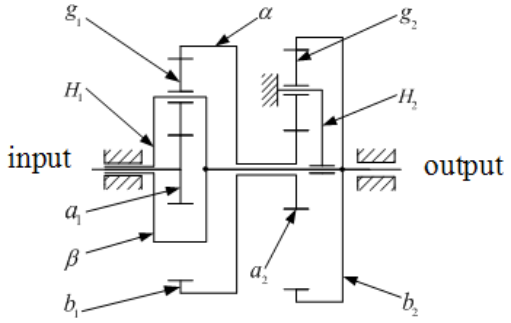


Fig.5 - Driving diagram of closed epi-cyclic gear

The Ant Colony Algorithm only can be a solution to the unconstrained optimization and univariate problems. However, the snowplow design involves constraint conditions and multiple variations which are difficult to be solved by the Ant Colony Algorithm.

蚁群算法只能解决无约束优化问题和单变量问题，而扫雪机械设计问题中出现有约束条件和多变量问题，蚁群算法难以解决。

Here we apply a combination of the Ant Colony Algorithm and the Interior Point Penalty Function in the parameter optimization design of the snowplow. The multi-constraint optimization in formula (1) can be translated into the unconstrained optimization in formula (2) [2]:

这里我们将蚁群算法和内点惩罚函数法结合后应用在扫雪机减速器的参数优化设计中，将公式(1)的多约束优化问题转变为公式(2)的无约束优化问题[2]：

$$\begin{cases} \min f(x) \\ s.t. g_j(x) \le 0 (j = 1, 2, \cdots, m) \end{cases} \tag{1}$$

$$\phi(x, r) = f(x) - r\sum_{j=1}^{m} \frac{1}{g_j(x)} \tag{2}$$

Where r is a sequence of the penalty factors in a descending order, and goes to zero: $r^0 > r^1 > r^2 \cdots \to 0$. $\sum_{j=1}^{m} \frac{1}{g_j(x)}$ is called barrier function. Determine variables based on the design requirements, as shown in table 1, there are 8 variables.

其中 r 为惩罚因子，它是由大到小且趋近于 0 的数列，即 $r^0 > r^1 > r^2 \cdots \to 0$。$\sum_{j=1}^{m} \frac{1}{g_j(x)}$ 称之为障碍项。根据设计要求确定变量如表 1 所示，共有 8 个变量。

Table 1

Optimization design parameters variables of the decelerator

Parameters	Module (mm)	Teeth of Sun Gear	Teeth of Planet Gear	Tooth Width (mm)
Stage 1	m_1	z_1	z_2	b_1
Stage 2	m_2	z_1'	z_2'	b_2
Valid digit	3	2	2	2

To set the constraint conditions: pitch diameters of the internal gears in two stages should not exceed 117 mm, the driving ratio should be larger than 10, the contact ratio of all gears should be larger than 1.2, the contact fatigue strength and the teeth bending strength should be less than the allowable value.

The minimum pitch volume of the decelerator's gears is regarded as the optimization objective. Firstly, the constraint objective function can be built as follows:

建立约束条件，两级内齿轮分度圆直径均不能超过117mm，传动比大于 10，所有齿轮重合度均大于 1.2，啮合接触疲劳强度和齿根弯曲强度小于许用值。

以减速器齿轮分度圆体积最小为优化目标，首先建立有约束目标函数为：

$$V = \pi[m_1^2 b_1 (z_1^2 + 4z_2^2) + m_2^2 b_2 (z_1'^2 + 3z_2'^2)]/4 \tag{3}$$

The objective function can be translated into the unconstrained optimization by adopting the Interior Point Penalty Function:

采用内点惩罚函数法将目标函数转化为无约束优化问题：

$$\phi = V - r\sum_{j=1}^{13} \frac{1}{g_j(x)} \tag{4}$$

After being optimized by the Ant Colony Algorithm and the Interior Point Penalty Function, the results are shown in table 2:

通过蚁群算法和内点惩罚函数法优化后的结果如表 2 所示：

Table 2

Results of the decelerator parameter optimization

Parameters	Module (mm)	Teeth of Sun Gear	Teeth of Planet Gear	Tooth Width (mm)
Stage 1	$m_1 = 2.5$	$z_1 = 16$	$z_2 = 14$	$b_1 = 59$
Stage 2	$m_2 = 2.0$	$z_1' = 21$	$z_2' = 15$	$b_2 = 62$

Meanwhile, the optimum values of the driving ratio, the output speed of the differential internal gears, the rotational speed of the planet gear, the torque of the output shaft, and the driving efficiency can be obtained. On account of the practical work conditions of the deceleration system, different FEA methods were adopted for different key components.

Due to the complexness of the model, we built a 3D model using Pro/E and then imported it into the software of ANSYS in the format of IGES. The model can be meshed, constrained with boundary conditions, loaded and treated by other finite element operations in ANSYS.

Finite element stress analysis of the bearing prong of stand planet mechanism

In the deceleration system, 33% power was split for stage 1, and the left 67% for stage 2. The stand planet mechanism has to suffer more stresses, thus, FEA for its bearing prong should be carried out.

As shown in figure 6, the point O is the centre of the planet bracket and the point O is the centre of the bearing bore. Given that the torque on the planet bracket is T, the number of the pinion gears is 3, the bearing prong has been fixed on the body frame; and the torque on each bearing bore is one-third of that of the bracket, namely T/3. A rough calculation may be made when the requirements do not need to be strictly satisfied. In this paper, a calculation based on the distribution function was proposed, and the pressure distribution on bracket was assumed to follow the cosine function, with the peak value *A* and unit MPa. Then, p, the pressure distribution function, can be obtained as follows:

同时可以获得传动比、差动机构内齿轮输出转速、行星机构行星轮转速、输出轴上的扭矩、传动效率的最佳值。结合减速系统工作的实际情况，不同的关键部件采用不同的有限元分析方法。

由于模型比较复杂，所以模型在 Pro/E 中建立，然后将三维模型以 IGES 的格式导入 ANSYS 中。在 ANSYS 中进行网格划分、定义边界条件、施加载荷等有限元操作。

准行星机构轴承支架有限元应力分析

在减速系统中，功率分配为第一级 33%，第二级 67%。准行星机构受力较大，故对准行星机构轴承支架有限元分析。

如图 6 所示，0为行星架中心，O'为轴承孔中心。已知作用在行星架上的扭矩为T，小齿轮个数为3，该轴承支架固定在机架上，作用在每个轴承孔上的扭矩为行星架上扭矩的$\mathrm{T}/3$，通常在要求不高的情况下，我们可以采用粗略估算法，本文提供一种基于分布函数的计算方法。规定作用在行架上的压力以余弦函数分布，设该压力峰值为 A，单位为MPa，压力分布函数p为：

$$p = A\cos\frac{(x-40.5)}{21}\pi \tag{5}$$

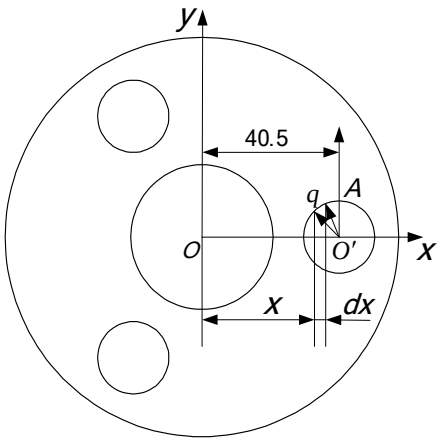


Fig.6 - The stress map of the bearing prong

As shown in figure 6, the distance from the point O, the centre of the planet bracket, to the point O', the centre of the bearing bore, is 40.5 mm. x (varying from 30 to 51 mm) is the horizontal line distance between any point on the circle and the bearing prong centre O. $\theta = \angle \mathrm{q}\, O'\, \mathrm{A}$, θ varying from 0 to π, is the angle between the pressure q and y-axis. dy is a differential variable with the direction along the moment arm, and the differential area can be calculated by:

如图 6 所示，其中轴承架中心0到轴承孔中心O'的距离为 40.5 mm，x为圆周上任意点与轴承架中心0的水平直线距离，在 30-51 mm之间变化。θ是压力与y轴的夹角，即$\angle \mathrm{q}\, O'\, \mathrm{A}$，在 0-π 间变化。沿力臂方向取一微变量 dy，微面积为：

$$dS = 9dx \tag{6}$$

Where the depth of the bearing bore is 9 mm. The differential force on this area and perpendicular to y-axis is formula (7), And the differential torque is $dT = xdF$. Appling Eq. (7), we get formula (8).

其中轴承孔深度为 9 mm。作用在此面上的垂直于 y 轴方向的微力为公式（7），则微扭矩为 $dT = xdF$ ，将公式(7)代入得公式（8）。

$$dF = pdS = 9Adx\sin\theta\cos[(x-40.5)\pi/21] \quad (7)$$

$$dT = 9Ax\sin\theta dxd\theta\cos[(x-40.5)\pi/21] \quad (8)$$

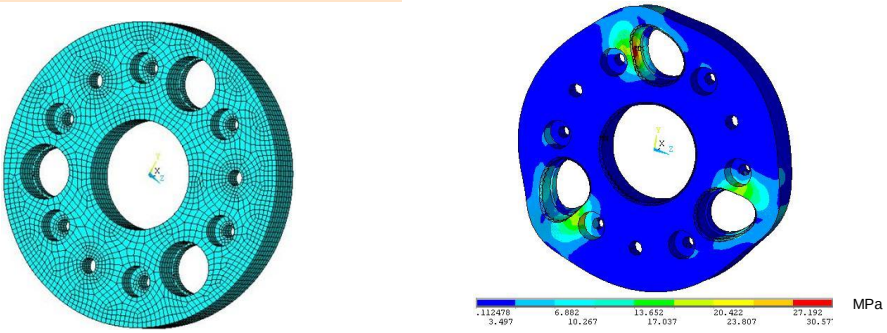
Then, the torque of the whole area is:

则作用在整个面上的扭矩为：

$$T = \int_0^{\pi}\int_{51}^{30} 9Ax\sin\theta\cos\frac{(x-40.5)}{21}\pi dxd\theta \quad (9)$$

We can get the solution A by substituting T into Eq. (9). Firstly, we set a local coordinate system with the origin at the centre of the bearing bore, and define the load function according to this coordinate. In ANSYS, the fixed bolt holes on the bearing prong have been fully constrained. And the pressure p distributes on the upper surfaces of these three bearing bores (i.e. the upper surface of the circle O' in figure 6). By applying the load function, a static solution can be obtained. Figure 7 show the mesh and the stress, respectively.

将 T 代入公式(9)，解得 A。首先在轴承孔中心建立局部坐标系，以此坐标系为参照定义载荷函数。在 ANSYS 中将轴承支架在固定螺栓孔处全约束，将压力 p 分布在三个轴承孔的上表面(即图 6 中圆 O' 的上表面)，通过载荷函数加载，进行静力求解。其网格图与应力云图如图 7 所示。



(a) The mesh map (b) The stress map

Fig.7 - FEA of the bearing prong

From the stress nephogram, it can be found that the maximum stress, which is less than the allowable value of the bearing prong material, was generated at the bearing bore farthest from x-axis. With the satisfaction of installation and strength conditions, we can minimize the size by adjusting the width of the bearing prong, and thus to reduce the weight of the whole deceleration system.

FEA of the connecting joint

One end of the joint was fixed to the internal gear ring of the differential mechanism, and the other was connected with the larger gear of the stand planet mechanism. According to the calculation, the torque on the internal gear ring of the differential mechanism is T, the joint was fixed to the internal gear ring of the differential mechanism by four bolts. The number of involute spline teeth: z =8, with pressure angle of 30° . The working line of the spline L=40 mm. Assume that the involute spline works under ideal conditions, and all eight gears are surface-contacted. Estimating the area of the contact surface of each gear to be S, and the working radius of involute spline to be R, and assuming the unit surface pressure to be p, then one can obtain the following expression: $T = z\cdot p\cdot S\cdot R$,by substituting T, z, S and

由应力云图可知最大应力的产生位置在轴承孔上到 x 轴最远处，其值小于轴承架材料的许用值，轴承架安全。通过调整轴承架的宽度，在满足轴承安装条件和强度要求的情况下使其体积最小，减轻减速系统整机重量。

联接接头有限元应力分析

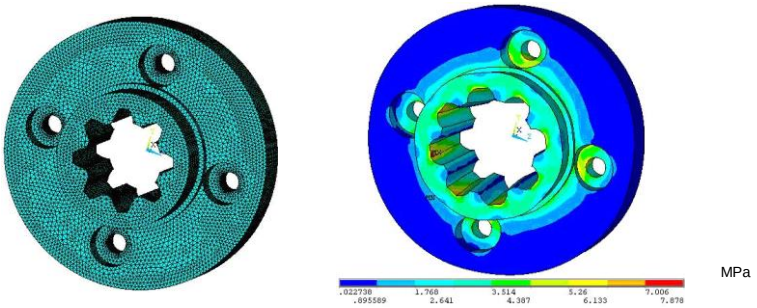
联接接头一端固定在差动机构内齿圈上，另一端和准行星机构大齿轮联接。根据计算出作用在差动机构内齿圈的扭矩为 T，联接接头采用 4 条螺栓固定在差动机构的内齿圈上，渐开线花键齿数 z =8，压力角为 30 度，渐开线花键工作长度为 L=40 mm，假设渐开线花键工作在理想状态，8 个齿全部面接触。粗略估算每个齿的接触面积为 S，渐开线花键工作半径为 R，则设作用的单位面压力为 p，可得：$T = z\cdot p\cdot S\cdot R$，将 T 、 z 、 S 、 R 代入公式，求得单

R into Eq., one can get the solution of the unit surface pressure p.

The eight working surfaces of the involute spline were picked to apply the surface pressure, respectively, as shown in fig.8-(a). The stress map is shown in fig.8-(b).

位面压力 p。在 ANSYS 中，将联接接头用于固定在差动机构的内齿圈的四个盲孔完全约束。

分别选择渐开线花键的 8 个工作面，施加面压力，如图 8-(a)所示，应力图如图 8-(b)所示。



(a) The mesh map (b) The stress map

Fig.8 - FEA of the joint

FEA of the fixed bracket

The fixed bracket was used for fixing the bearing prong and the sleeve of the stand planet mechanism. The bracket at one end of the differential mechanism was subject to no moment and constraint conditions, so this part was cut off for improving the calculation speed. Only the constrained and torqued part was left for analysis. The fixed bracket and the bearing prong of the stand planet mechanism were connected by 6 bolts. The influence of the thread was neglected. According to the calculation, the torque on the bearing prong of the stand planet mechanism is T, the torque on each bolt hole is T/3, and the working area is S. It is assumed that each surface works under the ideal conditions and all 6 holes are surface-connected. The working radius of the torque is R=40.5 mm and the unit surface pressure is *p*, then: $T/3=6p\cdot S\cdot R$ .The value of p can be determined by putting *T*, *S* and *R* into Eq.

In ANSYS, the outside ring of the fixed bracket was fully constrained. The eight working surfaces of the bolt holes were picked to apply the surface pressure, respectively. The elasticity modulus is 2.1×105 MPa. The Poisson's ratio is 0.3.

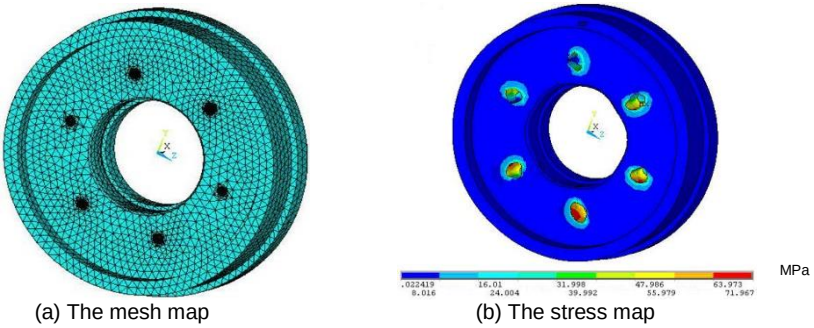
The automatic mesh generation was used by assigning 4 mm to the overall size of the mesh. Next, elements at bolt holes were refined with a mesh size of 2 mm, as shown in figure 9-(a). The stress diagram is shown in figure 9-(b).

固定支架有限元应力分析

固定支架用于固定准行星机构轴承架和套筒。由于在差动机构一端的支架不受力矩作用，也没有约束存在，所以为了提高有限元计算速度将其切下，只留下受约束和受扭矩的部分进行分析。固定支架和准行星机构的轴承架用 6 条螺栓连接，忽略支架上的螺纹等次要因素，根据计算出作用在准行星机构轴承支架上的扭矩为 T，则每个螺栓孔所受的扭矩为 $T/3$，工作面积为 S。假设各个面工作在理想状态，6 个孔全部面接触。扭矩工作半径为 R=40.5mm，设作用的单位面压力为 p，可得：$T/3=6p\cdot S\cdot R$，将 T、S、R 代入公式可得 p。

在 ANSYS 中，将固定支架外圈完全约束，分别选择螺纹孔的 6 个工作面，施加面压力。在材料属性中指定弹性模量为 2.1×10^5 MPa，泊松比为 0.3。

指定网格的总体尺寸为 4 mm，自动划分网格，然后将螺纹孔处单元选择进行细化，网格总体尺寸为 2 mm，如图 9-(a)所示，应力图如图 9-(b)所示。



(a) The mesh map (b) The stress map

Fig.9- FEA of the fixed bracket

From the analytic results, it can be found that the maximum stress was generated at the bolt holes. Because the bearing prong of the stand planet mechanism has a larger torque, the stress of a single hole can be reduced by appropriately increasing the number of holes.

Dynamic FEA of the gear meshing process

In the gear meshing process, the stress distribution of a gear is varying as the motion of the contact-point. According to the classical gear theories, the approximate load distribution was used instead of the concentrated-forces on the pitch circle, so some errors may be generated in the calculation results. While in the FEA, the practical process of the gear meshing can be effectively simulated. The changes of the stress at different positions of the gear can be observed. Besides, the classical gear theories regard the gear as being rigid, without considering that the gear deformation will generate impacts on both contact-forces and the contact ratio of a gear pair. On the contrary, the FEA takes the elasticity into account. The simulation of the meshing process of a gear pair can be realized by using the LS-DYNA. A thorough understanding about the distributions of bending stresses and contact stresses can be achieved.

After inputting the IGES profile generated by Pro/E into ANSYS, some simple treatments were made. And then the FEA was carried out. In this analysis, the surface-to-surface contact was used. The 3D solid element named Solid 164 which supports the LS-DYNA analysis was used. In order to improve the computational accuracy, the mesh of the contacting area was refined. Meanwhile, for the purpose of saving computer resource and speeding up the analysis, rough meshes were applied in other areas of the gear which were not engaged in the contact. Figure 10 shows the mesh results.

从分析结果我们可以看出，应力最大处在螺栓孔处。由于准行星机构的轴承支架上所受扭矩较大，所以可以通过适当增加螺栓孔的个数来降低单个螺栓孔的应力。

齿轮啮合过程动态有限元分析

齿轮在啮合过程中，其应力分布是沿接触点变化的，经典的齿轮设计理论是将分布载荷近似成集中力作用在分度圆上，计算出的结果有一定误差。用有限元法计算可以更有效地仿真齿轮啮合的实际过程，并且能观察出轮齿上各处应力的变化情况。经典的齿轮分析方法将齿轮假设为刚体，没有考虑齿轮变形对齿面接触力和齿轮副重合度的影响。而有限元将齿轮做弹性件处理，采用LS-DYNA有限元分析软件，对齿轮啮合过程进行有限元仿真分析，对其弯曲应力和接触应力分布状况进行透彻了解。

将 Pro/E 中生成的 IGES 文件导入 ANSYS 中进行简单的处理以便进行有限元分析。本文选择面与面接触，选用三维实体单元 Solid164 划分网格，该单元支持三维实体模型的LS-DYNA有限元分析。为了提高计算精度，在进行网格划分时，对于参于接触的轮齿部分进行了网格细化。而为了节约计算机资源，提高分析速度，将不参于啮合的其它轮齿采用粗略的网格进行单元划分。网格如图 10 所示。

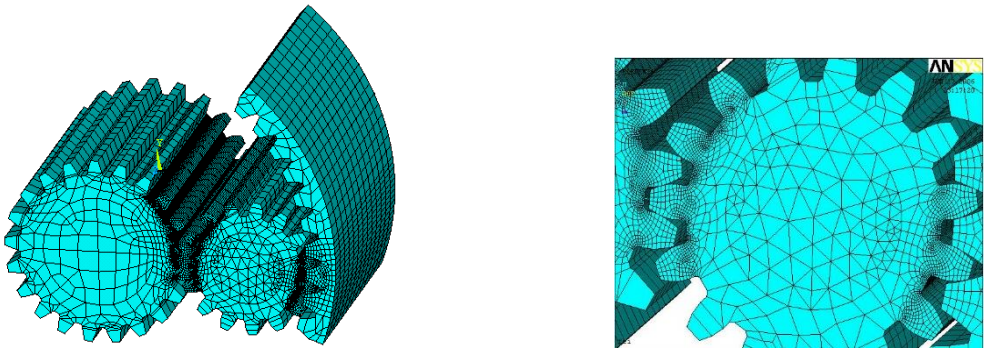


Fig.10- Mesh of the FEA in the gear mesh simulation

During the meshing process, a follow-load should be exerted because of the rotation of the gears. In ANSYS, the 3D solid shell element named Shell 163 can be easily exerted with the surface load. By such an advantage, we may use Shell 163 to create several auxiliary planes which are similar to spokes. The surface pressures were applied on these planes which are always contacted with these “spokes”. Hence, a constant resultant torque can be obtained to realize the exerting of the load during the meshing process of the gear pair. After the finite element computation by LS-DYNA, a module of ANSYS, the contact stress distribution of a certain moment is shown in

由于齿轮在啮合分析过程中转动，所以需要施加跟随载荷。在 ANSYS 中的 Shell163 三维实体壳单元可以很方便地施加面载荷。利用 Shell163 单元创建若个类似于轮辐的辅助平面，对其施加面压力。其大小和方向始终作用于轮辐上，合成为一个恒定的扭矩，实现了在齿轮副啮合过程中施加外载荷，通过利用 ANSYS LS-DYNA 模块经过有限元的求解后，在某一个瞬时的接触应力的分布情况如图 11

figure 11. It can be seen that the distribution of the contact stress in figure 11 matches entirely with the classical Hertz theory. It also testifies the precision and accuracy of the finite element model developed in this paper.

Figure 12 shows the contact stress distribution of a single tooth surface of a certain moment. It can be known from the equivalent stress map that the contact stress distribution of the tooth surface is in linear with slightly larger values near the sides of the tooth. In general, the stress shows a uniform distribution. The analytical results of the stress show that the gears designed in this paper are able to meet the requirements of contact strength. Besides, the meshing between two neighboring gears reveals that the contact ratio of a gear pair is larger than 1.2.

所示。由图可以看出其接触应力的分布与经典的赫兹理论是完全相符的，从而也验证了本文提出的有限元模型的精度与正确性。

单个齿面上某一瞬时的接触应力的分布情况如图 12 所示。通过该图等效应力可以看出，齿面上的接触应力成线性分布，两侧略大，从总体上看，应力分布比较均匀。分析出的应力结果表明，本文设计的齿轮满足接触强度要求。另外，通过相邻两个齿进入啮合的情况可以看出，齿轮副的重合度大于 1.2。

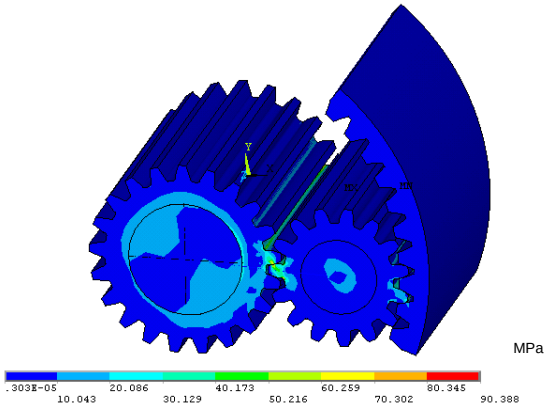


Fig.11- The Contact stress of gear pair

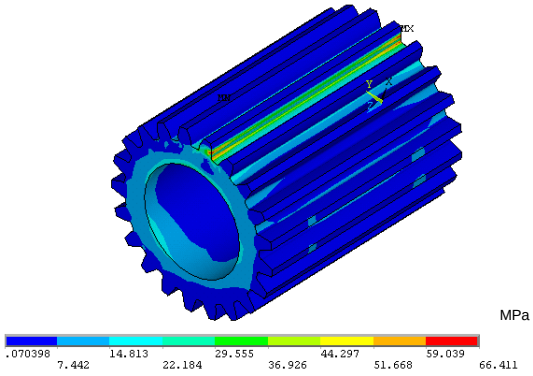


Fig.12- The Contact stress of the larger gear

Motion simulation on the operation of the decelerator

Simulation on the motion of the deceleration system was performed. The interference detection and modification were done based on the simulation results. The 3D components and 3D assembly of the efficient oil-injecting pipe in the deceleration system were developed. The reasonability of this design was proved by comparing the simulation results with the theoretical values.

Modeling of differential mechanism and the stand planet mechanism

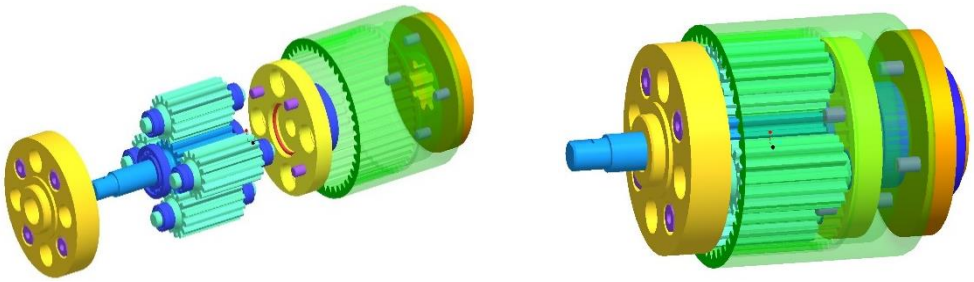
Considering their small pitch diameters, the sun gear and the planet gear were designed to be of the “shaft shape” with short teeth to enhance the strength. For the convenience of assembly, the planet bracket, with two plates on the right and left sides, was designed. That is one trochal disk on each side and fixed by bolts. The differential mechanism, with function of power-splitting, directly outputs a part of the power to the output-shaft through the planet bracket. Another part of the power is output through the stand planet mechanism. Taking the uniform load of the planet gear into account, the involute spline connection was adopted between the right planet bracket and the output-shaft, as well as between the internal gear ring and the sun gear of stage 2. The exploded and assembly drawing of the differential mechanism are shown in figure 13-(a) and (b), respectively.

减速器工作状况运动仿真

对减速系统进行运动仿真并进行干涉检测，根据仿真结果对高效采油管内减速系统的三维零件和三维装配进行修改，将仿真结果和理论值进行比较，验证了该方案的合理性。

差动机构和准行星机构建模

考虑到太阳轮和行星轮的分度圆直径较小，为增加齿轮的强度，将太阳轮和行星轮设计成齿轮轴及短齿齿形；考虑到装配方便，将行星架设计成左右侧板型，即在左右各有一个轮盘，中间用螺栓固定。由于功率分流，所以差动机构将一部分功率通过行星架直接输出到输出轴上，另一部分通过准行星机构输出，考虑到行星齿轮的均载问题，将右侧行星架和输出轴采用渐开线花键联接，内齿圈和第二级太阳轮也采用渐开线花键联接。差动机构模型爆炸图如图 13-(a)所示，装配图如 13-(b)图所示。

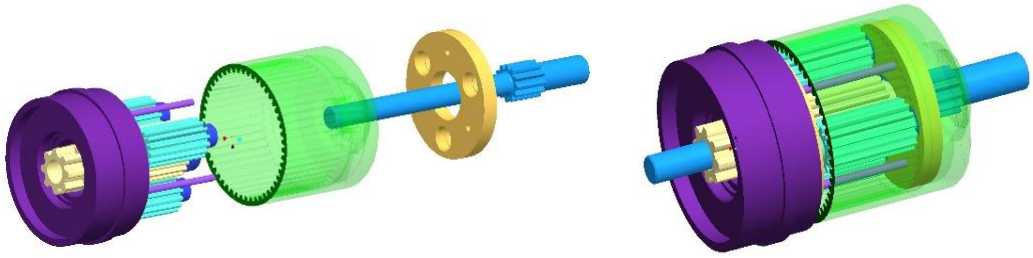


(a) The exploded drawing (b) The assembly drawing

Fig.13 - Exploded and assembly drawing of the differential mechanism

Like the design of the differential mechanism, the exploded drawing of the stand planet mechanism is shown in figure 14-(a) and the assembly drawing is shown in figure 14-(b).

同差动机构设计一样，准行星机构模型爆炸图如图 14-(a)所示，装配图如图 14-(b)所示。



(a) The exploded drawing (b) The assembly drawing

Fig.14 - Exploded and assembly drawing of the stand planet mechanism

End-caps and outer-sleeves were designed and installed on both sides of the decelerator for assembling the differential mechanism, the bracket and the stand planet mechanism. Under the assembly mode, the position and volume of the interference were figured out through detections. The structure adjustment or the assembly readjustment was made until they met the requirements of interference detection. In this study, the global interference of the decelerator was detected, and the adjustment was made based on the detection results.

在减速器两端设计了端盖以及外套筒，将差动机构、支架、准行星机构等约束装配。在装配模式下，通过干涉检测，计算出干涉的位置和干涉的体积，根据计算的结果进行结构调整或者重新调整装配，直到通过干涉检测为止，本设计对减速器全局干涉进行了检测并根据结果进行了调整。

RESULTS

Motion analysis of the decelerator

Figure 15 shows the speed curve of the stage-1 differential mechanism. It can be seen from the map that, when t=10 s, the speed of the input shaft is 100 deg/s, the internal gear ring is -23.19 deg/s (the minus here means its angular velocity is opposite to the speed of the input shaft), and the planet bracket is 9.59 deg/s. Likewise, the acceleration curve and its value can also be obtained.

Speed and acceleration curves of the planet mechanism components are similar to that of the differential mechanism. Calculated by the theoretical driving ratio, the theoretical calculation values match to the results of simulation when the motor input q=10t. Preferable simulation results were obtained. The validity of the system was verified. A special mechanical seal for the input and output shaft is designed. It can atenuate the abrasion automatically when the material used is destroyed.

结果

减速器运动分析

第一级差动机构速度曲线如图 15 所示，由图可以看出，当 t=10s 时，输入轴速度为 100 deg/ s；内齿圈为-23.29 deg/ s，负号表示其角速度与输入轴相反；行星架为 9.59 deg/ s，加速度曲线和加速度值同样可以得到。

准行星机构各元件速度和加速度曲线和数值与差动机构类似。按理论计算的传动比计算，当电机输入为 q=10t 时，其理论计算值与仿真结果相吻合，得到了较好的仿真结果，证明了系统的正确性。设计可补偿式机械密封，保证了减速系统的安全。

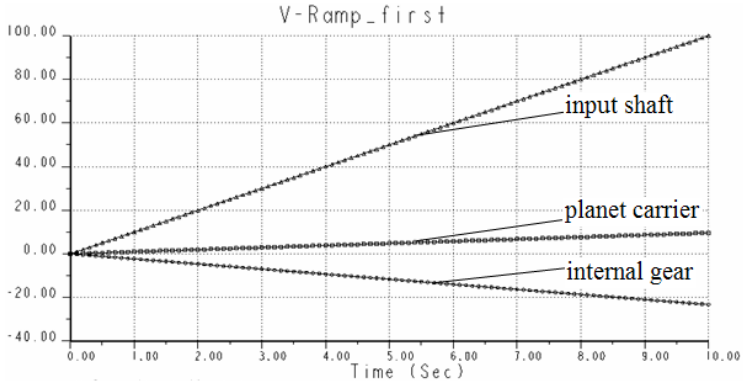


Fig.15 - The V output map of the differential mechanism when q=10t

Prototype test for an agricultural greenhouse

The main parameters of the new type decelerator are superior to the traditional decelerator through comparison as shown in table 3.The new decelerator was applied in the snowplow for an agricultural greenhouse. The technical parameters of new snowplow are as follows: The maximum working load is 2200 lbs/min. The maximum throwing distance is 10-15m. The maximum working width is 28". The maximum working thickness is 22". The chute rotating angle is 190 degree. The power distribution of the snowplow was smooth. The snowplow had a stable body and a low failure rate. It played a good performance in snow removing, as shown in figure 16.

样机测试

将新型减速器与传统减速器对比，如表 3 所示，新型减速器的主要参数优于传统减速器。将新型减速器在大棚清雪车上进行测试，技术参数如下：最大工作载荷 2200 lbs/min，积雪最大抛投距离 10-15 米，最大工作宽度 28"，最大清雪厚度 22"，抛雪筒旋转角度 190 度。大棚清雪车动力分配平稳，车体稳定，故障率低，新型减速器工作状态良好，如图 16 所示。

Table 3

Parameters contrast between traditional decelerator and new type decelerator

Decelerator	Transmission Mode	Power Allocation	Power Range(KW)	Maximum Deceleration	Diameter (mm)	Transmission Efficiency	Maximum Torque (mm)
Old type	Fixed axis gear Train	Power reflux	7.35-16.75	6	190×180	94%	610
New type	Closed epi-cyclic gear train	Power Split	7.35-21.54	10.43	ϕ 138	96.48%	750.35

Fig.16- Snowplow equipped with the new decelerator for a greenhouse

CONCLUSIONS

(1) By considering the working conditions of the decelerator, several driving types of internal gearing planetary gears with the coaxial deceleration were compared. The closed epi-cyclic gear matches the rotational speed of the combustion engine to the speed of the output shaft, and gives solution to the connection between the engine with a high speed and low torque and the shaft with a low speed and high torque.

(2) By combining the Ant Colony Algorithm and the Interior Point Penalty Function, a step optimizing model was proposed to cope with the problems on multivariable,

结论

（1）通过分析减速器工作环境，将能实现同轴减速的几种内啮合行星齿轮传动进行分析比较，最终采用具有功率分流功能的封闭周转轮系。该轮系是能够使内燃机转速与输出轴转速相匹配的减速增矩装置，解决内燃机转速高、扭矩小，与输出轴转速低、扭矩大之间的连接。

multiple constraints and multiple discrete points. It overcomes the difficulties in mechanical optimization design by only using the Ant Colony Algorithm.

(3) The contact element in ANSYS was adopted to the FEA of the gearing in the stand planet mechanism suffering a larger load. In addition, a new loading method was presented to exert the dynamic forces of the gears. This method can reflect the real stress-changes of the gear meshing process. Motion simulation of the whole decelerator system was carried out. The decelerator was restructured according to the FEA results, for achieving the optimum state.

ACKNOWLEDGEMENT

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（2）将基本蚁群算法和内点惩罚函数法结合起来，提出“阶梯”寻优模型，解决基本蚁群算法在机械优化设计中遇到的多变量、多约束、多离散点等难点。

（3）采用有限元中接触单元对受力较大的准行星机构进行齿轮啮合接触有限元分析，使用新的载荷加载方法实现齿轮动态作用力，真实反映齿轮在啮合过程中的应力变化情况。对整个减速器系统进行运动仿真，根据分析结果对减速器结构进行调整，以达到最优。

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DESIGN OF A LOW-COST SYSTEM WITH BUILT-IN-GPS AGRICULTURAL MACHINERY / 一种基于嵌入式的低成本农业机械 GPS 导航定位系统设计

Assoc. Prof. Ms. Lin Hanhui[1)], Assoc. Prof. Ph.D. Cai Ken[2)], Eng. Zeng Zhaofeng[3)]
[1)] Center for Educational Technology, Guangdong University of Finance and Economics, Guangzhou / China;
[2)] School of Information Science and Technology, Zhongkai University of Agriculture and Engineering, Guangzhou / China;
[3)] Department of Mathematics and Computer Science, California State University, East Bay/ U.S.A
Tel: +8634172680; Email: icken@126.com

Abstract: *Intelligent agricultural machinery is a key component in developing precise and intellectual agriculture. However, achieving the accurate operation of intellectual agricultural equipment depends on precisely sensing the field position. This study adopts built-in technology and integrates wireless communication and Global Positioning System (GPS) stand-alone positioning to obtain low-cost and high-precision positioning in production. Information collection and transmission by the low-cost agricultural machinery are realized to implement overall management, monitoring, and scheduling. Test results show that the measured and actual errors can be stabilized to less than 3%, and the accurate position of an agricultural vehicle can be obtained. The system exhibits good expandability, functional implementation, and stable performance. It is significantly useful in engineering applications.*

Keywords: *agricultural machinery, GPS, built-in system, wireless communication*

摘要: *智能农业机械是发展智慧农业和精准农业的关键设备，然而要实现农业装备的精确作业取决于对农田位置的精确定位。为了解决低成本和高精度定位的目的，本论文采用全球卫星定位系统(GPS)单机定位方式，并综合无线通讯、嵌入式技术等先进技术手段，实现了一种低成本高精度的农业机械定位信息的采集、传输，从而完成了对农业机械的综合管理、监控和调度。试验测试结果表明使用该系统对收割面积进行计算其平均统计误差能稳定在 3%以下，也能准确获取农用车辆行驶过程中的位置信息。该系统可扩展性强，功能实现良好，性能稳定，具有重要的工程应用价值。*

关键词: *农业机械；GPS；嵌入式系统；无线通信*

INTRODUCTION

The 20th century is the development period for agricultural mechanization, which is actually the integration of agricultural machinery with modern hydraulic, instrumentation and control, modern microelectronics, sensor (including 3S), and information technologies. This integration then evolves into intelligent, mechanical, and electrical integrations [4,5,7]. The application of GPS and information technology (IT) to agricultural machinery was initially implemented in the information management system of farming office personal computers (PC) and mobile machinery via wireless communication, which enables the system dispatching center to transmit data between field-operation machinery and crop-growing environment [1]. The central computer, with its functions of information storage, processing, expert knowledge base and management decision-making panel, can create detailed agricultural operation and navigation operation plans from the data collected from the field operation. Such plans are utilized to instruct field-operation agricultural machinery, being widely applied in the USA [2,3,11]. GPS is the core technology in navigating agricultural machinery or equipment. How to improve the overall performance of agricultural machinery and equipment with related technology is currently under development. Therefore, the study of the navigation application of agricultural machinery and equipment is necessary and significant in realizing the modernization of China's agricultural machinery [12]. This study aims to design a low-cost system with built-in-GPS agricultural machinery through the use of IT, built-in technology, and GPS technology. Such system can receive GPS real-time data through serial ports and receive and send data in a Wi-Fi

引言

二十世纪是农业机械化发展的时期，这实际上是农业机械与现代液压技术、仪器仪表控制技术、现代微电子技术、传感器技术（包括3S技术）和信息技术的整合。同时它也是智能化、机械化、电子化的整合[4,5,7]。运用 GPS 和信息技术（IT）的农业机械已开始应用于农业办公的个人计算机（PC）中的信息管理系统和通过无线网络连接的移动终端设备，这些系统和移动终端设备能够和系统调度中心进行通信，并使其控制在田间进行作业的农业机械和农作物生长环境之间的数据交互[1]。另外，具有信息存储功能、处理功能、专家知识库和管理决策模块的中央计算机，可以实施控制具体的农业作业操作和利用从现场收集回来的有效数据指导导航操作计划。这些指导农业现场作业计划的方法已广泛应用于美国等国家的农业机械中[2,3,11]。GPS 是农业机械或设备导航的核心技术，如何提高农业机械和相关设备的整体性能目前还处于发展阶段，因此，研究应用于农业机械与设备的导航技术就显得相当的必要，其对实现中国的农业机械现代化具有重要意义[12]。本文的目的是设计使用信息技术、嵌入式技术和 GPS 技术的低成本农业机械导航定位系统，这样的系统可以通过串口接收 GPS 的实时数据，并在 Wi-Fi 环境下接收和发送数据，从而实现农业机械的导航和定位，在提高农

environment to achieve navigation and positioning of the machinery, thereby improving efficiency while lowering the operation cost and increasing economic and ecological benefits in agricultural production.

MATERIALS AND METHODS

Overall Design of the System

The controlling system is the most vital part of agricultural navigation and positioning system; the former is directly relevant to the latter's intellectual level. The controlling system consists of lithium battery power supply, GPS, electric machine control, and wireless communication modules. In the typical design, each hardware and software should be independent of each other as much as possible, as shown in Figure 1, to allow for future updating.

Fig.1- System structure

GPS Positioning Principle

The basic principle of GPS positioning is using ΔTIME to calculate the distance between the receiver's antenna and satellite [8]. The message received by the satellite is decoded and generated into the 3D position of the receiving antenna. The GPS satellite constantly sends navigation messages that include position information (x_i,y_i,z_i) with the time stamp of each position attached. As the receiver receives the messages, the satellite time (t_i) and the receiver's internal time (t) are extracted to obtain transmission $\Delta t_i = t - t_i$, which multiplies the speed of wireless wave (c) which is light speed. The distance between the antenna and satellite ($d_i = \Delta t_i \times c$) is obtained with the following equation.

The position (x,y,z) of the receiver's antenna is obtained when the equation is solved (as shown in Figure 2).

This equation only has three unknown numbers, which means only three satellites are required to fully acquire the position of the antenna. However, in actual situations, three satellites are insufficient. Four or more are required to acquire the position precisely because c is a large value, and d (distance) is obtained by Δt, which multiplies c (light speed), and can be magnified numerous times by even a small error of Δt. The error of Δt originates from the receiver because the timing device in the receiver is not as expensive as the cesium atomic clock in GPS satellites. Therefore, adding another satellite is the best solution to minimize the error when considering the receiver's internal time (t) as a variable value.

业作业效率的同时降低运营成本，提高农业生产的经济效益和生态效益。

材料与方法

系统总体设计

控制系统是整个农机导航定位系统设计中最重要的部分，直接关系到系统的智能化程度。该系统主要包括：锂电池供电模块、GPS 模块、电机控制模块、无线通信模块。如图 1 所示。在具体的设计中，控制系统的每个硬件模块和软件部分以相对独立的方式进行设计，这样做的目的是为以后的更新升级提供便利。

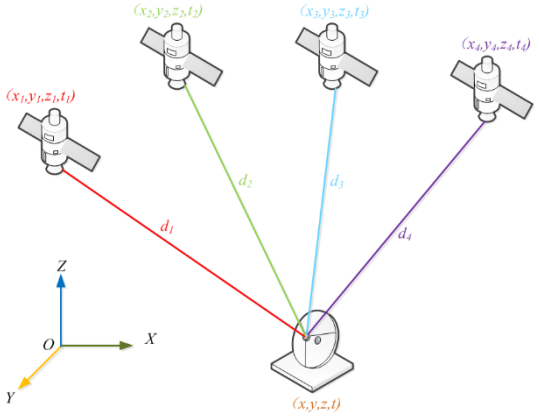

Fig.2- GPS positioning principle

GPS 定位原理

GPS 定位的基本原理[8]就是利用时间差的方式来测量接收机天线到卫星之间的距离，然后通过解析接收到的卫星导航电文数据来计算出接收机天线的三维位置。GPS 卫星不断的发送导航电文，导航电文不仅包括了卫星的位置信息(x_i,y_i,z_i)还附加了电文发送的时间戳 t_i。接收机接收到电文时，通过提取的卫星的时间 t_i 与接收机内部的时间 t，便可得到电文在空中的传输时间差 $\Delta t_i = t - t_i$，再乘以无线电波传输速度 c(即光速)，就可以得到接收机天线到卫星的距离为 $d_i = \Delta t_i \times c$，于是就可以得到下面的方程组：

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} = c \times \Delta t_i, i = 1,2,3,4 \quad (1)$$

根据上面的方程可得到接收机天线的位置(x, y, z)(如图 2 所示)。

上面的方程组中只有三个未知数，求解它们只需要三颗卫星即可。但是实际应用中，必须要四颗或更多卫星。因为上面方程组右边距离 d 是由时间差 Δt 和光速 c 相乘得到，而光速 c 的值很大，时间差 Δt 一个很小的误差就会被放大很多倍。然而 Δt 的误差主要来源是接收机，因为 GPS 卫星上是通过铯原子钟来计时，但接收机不可能配备昂贵的精确时钟，为了降低成本一般都是通过增加一个卫星的方式来减小误差，也就是将接收机内部的时间 t 也看成变量，于是式(1)变为下式：

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} = c \times (t - t_i), i = 1,2,3,4 \quad (2)$$

A more accurate position (*x*,*y*,*z*) of the receiver can be obtained by solving the equation above. Different interfering factors may cause errors during GPS positioning, and each interference may generate a different effect on the accuracy of GPS positioning. This factor should be considered when designing the GPS.

这样，通过解公式(2)就可以获得在时间 *t* 的相对更为精确的接收机的位置 (*x*,*y*,*z*)。当然GPS的定位精度还受其他各种因素干扰，不同因素的影响程度也不同，因此在进行 GPS 的相关设计时都需要考虑。

Design of the Hardware in the System

Micro-controller module

The agricultural navigation and positioning system should complete data collection, processing, and transmittance, and an algorithm should be adopted. Therefore, the core processor must have high processing speed. The STM32F103RBT6 chip manufactured by ST Microelectronics is utilized as the core processor of the core controller of this machine to complete information collection and processing from the sensor and control the machine. The STM32F103RBT6 chip is ARM Cortex-M3 32 digit reduced instruction set computing (RISC) with a working frequency of 72 MHz. It can achieve high-speed operation. It has 128 Kb flash memory, 20 Kb static random-access memory, and a large number of enhancement mode I/O ports.

系统硬件平台的搭建

微控制器模块

农机导航定位系统需要完成数据的采集、处理、传输等功能，并涉及到一些算法的设计，因此要求系统的核心处理器具有比较快的运行和处理速度。本论文选择STMicroelectronics公司的STM32F103RBT6 芯片作为系统的核心处理器来完成各类外围设备的信息采集和处理。STM32F103RBT6是ST公司推出的高性能 ARM Cortex-M3 32 位精简指令集计算机(RISC)内核芯片，工作频率是72MHz，能实现较快速度的运算。其内置128Kb的闪存存储器、20Kb 的静态随机存储器，以及大量的增强型 I/O 端口。

Fig.3- NEO-6M GPS module

GPS module

The task of the GPS module is to capture the signal of the satellite to be measured at a certain drag angle of the satellite height and keep the track of such satellite. It transforms, magnifies, and processes the received GPS signals to obtain the transmission time from the satellite and the receiver's antenna, decode the navigation message sent by the GPS satellite, and calculate the real-time 3D position, 3D speed, and time. NEO-6M is adopted as the GPS module in this study because it has high performance and low power consumption. It is an intelligent satellite signal-receiving module with complete functions of a satellite positioning receiver; it meets the strict requirements of professional positioning and individual consumption. The shape of the GPS module is shown in Figure 3. The NEO-6M mode GPS module is based on the No. 0183 Act of the National Marine Electronics Association, which stipulates that the sentence transmission format of a GPS navigation message should have "$" illustration as its frame header, followed by data segments that are separated by "," and end with pressing “enter to line feed.”

GPS 模块

GPS 模块的任务是能够捕获到按一定卫星高度截止角所选择的待测卫星的信号，并跟踪这些卫星的运行，对所接收到的GPS信号进行变换、放大和处理，以便测量出GPS信号从卫星到接收机天线的传播时间，解译出 GPS 卫星所发送的导航电文，实时地计算出测站的三维位置，甚至三维速度和时间。本论文采用的 GPS 模块为 NEO-6M，该模块是一个高性能、低功耗的智慧型卫星接收模块，具备完整的卫星定位接收器的功能，能满足专业定位的严格要求与个人消费需求。GPS 模块外形如图 3 所示。NEO-6M 型 GPS 模块遵循美国国家海洋电子协会 (National Marine Electronic Association)所制定的 0183 标准协议。NMEA-0183 规定的 GPS 导航电文的语句传输格式是以“$”加语句类型说明作为帧头，其后为各数据段，各数据段以“，”分开，最后以回车换行标志结束。

Wi-Fi module

The Wi-Fi circuit is designed to enable the users to retrieve the GPS information and data in the Wi-Fi environment. S2W-M02 ports that transmit to the Wi-Fi module are adopted to facilitate hardware design. S2W-M02, produced by Beijing Simple-WiFi Co.Ltd, contains low-cost built-in ports of Ethernet to the Wi-Fi module. It is based on universal serial ports, Wi-Fi built-in module, and TCP/IP protocol stack to perform data transmission of serial and Wi-Fi ports. The serial port data can be transferred into Internet data and transmitted via the S2W-M02 module. Through this process, the hardware can support the UART ports and facilitate the Wi-Fi circuit. The Wi-Fi module in this study operates under the client end, which is connected to the external router via Wi-Fi. With software configuration, the ports of the data field can be mutually transferred and transmitted through Wi-Fi. The Wi-Fi LAN structure is shown in Figure 4. S2W-M02 is connected to the exterior router via Wi-Fi and connected to the microprocessor via the UART port. S2W-M02 is utilized as Station (STA) to connect to the router and form a wireless network. The router is the center of the wireless network, and the communication between the Wi-Fi module and the PC is achieved via the router. The S2W-M02 module transmits the data through unvarnished transmission, and the TCP handshake protocol should be added to ensure the reliability of data transmission.

Wi-Fi 模块

Wi-Fi 电路的设计目标是能够方便用户在无线网内方便访问系统的 GPS 信息和数据。为了方便硬件设计，选用了 S2W-M02 串口转无线网模块。S2W-M02 是 Beijing Simple-WiFi Co.Ltd 推出的低成本嵌入式串口-以太网-无线网模块。它是基于通用串行接口和无线 Wi-Fi 网络标准的嵌入式模块，内置 TCP/IP 协议栈，能够实现串口和无线网（Wi-Fi）之间的数据转换。通过 S2W-M02 模块，串口数据可转化为 Internet 网络传输数据。这样系统在硬件上支持 UART 接口就可以方便的实现 Wi-Fi 电路。在本论文中，Wi-Fi 模块工作于客户端模式，通过 Wi-Fi 连接到外部路由器，通过软件配置，即可实现数据域的串口与 Wi-Fi 的互转换传输。Wi-Fi 局域网结构如图 4 所示。S2W-M02 模块通过 Wi-Fi 和路由器连接，通过 UART 接口和微处理器连接，S2W-M02 模块做为 STA 连接到路由器上，组成一个无线网络，以路由器做为无线网络的中心，Wi-Fi 模块与 PC 之间的相互通信都通过路由器转发完成。S2W-M02 模块数据传输采用透传模式，在软件设计中增加 TCP 握手协议保证数据传输的可靠性。

Fig.4 - Wi-Fi LAN structural diagram

Solar power supply module

The power supply is an integral part of this agricultural navigation positioning system. Solar modules and a rechargeable battery are adopted to supply power because solar energy is clean energy; it can be easily obtained and has zero emission. The lithium battery is charged by solar energy from the solar modules. The energy is stored in the battery to power the navigation system. The solar power supply diagram is shown in Figure 5.

太阳能供电模块

电源系统是农机导航定位系统设计的重要组成部分。本论文采用的供电方式是太阳能电池板和可充电电池结合的方法，太阳能是一种清洁能源，自获取、零排放。太阳能电池获取能量之后给锂电池充电，锂电池将能量存储起来给导航定位系统供电。太阳能供电系统如图 5 所示。

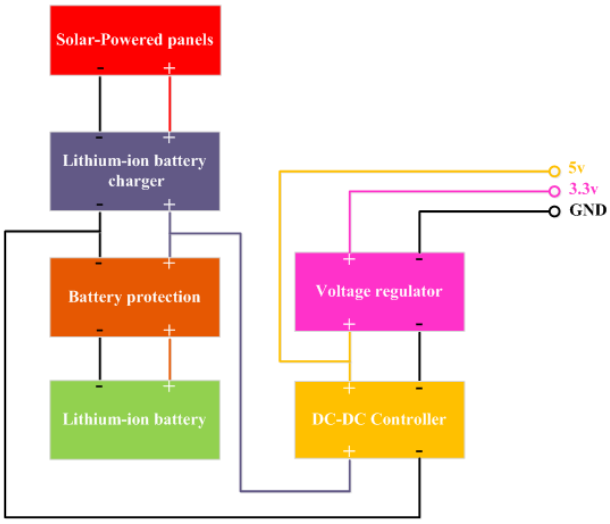

Fig.5 - Power supply diagram of solar power

(1) The solar module consists of 10 polycrystalline solar cells that are connected in parallel. The working voltage is 5 V, and I_{max} is 1.3 A.

(2) The rechargeable battery pack includes four sets of 18650 lithium batteries manufactured by Samsung Korea. Each battery is 2600 mAH, with a rechargeable voltage of 4.2 V, nominal output voltage of 3.7 V, and minimum output voltage of 2.8 V. The advantages of a lithium battery are small size and large capacity. It can also be repeatedly recharged and re-discharged.

(3) The controlling circuit of the solar module consists of CN3063 and its external circuits. CN3063 is employed as the battery recharging chip to control each single set of lithium battery in this solar power supply system. Inside the chip is an eight-digit analog–digital conversion circuit that can automatically adjust the recharging current according to the output capacity of the current from the input voltage source. Considering the worst situation is unnecessary. Hence, the output current from the input voltage source can be fully used. This solution is ideal for recharging solar energy.

(4) The voltage booster circuit of the system consists of CN5136 and its exterior circuits. CN 5136 is a DC–DC converter with high-efficiency pulse frequency modulation (PFM), and its I_{max} can be 500 mA. Power transistors are integrated inside CN5136 to minimize the number of external components. The output voltage from CN5136 can be set via the external resistance. The high-precision voltage reference guarantees the accuracy and low-temperature drift of the output voltage. The working voltage of CN5136 ranges from 2.7 V to 6 V, which is applicable for lithium batteries.

(5) The protection module of lithium batteries is a crucial part of the design. The module protects the battery from being over-charged or over-discharged and from experiencing short circuit and over-current caused by the integration of the G3PU chip with IM8205.

(6) The core processor of this system is STM32F103RBT6 powered by +3.3 V. The 5 V power should be converted to 3.3 V so that the micro-processor can be utilized. AS1117-3.3 is also applied in this study. It is a linear voltage regulator with low drop-out performance. It provides protection from over-current and over-heating to ensure the stability of the chips and power supply. Amendment technology is adopted during its manufacture, thereby ensuring that output voltage and reference source accuracy is within ±1%.

The power supply circuit is shown in Figure 6.

（1）系统所采用的太阳能电池板由十块“多晶硅太阳能环氧树脂滴胶板”并联构成，工作电压为5V，最大电流为1.3A。

（2）锂电池采用四节韩国三星18650锂电池并联供电，每节电池容量为2600mAH，充电电压为4.2V，标准输出电压为3.7V，最低输出电压为2.8V。锂电池具有体积小、容量大等优点，并且可以反复充放电。

（3）太阳能充电控制电路主要由CN3063及其外部电路组成，CN3063是可以用于太阳能电池供电的单节锂离子电池充电管理芯片。该器件内部包括8位模拟-数字转换电路，能够根据输入电压源的电流输出能力自动调整充电电流，不需要考虑最坏情况，可最大限度地利用输入电压源的电流输出能力，非常适合太阳能充电。

（4）系统的升压电路主要由CN5136及其外部电路组成，CN5136是一款高效率的脉冲频率调制型(PFM) DC-DC转换器，最大输出电流能力可以达到500mA。CN5136内部集成有功率晶体管，大大减少了外部元器件的数目。CN5136的输出电压可以通过外部电阻设置。片内高精度的电压基准源保证了输出电压的精度和低温度漂移。CN5136的工作电压范围为2.7V-6V，非常适合锂电池供电的应用。

（5）锂电池保护模块电路是本设计中的关键部分，此部分主要用集成电路芯片G3PU与IM8205组合搭建，负责锂电池的过充保护、过放保护、短路保护以及过流保护等功能。

（6）系统采用的核心处理器STM32F103RBT6是由+3.3V供电的，因此需要将升压得到的5V电源转化成3.3V以供微处理器使用。本论文采用AS1117-3.3这款芯片，它是一款低压差的线性稳压器，提供完善的过流保护和过热保护功能，确保芯片和电源系统的稳定性。同时在产品生产中应用先进的修正技术，确保输出电压和参考源精度在±1%的精度范围内。

电源模块电路图如图 6 所示。

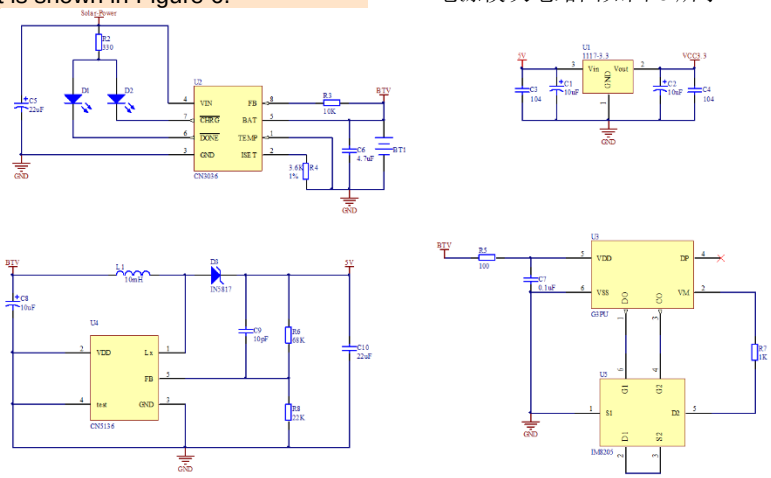

Fig.6 - Power circuit diagram

Design of PWM driving circuit

PWM control, a technology that modulates pulse length, modulates the duty circle to smoothly control the speed of electronic machinery. The developed system employs PWM technology to control electronic machinery. However, the amplitude voltage of the PWM signal reaches only 3.3 V in the micro-controller of this system. The electronic machinery can only be controlled when transferring level and improving the driving ability of the signal. Therefore, the abutment of a photon-coupled insulator and electronic machinery modules are adopted in this study.

Design of the Software in the System

GPS data processing

The GPS module and STM32 are connected by serial ports. The GPS module sends a standard NMEA-0183 instruction to serial ports each second. The program can handle received data during this period. When processing the positioning and navigation, time and latitude–longitude are the only required information. Instruction GPRMC includes all positioning-required data. Therefore, collecting GPRMC instruction and selecting requisite information based on the meaning of each segment data are the only tasks we need to perform. Figure 7 shows the collection and disposal process of GPS data.

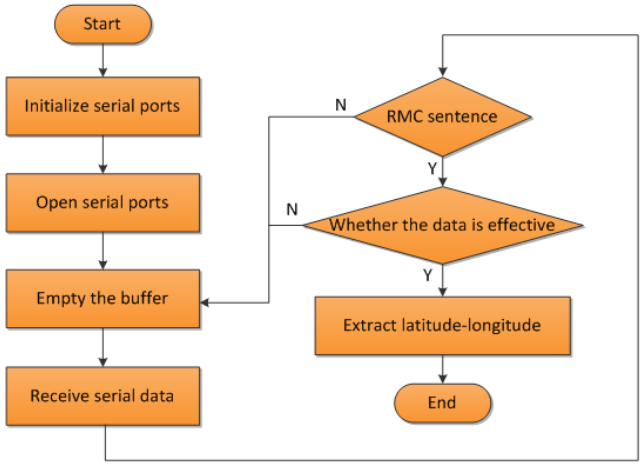

Fig.7 - GPS data processing

Given that the standard NMEA-0183 instruction selects $GPXXX as the initial sign with enter or line break as a completed sign for each instruction, data can be judged whether they are RMC instructions as soon as they are written in buffer. The principle is to search RMC in strings. If it can be found, the next step is to return to the position where RMC is and if not, return to −1. If it is an RMC instruction, the next step is to judge whether the data are effective. Two standards are employed to judge whether the data are effective. The first standard is whether the data are complete, which can be judged by data length. The second standard is whether the locator data are effective, which can be judged by a specific data segment. V represents ineffective locator data, and A represents effective locator data. Information on latitude and longitude will be extracted if the data are effective. The first data segment after the initial sign is time. Following it are the positioning state, latitude, direction of latitude, longitude, and direction of longitude. Other data are of no importance because they are useless in positioning.

PWM 驱动电路设计

PWM控制就是对脉冲宽度进行调制的技术即通过调制其占空比实现对电机转速的平滑控制。本系统就是采用PWM技术对电机进行控制。然而系统采用的微控制器输出的PWM信号的幅值电压只有3.3V，需要进行电平转换并提高信号的驱动能力才能控制电机的运转，因此在论文中采用光耦隔离器件和电机驱动模块进行对接。

系统软件设计

GPS 数据处理

GPS 模块与 STM32 之间通过串口进行通，GPS 模块每隔一秒向串口发送一条 NMEA-0183 标准的语句，程序可以在这个周期内将接收到的数据进行处理。在进行定位和导航处理中，只需要用到时间、经纬度信息。GPRMC 语句完整的包含了定位所需的所有数据信息。因此，只需要对 GPRMC 语句进行采集，然后根据各段数据的意义，提取出需要的数据信息。图 7 所示为 GPS 数据采集和处理流程。

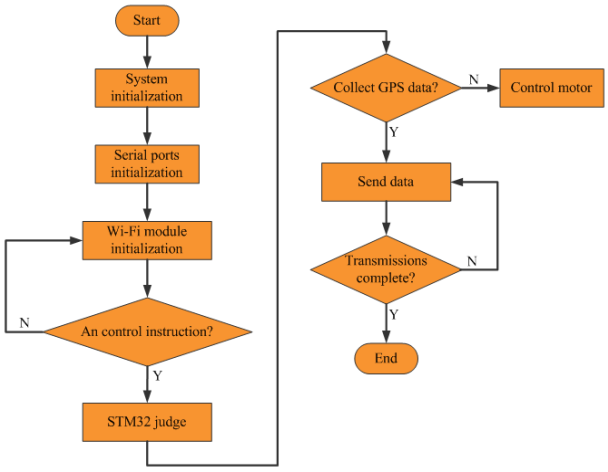

Fig.8 - Wireless data processing

由于NMEA-0183标准的语句是以$GPXXX作为每条语句的起始标志，以回车或者换行符作为语句的结束标志，因此读入一行数据到缓冲区后，就可以判断这行数据是否是所需要的RMC语句，这主要通过在字符串中查找RMC，如果找到就返回RMC在的位置，否则返回-1。如果是RMC语句，则进行下一步判断，判断数据是否有效。数据是否有效有两个标准：第一，这行数据是否完整，这个可以通过判断数据长度来确定。第二，数据中有一个数据段专门用来表示这行数据是否为有效定位数据，V表示无效定位数据，A表示有效定位数据。如果数据有效，则进行经纬度等信息的提取。起始标志之后的第一个数据段是时间，接着是定位状态、纬度、纬度方向(N或S)、经度以及经度方向(W或E)，再之后面的数据不需要关心，因为在定位中用不到。

Meanwhile, the information of time and date extracted from the GPS module is UTC time. Converting UTC time into local time is necessary. UTC time is similar to that of Greenwich's. Beijing time is adopted in China. Beijing belongs to the East Eight time zone, which is ahead of UTC time by eight hours. Eight hours should be added to UTC time when changing the time zone to obtain the local time. If UTC time is after 1600, Beijing time is in the next day, and the date should be changed.

此外，从GPS模块中提取出来的时间和日期信息均为UTC时间，因此需要将其转换为本地时间。UTC时间和格林威治时间相同，在我国，都采用北京时间，北京在国际时区中位于东八区，领先UTC时间8小时，因此在转化的时候，需要将UTC时间加上8小时获得本地时间。需要注意的是，如果UTC时间在16点之后，此时北京时间已经是第二天了，需要改变日期。

Wireless data transmission

Data form is called data frame when the Wi-Fi network is used. When performing serial transmission, byte throttling is implemented. Data from the terminal can be successfully transferred to the controller STM32 only when the system changes the form of data. The constraint mechanism of the Wi-Fi module S2W-M02 used in this study includes the fully automatic mode and the length of automatic framing. The forms of data can be freely transferred using this constraint mechanism to achieve data transmission between the serial port and the wireless network. The flowchart is shown in Figure 8.

无线数据传输程序设计

Wi-Fi 网络传输时，数据形式为数据帧；在串口传输时，为字节流。基于此，系统就需要先转换数据形式，才能将终端的数据成功地传输到 STM32 控制器。本文选用的 Wi-Fi 模块 S2W-M02 的约束机制中，包含“全自动方式”，和“自动组帧长度”，通过这种约束机制，可以成功地实现数据类型的转换，从而实现数据在串口和无线网络之间的传输。其传输流程图如图 8 所示：

Coordinate Transformation

The coordinate system WGS-84 (World Geodetic System) can directly obtain latitude–longitude from the GPS receiver, but most electronic maps do not use this coordinate system. Unifying coordinate systems is necessary to meet the requirements of the display of positioning points in electronic maps [9, 10]. In China, the coordinate systems of many electronic maps of cities are based on the elliptical coordinate system of Beijing 54 (BJ-54). Therefore, the WGS-84 coordinate must be converted into the BJ-54 coordinate. The Bursa–Wolfe model is used in coordinate transformation in this study [13]. The formula of the model transformation is as follows:

坐标转换

从 GPS 接收机得到经纬度属于 WGS-84 坐标系统(World Geodetie System 1984)，而大多数的电子地图并不是采用 WGS-84 坐标系统。为满足电子地图显示定位点的需要，有必要统一坐标系统[9,10]。中国的许多城市电子地图的坐标系统是基于北京 54 的椭圆坐标系（北京-54）。因此，WGS-84 坐标必须被转换成北京 54 坐标。在本文中，使用 Bursa-Wolf 模型进行坐标变换[13]。模型的变换公式可列为：

$$\begin{bmatrix} X_{54i} \\ Y_{54i} \\ Z_{54i} \end{bmatrix} = \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} + (1+\mu) \begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} + \begin{bmatrix} 0 & \varepsilon_Z & -\varepsilon_Y \\ \varepsilon_Z & 0 & \varepsilon_X \\ \varepsilon_Y & \varepsilon_X & 0 \end{bmatrix} \begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} \quad (3)$$

where X_0, Y_0, and Z_0 are translational transformation parameters; ε_X, ε_Y, and ε_Z are rotation parameters; and μ is the zoom scale transformation factor. Seven parameters are used in the above-mentioned formula. Therefore, three or more common points and their coordinates in two coordinate systems are required when calculating transformation parameters. When only three common points are available, the translation, rotation, and zoom scale parameters in the formula can be directly calculated with the plane coordinates of two common points. When more than three common points are available, seven parameters can be calculated according to the principle of least squares. Formula (3) can then be written as follows:

其中X_0，Y_0，Z_0为平移转换参数，ε_X，ε_Y，ε_Z是旋转参数，μ为缩放尺度变换因子，上式中共7个参数，因此，一般说来，需要有三个或三个以上的公共点，利用它们在两个坐标系中的坐标来求出转换参数。当只有三个公共点时，式中的平移、旋转和尺度缩放参数，可由两个公共点的平面坐标直接求得。当公共点个数多于三个时，可以按最小二乘原理求解七参数，这时(3)式可写成如下形式：

$$\begin{bmatrix} X_{54i} \\ Y_{54i} \\ Z_{54i} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & X_{84i} & 0 & -Z_{84i} & Y_{84i} \\ 0 & 1 & 0 & Y_{84i} & Z_{84i} & 0 & -X_{84i} \\ 0 & 0 & 1 & Z_{84i} & -Y_{84i} & X_{84i} & 0 \end{bmatrix} \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \\ \mu \\ \varepsilon_X \\ \varepsilon_Y \\ \varepsilon_Z \end{bmatrix} + \begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} \quad (4)$$

$$C_i = \begin{bmatrix} 1 & 0 & 0 & X_{84i} & 0 & -Z_{84i} & Y_{84i} \\ 0 & 1 & 0 & Y_{84i} & Z_{84i} & 0 & -X_{84i} \\ 0 & 0 & 1 & Z_{84i} & -Y_{84i} & X_{84i} & 0 \end{bmatrix} \quad (5)$$

$$B_i = [X_{84i} - X_{54i}, Y_{84i} - Y_{54i}, Z_{84i} - Z_{54i}]^T \quad (6)$$

Coordinate Transformation

The coordinate system WGS-84 (World Geodetic System) can directly obtain latitude–longitude from the error equation can be obtained, and its matrix form is as follows:

坐标转换

从GPS接收机得到经纬度属于WGS-84坐标系统(World 则可以列出误差方程，其矩阵形式为：

$$V = AR + L \quad (7)$$

where $R = [X_0, Y_0, Z_0, \mu, \varepsilon_X, \varepsilon_Y, \varepsilon_Z]^T$, $V = [V_X, V_Y, V_Z]^T$, $L = [B_1, B_2, ..., B_n]^T$, and $A = [C_1, C_2, ..., C_n]^T$.

If each measurement is supposed to be equal in accuracy, the least square solution of the transformation parameter can be expressed as

其中 $R = [X_0, Y_0, Z_0, \mu, \varepsilon_X, \varepsilon_Y, \varepsilon_Z]^T$ ， $V = [V_X, V_Y, V_Z]^T$ ，$L = [B_1, B_2, ..., B_n]^T$， $A = [C_1, C_2, ..., C_n]^T$。

若认为各观测量是等精度的，则可得转换参数的最小二乘解为：

$$R = (A^T A)^{-1} A^T L \quad (8)$$

Finally, the computing result is *R* with seven transformation parameters. After transforming the coordinates through the above mentioned models, the WGS-84 coordinate can be transformed into the BJ-54 spatial rectangular coordinate. Gauss projection is then conducted, and the spatial coordinates are transformed into plane coordinates that are compatible with electronic maps. The process flowchart is shown in Figure 9.

最后解得 *R*，求得 7 个转换参数。再利用上述模型进行坐标转换，就可以把WGS-84坐标转换到北京54空间直角坐标系下，然后进行高斯投影,把空间直角坐标转换成电子地图所用的平面坐标系中。其程序流程图如图 9 所示。

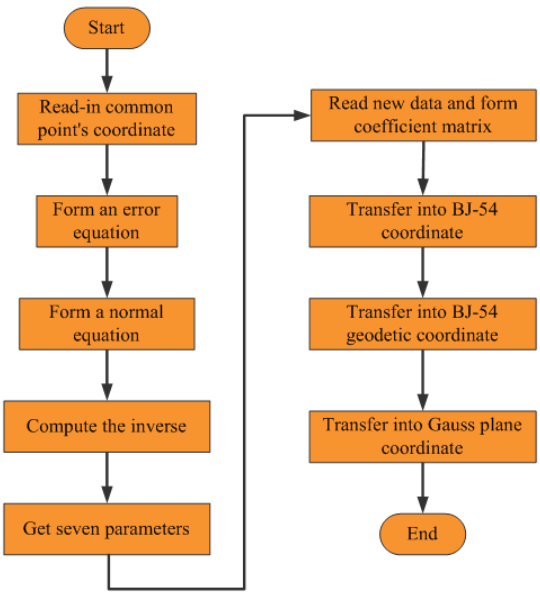

Fig.9 - Coordinate transformation

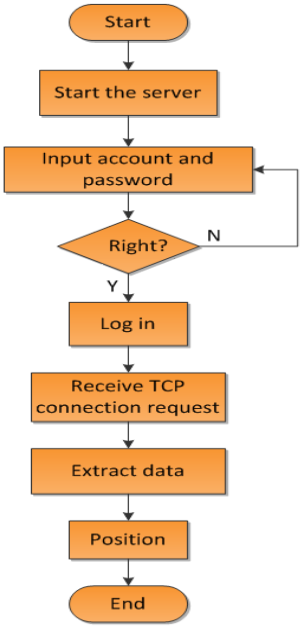

Fig.10 - Sever data processing

Server design

The program of TCP/IP agreements employs the client–server model. In server-side programs, data from the client side are received as soon as connection request data are found. The corresponding positions are displayed on maps. Figure 10 shows a flowchart designed for servers.

服务器设计

TCP/IP 协议的程序使用的是客户端/服务器模式。在服务器端的程序中，通过监听本地主机的一个端口，一旦有客户端的连接请求，就接收来自客户端的数据，并在地图上显示出相应的位置，图 10 为服务器设计流程图。

RESULTS

A low-cost system with built-in-GPS agricultural machinery is developed in this study according to the abovementioned principles of operating the software and hardware. The hardware system is shown in Figure 11.

结果

根据前面所述的软硬件原理，本文开发了一套低成本的农机 GPS 导航定位系统，其硬件系统如图 11 所示。

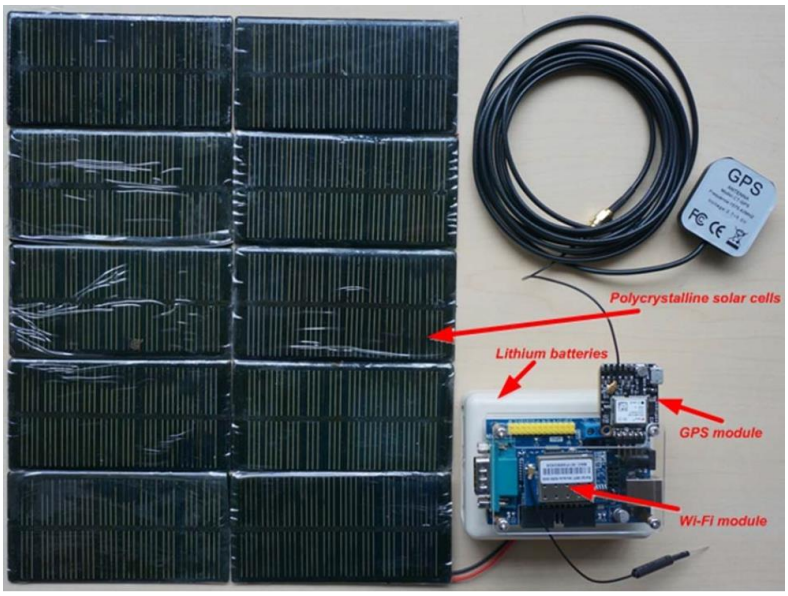

Fig.11 - Hardware system

Two experiments are conducted to verify the navigation precision of the designed system. The first experiment aims to measure the reaping area [5], and the second one aims to obtain the location of the agricultural machine. In Experiment 1, the reaping pitches range from 112 m^2 to 2166 m^2. Most pitches are rectangular, and several are irregularly shaped. A comparison of the measured reaping and actual areas is shown in Table 1.

为了验证该系统的定位精度，本论文通过两种实验进行测试验证，一种是通过测量收割面积[5]，一种是获取农机行车位置信息。实验 1，通过对实际的田间收割地块进行测量，收割地块大小从 112m^2 到 2166 m^2，地块区域大多数是矩形，有些是不规则形。将测量得到的收割面积与地块实际面积的对比统计如表 1 所示。

Table 1

Area measurement table

No.	Measurement area(m^2)	Actual area(m^2)	Error (%)
1	131.14	112.00	1.70
2	466.03	408.37	1.41
3	903.19	763.82	1.82
4	1329.83	1321.57	0.62
5	1883.58	1873.98	0.51
6	2174.98	2166.32	0.39

The measured and actual errors can be stabilized to less than 3%, as shown in Table 1, which meets the requirement of within the 5% error standard. Table 1 shows that the error between the statistic area of the relatively large area and the actual reaping area is small (less than 1%).

The server interface is designed with Qt. The multi-threaded approach is applied to enhance system performance. A thread is responsible for processing wireless data. Another thread mainly processes the map display and user input. The interface is shown in Figure 12.

从表1所列的系统所得的收割面积与实际收割面积之间的误差一般能稳定在3%以下，符合现行农机跨区收割时对收割面积统计所允许的5%的误差要求。而且从表中可以看出，在收割较大面积时系统的统计面积与实际收割面积的误差相对较小，一般在1%以下。

服务器界面采用 QT 进行设计。为了提高系统的性能，本论文使用多线程的方法。一个线程负责处理无线给的数据。另一个线程主要处理地图显示和用户输入。其界面如图 12 所示。

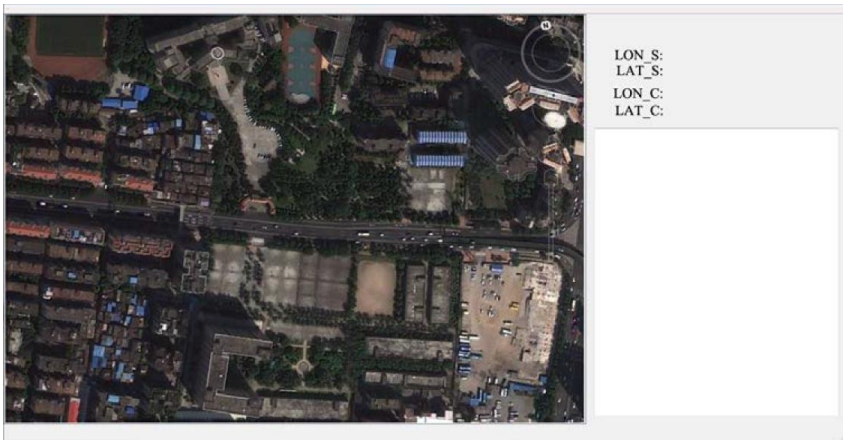

Fig.12 - Server interface

In Experiment 2, an agricultural university is selected as the experimental area. This area is from (113° 16′ 28.00 ″ E to 113° 16′ 45.7″ E) to (23° 06′ 81.02″ N to 23° 06′ 34.12 ″ N). The experiment adopts real-time field data. The position of the agricultural vehicle is accessed by GPS, and the data are sent to server-side maps via Wi-Fi to test the system's accuracy and reliability. The result (shown in Figure 13) indicates that the accuracy of locator data satisfies the operating qualification of the system but has errors when matched with real maps. Such errors are probably caused by the difference between the database of electronic maps and orientation modules. Corrections should be made on positioning data in the late stages of development.

实验 2 以某农业院校为实验区域，这一区域为东经 113° 16′ 28.00″ 到东经 113° 16′ 45.7″，北纬 23° 06′ 81.02″ 到 23° 06′ 34.12″，采用实地实时采集数据，利用系统中的 GPS 模块获取农用车辆行驶过程中的位置信息，然后将采集的数据通过 Wi-Fi 的方式传到服务器端的地图进行显示，从而验证系统的准确性和可靠性，其结果如图 13 所示。测试结果表明，定位数据的精度满足了系统的使用要求，但是和实际电子地图之间的匹配有一定的误差，这可能是电子地图的数据库和定位模块之间存在的系统的差异，在后期的开发中，需要对定位的数据作出修正。

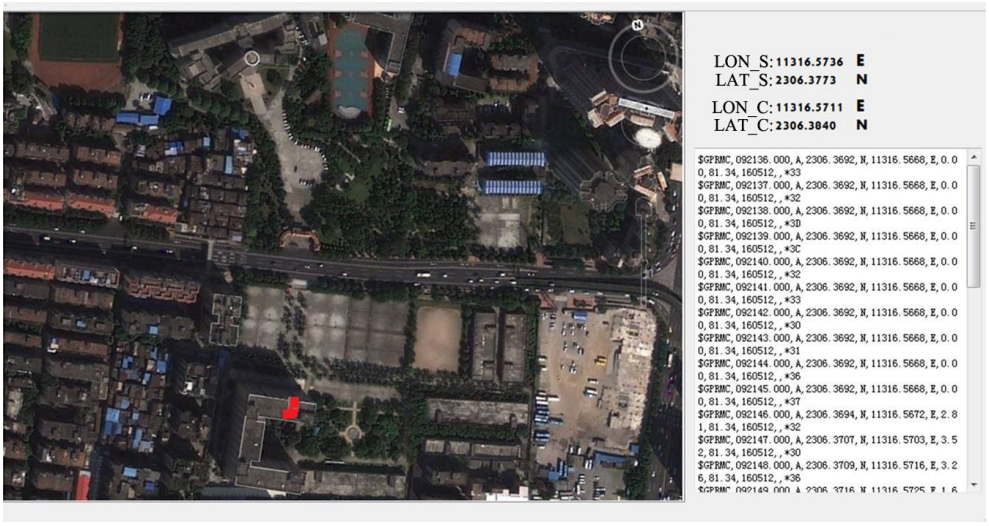

Fig.13 - Demonstration of agricultural machinery positioning

CONCLUSIONS

Intelligent agricultural machinery, which is driven and supported by modern science and technology, is an integral part of precision agriculture and development of intelligent agriculture. On one hand, it can improve working efficiency and production output. On the other hand, it can minimize labor intensity and injury. In the operation process of intelligent agricultural machinery, the intelligent function depends on how precisely the machine can locate and navigate in farming fields. GPS is the first option in sensing the location. At present, the common agricultural

结论

现代科学技术支撑的智能农业机械被认为是精准农业和智慧农业发展的关键设备，发展智能农业机械一方面可以提高生产效益和劳动生产率，另一方面可以大大减轻在农业实施过程中农民的劳动强度和减少对农民的安全伤害。然而农业机械的智能化作业其功能往往在依赖于它在农田中的精确定位导航。一般来说，对农田位置的精确感知，GPS 是的首选设备。目前，常见的农用 GPS 设备往往是

GPS facility is the double-satellite double-frequency high-cost receiver, which hinders the popularization and application of such systems. Agricultural navigation specialists also integrate inertial navigation with GPS to increase the locating precision. However, the inertial navigation device increases the cost of the system. Therefore, a low-cost system with built-in-GPS agricultural machinery was designed in this study based on the actual demand for low cost and high precision in agricultural production. The key software and hardware technology was analyzed and applied to the built-in-GPS agricultural machinery, and all the functions were accomplished to satisfy the requirements of agriculture location and realize automation and modernization.

ACKNOWLEDGEMENT

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双星双频接收机，但由于其价格高昂成为 GPS 精确定位在农业生产领域普及应用的障碍。除此以外，为了提高定位精度，还可以把惯性导航设备与 GPS 进行结合，但惯导设备的引入也大大增加了系统的定位成本。因此，本文从农业生产中低成本高精度定位的实际需求出发，开发基于低成本 GPS 设备的农机导航定位系统。通过对软硬件的关键技术进行了系统学习和理论研究，并将结果应用到嵌入式农机 GPS 导航定位系统的设计与功能实现中，最终完成系统的功能，满足农田定位精度要求，实现了农业机械的自动化和现代化。

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RESEARCH ON SAVING IRRIGATION CONTROL SYSTEM BASED ON THINGS
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基于物联网的节水灌溉控制系统研究

M.E. Lect. Xiaoying Yang, M.E.. Lect. Wanli Zhang, M.E..Prof. Qixiang Song
College of Information Engineering, Suzhou University, Suzhou, China
Tel:13866547730; Email: yxiaoying2000@163.com

Abstract: *Drought and water shortage is one of the main factors restricting the development of China's agricultural production, with the advance of modern agricultural policy, water resources become tighter. The emergence of the Internet of Things, will provide a good way for modern agriculture intelligent water-saving irrigation. In order to effectively solve the problem of waste water on irrigation and rationally use water resources to effective irrigate, a water-saving irrigation control system based on Internet of things is designed in this paper. Firstly, design the structure of the system. Then, according to the specific application environment, depending on the acquisition terminal of sensing layer, the gateway of the transport layer and the control end of the application layer are analyzed, the hardware is designed and the structure charts are given. According to the composition of the system, software structure of the system is designed. Finally, collecting data of the system is processed by data filtering and difference analysis, so as to obtain the control data effectively, and achieve the purpose of automatic control and water saving irrigation.*

Keywords: *Internet of things, water-saving irrigation, software architecture, data filtering*

INTRODUCTION

China is a large agricultural nation and agricultural water consumption occupy most of water in China, accounting for about 80%, while the agricultural irrigation efficiency is low at present, only 45% [11], [6]. Saving agricultural irrigation water can effectively alleviate the problem of shortage of water resources [13], [9]. In China, farmland is widely scattered and different crop have different water consumption, which lead to difficulties in agricultural water-saving irrigation [5], [4], [1]. Using trench irrigation, waste farmland utilization and water resources, while adopting the automatic control irrigation technology, not only can meet the different crops requirements of different water, rationally allocate of various water supply equipment but can also realize the statistical analysis of use of resources of farmland system, so that the staff can grasp the relevant information resources and reasonable dispatch water resources to achieve the purpose of saving water [14].

The Internet make people without space limitation come true, the Internet of things mainly make the human coherence together at any place at any time, the most important is to connect people and objects, make more intelligent and efficient management on things, to achieve the highest output at the lowest cost maximum efficiency. The Internet has changed the life, but the Internet of things is the essence of the change. The ultimate goal is to control the material, to realize the resource optimal allocation of control, material precise management, the most intelligent monitoring, with the minimum cost for the biggest value [15], [8], [12]. A lot of foreign agriculture has been implemented irrigation system based on the Internet of things,

摘要：*干旱缺水是制约我国农业生产发展的主要因素之一，随着现代化大农业方针的推进、水资源日趋紧张。物联网的出现，将为现代农业智能节水灌溉提供了有效的方法。为了有效解决农田用水中的浪费问题，合理使用水资源进行有效灌溉，本文设计实现了基于物联网的节水灌溉控制系统。首先对系统的结构进行设计，根据具体的应用环境，分析了感知层的采集终端、传输层的网关以及应用层的控制端功能，对其采用的硬件进行设计并给出了结构图。根据本系统的组成，设计了系统的软件结构，最后对系统采集到的数据采用数据过滤和差值分析进行处理，从而得到有效的控制数据，进而达到自动控制节水灌溉的目的。*

关键词：*物联网, 节水灌溉, 软件结构, 数据过滤*

引言

我国是农业大国，农业用水量占据了我国大部分用水，约占 80%左右，而目前的农业灌溉效率较低，仅为45%[1][2]。节省农业灌溉用水能够有效缓解水资源的紧缺问题[3][4]。在我国，农田分布范围广泛，加上各种农作物用水量各不相同，导致农业节水灌溉困难[5][6][7]。采用沟渠灌溉技术，既浪费农田的利用率又浪费水资源，而采用自动化控制的灌溉技术，既能够满足不同农作物对水量的不同要求，又能够合理配置各个供水设备，还能够实现农田系统中的各种资源使用情况的统计分析，从而让工作人员能够及时掌握了相关资源信息，合理进行水资源的调度，达到节水的目的[8]。

互联网改变了人生，而物联网起来之后是本质的变。最终的目的是对物质的控制，人对物质的控制精准的管理实现资源最优的配置，最智能化的监测，以最小的代价换取最大的价值[9][10][11]。国外农业很多已经实现基于物联网的灌溉体系，但国内这方面的应用还很少。因此本文设计了一个基于物联网的节水灌溉控制系统，主要是通过传

but it is rarely used in this aspect of the domestic. Therefore, this paper designed a water-saving irrigation control system based on the Internet of things, which mainly collect soil data by temperature and humidity sensor, set parameter of the open or close the pumps, once reaches the valve of opening, irrigation system automatically open the pumps, if it reaches closing, irrigation system automatically close the pumps, which achieves the goal of automatic irrigation and water conservation.

MATERIALS AND METHOD

The Design Of The System Structure

Irrigated data situation of farmland can be collected, analyzed and processed by the system designed in the paper. The system can develop an appropriate scheme and timely irrigate. First, are set parametric conditions of irrigation on monitoring computer, in advance of irrigation operations depending on weather conditions provided by the Internet. The system consists of three layers: the perception layer, which is responsible for collecting air temperature, light, soil moisture and other data related to irrigate farmland, is also responsible for neighbouring node routing; transmission network layer is responsible for data transmission; l; terminal control layer, which used for monitoring terminal data and control transmission network layer, deploy related services on the server for network members to connect, and provides data service, the user can view the data on the server by different ways. The structure of the system is shown in fig.1.

感器收集土壤的温湿度数据，设置打开关闭阀门的参数，一旦达到打开阀门的条件，灌溉系统阀门自动打开，如果达到关闭阀门的条件，则自动关闭灌溉系统阀门，从而实现了自动灌溉和节水的要求。

材料和方法

系统结构设计

本文设计的系统能够采集农田的灌溉数据情况、对采集到的数据信息进行分析处理、制定相应的灌溉方案和及时进行灌溉。首先在监控计算机一端设置灌溉的参数条件，根据互联网提供的天气情况，提前进行灌溉操作。系统主要分为三层：感知层，负责农田中空气温度、光照、土壤湿度的等相关灌溉数据的采集，同时负责相邻节点的路由；传输网络层，负责数据的传输；终端控制层，监测数据及控制传输网络层，用户可通过不同方式查看服务器上的数据。系统结构如图 1 所示。

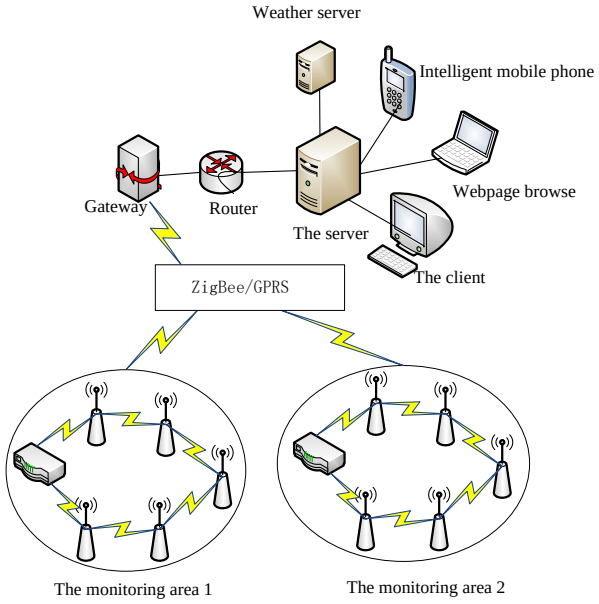

Fig. 1 – System structure diagram

Wireless sensors of temperature and humidity embedded in the soil are the Internet of things acquisition unit, which collect soil moisture information and the other using GPRS network model to transfer soil moisture information to the monitoring computer installed in the control center. Since the ZigBee wireless communication technology with the advantages of low power consumption, low cost, short time delay, large network capacity and safety and reliability [7], so use ZigBee wireless communication technology as a technology center. Each ZigBee monitoring network has a plurality of soil temperature and humidity data acquisition node. The monitoring center computers recycling receive soil moisture information sent by every acquisition terminal, analyze and compare the received data and the crop water requirement to them in historical database. Then analyzed

物联网终端采集单元为埋入土壤中的无线温湿度传感器，它们负责感应和采集土壤的水分情况，然后通过 GPRS 网络将收集到得这些数据信息传送到监控中心的计算机上。由于 ZigBee 无线通信技术具有低功耗，成本低，时延短，网络容量大，安全可靠等优点[12]，因此采用 ZigBee 无线通信技作为中心技术。每个 ZigBee 监测网络有若干土壤温湿度数据采集节点。监控中心计算机循环接收各个采集终端发送的土壤墒情信息，监控计算机将接收到的数据与历史数据库中的对应作物需要的水资

the data meet or do not meet the need, the most suitable for crop irrigation scheme is maken according to the analysis results. Watering orders are transmitted from computer monitors to the sprinkler control terminal, which is responsible for controlling the implementation of tasks sprinkler irrigation and other irrigation equipment.

System Hardware Design

A. Acquisition Terminal Design

Sensing layer is responsible for rapidly, accurately collect and transmit related data information, provide an effective basis for the development of irrigation schemes to adapt to the environment.Terminals are composed of sensing nodes which represent the basic functional unit. Given that the farmland under irrigation for the use of detection covers a wide range as well as plenty of senser nodes scatters in the farmland etc, the acquisition terminals shall be designed to be flexibly move and easily installed. Analysis of functional characteristics of sensor nodes, the design of sensing node structure are shown in Fig.2, mainly make up of components such as the general information collection board, power supply, communication unit, GPS positioning unit etc.

源量作比较，然后分析是满足还是不满足，根据分析结果制定好最适合作物的灌溉方案。浇水命令由负责监控的计算机传送给喷灌机控制终端，由其负责控制执行灌溉任务的喷灌机等喷灌设备。

系统硬件设计

A. 采集终端设计

感知层负责迅速、精确地采集和传输相关数据信息，为制定适应环境的灌溉方案提供有效依据。感知节点构成采集终端，是最基本的功能单元。因为具有灌溉需要检测的农田范围广，大量的感知节点随机分布在农田中等特点，因此设计采集终端时应该采用灵活移动，容易安装的策略。分析感知节点的功能特点,设计感知节点结构如图 2 所示，主要由通用信息采集主板、电源、通信单元、GPS 定位单元等部分组成。

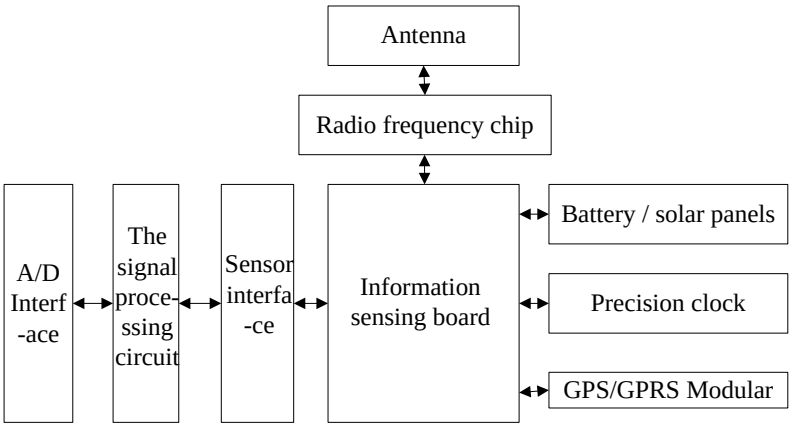

Fig. 2 – Sensor nodes structure diagram

General information acquisition board is mainly composed of MCU (Micro-Controller Unit) unit, acquisition unit, memory and so on. Acquisition unit uses soil humidity and temperature sensor to collect soil moisture data; after processing by MCU, the data is sent to the monitoring center computer through the GPRS network, center computer collects the temperature and humidity data and automatically displays the relevant information. The core control of acquisition terminal MCU is the core of acquisition system, this system chooses ATmega128L, which is a 8 bit single chip microcomputer with high performance and low power consumption[2]. Wireless transmission module selects the high price of the RF chip CC2420. The data acquisition unit uses "solar panel and battery" to power for collection unit. The output signal of sensor nodes is transferred to digital converter A/D of internal subsystem after processing by signal conditioning circuit. MCU starts A/D timely, converts analog to digital and takes data. Then sends the processed data to wireless transmission module through the serial port, and starts the module to send the data to the GPRS wireless network. After receiving by the network, the data is transferred to Internet via a gateway, eventually received by central station computer which is connected to the Internet.

通用信息采集主板主要由 MCU(MicroControUer Unit) 单元、采集单元、存储器等构成。通过土壤湿温度传感器，采集单元采集到农田中的土壤墒情信息，然后由 MCU 进行处理，将处理好的数据经由经 GPRS 网络传到监控中心，位于监控中心的计算机收集与灌溉相关温湿度和光照信息，并将其显示到屏幕。采集终端的核心控制 MCU 是整个采集系统的核心,本系统选用的是 ATmega128L，是一款高性能、低功耗的 8 位单片机[13]。无线传输模块选用了性价比较高的射频芯片 CC2420。数据采集单元采用“太阳能电池板 +电池”的形式为采集单元供电。信号调理电路负责处理传感器节点输出的信号，处理好的数据信号传至模数转换器 A/D，由 MCU 按特定时间启动，将该模拟信号数据转换成数字信号数据，转换后的数据被取走并经由串行口发送至无线传输模块，无线传输模块被启动，GPRS 网络接收来自该模块的数据信息，通过网关发到 Internet 中，最终监控中心计算机接收该数据。

B. The Transport Layer Design

The communication system of water saving irrigation control system based on the Internet of things is set in the fundamental of ZigBee wireless communication technology and GPRS. ZigBee network connects control nodes, wireless routing nodes and wireless gateways whereas GPRS network transmits the collected data to remote monitoring computers. Wireless gateways plays a central role in the system because it is used for protocol conversion between ZigBee network and GPRS network, just as a bridge between them. The structure diagram is shown in Fig. 3.

B. 传输层设计

基于物联网的节水灌溉控制系统的通讯系统是树立在 ZigBee 无线通讯技术和 GPRS 的根本上。ZigBee 网络负责控制节点、无线路由节点、无线网关之间的通信。GPRS 网络负责将采集到的数据传送至远程的监控计算机中。无线网关是本系统的中心局部，负责这两种网络之间协议的转换，是 ZigBee 网和 GPRS 网络连接的桥梁，其构造图如图 3 所示。

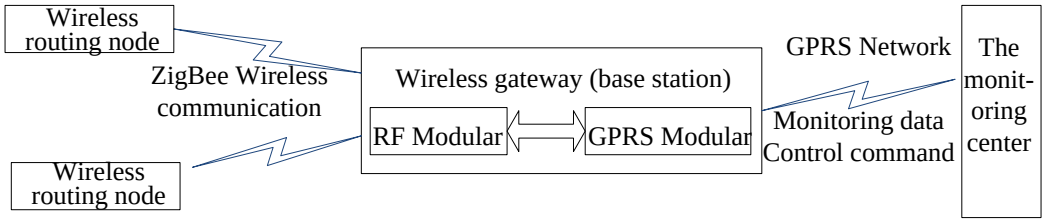

Fig. 3 – Schematic diagram of the gateway structure

Gateway with ZigBee RF module, GPRS module, RS232 interface, Ethernet interface, in order to realize the conversion of two arbitrary communication buses.In interface, mismatch of the industrial control field can facilitate to interconnect various interface equipment. In the application of engineering control, if interfaces do not match, the devices with different interfaces can be connected through a wireless gateway. More than that, ZigBee can transmit data in the environment, in which the arrangement of wire is hard to realize, to the monitoring and control center by means of wireless communication while GPRS can also transmit data to the public network in the same way. Thus, remote control is achieved.

C. Control Layer Design

Based on analyzing the overall perception of information, control layer realizes the automatic control of water saving irrigation. Control terminal realizes the direct controlling of irrigation equipment. Terminal is connected with the scene equipment through standard interface, after receiving the scene perception information, control terminal firstly treats, and sends the control command according to predetermined rules. Besides having the function of automatic control, it also can realize the control of field devices through the controller and PC machine etc. Control terminal structure is shown in fig.4.

无线网关主要由 RF、GPRS 两种模块以及 RS232 、以太网两种接口构成，因而达到对任意两种通信总线之间的相互转换的目的。一方面，在工程控制应用中，若接口无法匹配，经无线网关即可实现不同接口设备之间的互连；另一方面，在布线困难的环境中，通过 ZigBee 可以将困难环境中的数据以无线通信方式传送至监控控制中心，公网也能够接收来自 GPRS 网络传送过来的数据，从而实现远距离的控制。

C. 控制层设计

经过全面分析感知信息，控制层实现节水灌溉的自动控制。由控制终端控制，灌溉设备经由标准接口连接到现场设备,处理采集到的信息，依据设定的条件发出灌溉控制命令，现场设备根据命令进行灌溉作业。除此之外，控制终端还能够利用 PC 及等控制现场设备，具体的结构如图 4 所示。

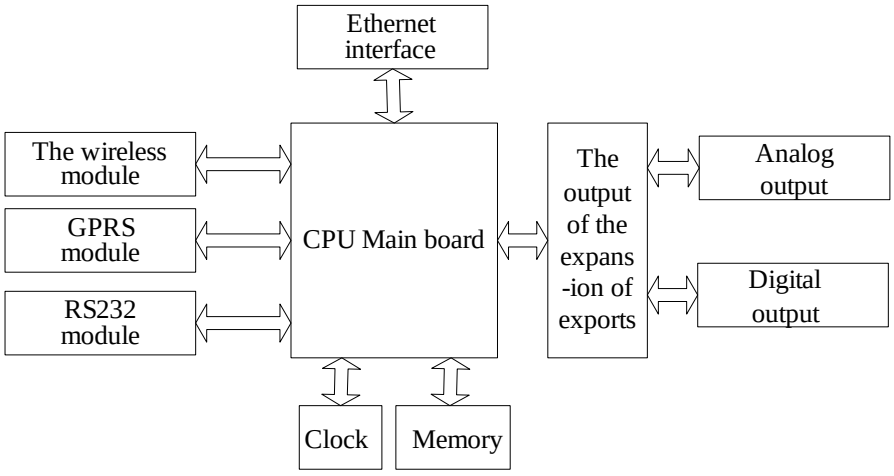

Fig. 4 –Control terminal structure diagram

Software Structure Design

The system uses the Internet environment, using B/S mode to develop. The system server uses Linux operating system which is the most popular operating system. Java language is used to develop the front interface and background database system uses SQL Server 2005 which is a medium-sized database which is easy to develop and maintain. The structure of the software is shown in fig. 5. The field data can be timely processed by real-time database and the processing results are displayed on the screen, which can be used by staff to form operators and quickly reach the field end.

软件结构设计

本系统采用 B/S 结构，在网络环境下开发。服务器端采用目前最流行的 Linux 操作系统，系统前台界面的开发语言采用 Java 进行，后台数据库选用易于开发和维护的中型数据库 SQL Server 2005，软件结构如图 5 所示。通过实时数据库，农田数据得到及时的处理，将处理的结果反映到各种终端设备屏幕上，管理人员根据屏幕显示的数据发出相应的指令并及时传至农田终端。

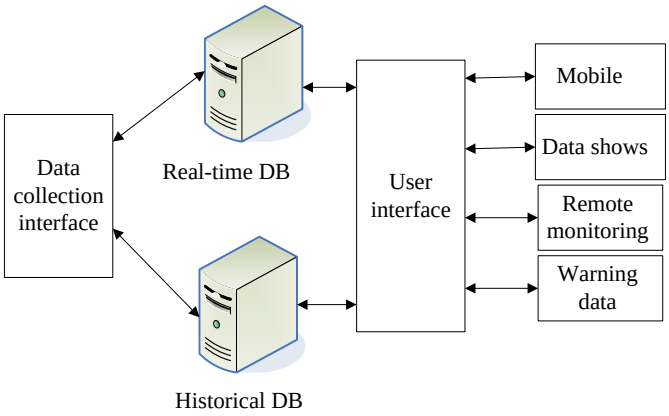

Fig. 5 – The structure of the software

First the sensors collect data and feedback to the central computer. Then the system database based on a pre-set alarm conditions call control algorithms, open or close irrigation equipment based on the data values which are output by control algorithm, until the soil moisture reaches the optimum preset value of crop growth. The user can view the data, also can realize remote monitoring irrigation. The flow chart of control program of runtime system is shown in fig. 6.

首先中心计算机接收来自传感器节点采集到的农田数据信息，然后系统数据库依据预设定的报警条件调用控制算法，根据算法输出的数据值控制打开或关闭灌溉设备，直到土壤湿度达到预先设定的最适宜作物生长的值，用户可以查看数据，也可以远程监控灌溉。系统运行时的控制程序的流程图如图 6 所示。

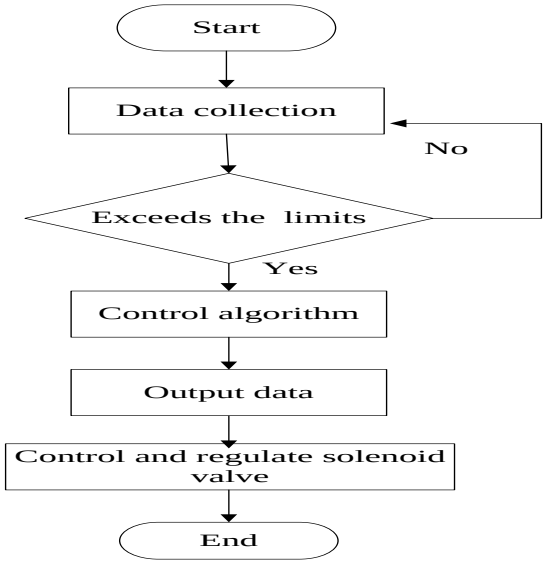

Fig. 6 – Flow chart of control processing system

Data Processing

In this system, not only manual intervention can be achieved, but also automatic irrigation can be achieved. Monitoring centre of the system processes the data which are collected by sensing terminal, the user determine

数据处理

在本系统中，即可实现人工干预，也可实现自动灌溉。感知终端收集到的数据由监控中心进行分析处理，

whether need for irrigation according to the obtained data. If the automatic irrigation is enabled, the real-time database processes the received data, analyzes and compares them with the historical database. The system automatically sends command when the soil is dry, opens the solenoid valve for irrigation. Because the Internet of things emphasizes the connectivity between each connected things, and the controllability of the system, sensor network in the Internet of things is the channel of connecting the observer and the observed object. Therefore, it needs to process the data collected by sensor networks, release out as observers need form to achieve better control of irrigation purposes. This system uses the filtering and interpolation for data processing.

Data Filtering

In the physical experiment, data obtained whether by artificial observation or by acquisition system, is inevitably superimposed noise signal. In order to improve the quality of the data, the noise must be removed. Because sensor networks is no filtering at the sensor end, there some singular data may have been collected back, in general use, it needs to be filtered, only observe reasonably reliable data. To ensure that only reliable data will be observed, it's necessary to subject the collected data to filtering procession. Therefore, the system employs smoothing filtering [3] easy to calculate, in which high-frequency components and minor disruption in the observation value are decreased or removed on the premise that low-frequency components are not affected, as shown in formula (1).

工作人员根据处理得到的最终数据，结合农田的实际情况，决定灌溉作业。如果启用自动灌溉功能，则由实时数据库根据接收到的数据进行处理，与历史数据库进行分析比对，自动发出灌溉指令控制终端灌溉设备进行灌溉。物联网注重事物之间的关联性和系统的可控性，而观测者与被观测对量之间连接的桥梁是传感器节点构成的传感器网络，因此，对该网络采集到的数据信息作相应的处理，然后根据观测者的需要发布出去，以达到更好控制灌溉的目的。本系统采用滤波和插值对数据进行处理。

数据滤波

在物理实验中，不论是人工观测的数据还是由数据采集系统获取的数据，都不可避免叠加上噪声信号。为了保证采集到的数据质量，需要将噪声过滤掉。而传感器网络终端未对数据进行过滤，因而会采集回部分奇异数据。为了保证只观测合理可靠的数据，需要对采集到的数据进行滤波处理。基于此，本系统采用易于计算的平滑滤波[14]，保证图像在低频率分量不受影响的前提下，减少或去掉高频率的分量以及连接观测值中的微小中断，如式（1）所示。

$$y_k = \sum_{i=k-N}^{i=k+N} a_i x_i \tag{1}$$

Any of the output value y_k after processing is the result of observed value x_i compute with the adjacent elements. The filter window width is $2N$, k is the median filter window, a_i is the weighted coefficient. In order to easily calculate, must be used the matrix expression, available formula (2).

其中，y_k 为被平滑滤波处理后得到的任一输出值，x_i 为与邻元素运算后的值。$2N$ 为滤波窗宽度，k 为滤波窗中值，a_i 为加权系数。采用矩阵表达可以便于计算，如式（2）所示。

$$Y = [A]X / n \tag{2}$$

Where $[A]$ is the filter matrix, X is the input vector, n is average parameters and Y is output vector. The filter matrix is 7 ranks with matrix elements 1, n is 7.

The corresponding service is *record [] Data Process. Smooth (Datetime start, Datetime end, bool linear),* of which, the return value is the value of the output filtering, *start* is the starting time, *end* is the termination of time, *linear* is linear filtering.

其中滤波矩阵是 $[A]$，输入向量是 X，平均值参数是 n，输出向量是 Y。滤波矩阵为行列元素皆为 1 的 7 阶矩阵，n 为 7。

record [] DataProcess.Smooth (Datetime，start, Datetime end, bool linear) 为对应服务。其中，滤波后的输出值就是返回值，起始时间是 start，终止时间是 end，线性滤波标志是 linear。

Linear Interpolation

If observers only get the sensor location data, it cannot reflect the relationship between observed farmland and the observer. Thus, it is necessary to interpolate the acquisition of sensor data; data after space interpolating will be provided to the user, so that the observer only has to input the location information to obtain the required data. Because the temperature, humidity and light are continuously changing in the same farmland, the obtained data by using the interpolation analysis is credible. The system uses two simple interpolations [10].

线性插值

观测者与被观测对象即农田之间的关系无法通过观测者收到的传感器节点的位置信息体现出来，所以需要对传感器节点采集到的数据信息做插值处理。数据经过空间插值处理后再传给观测者，使他仅输入位置数据就能获得需要的信息。而温湿度以及光照在相同农田里是连续变化的，因而通过插值处理后得到的数据信息可信度很高。本文利用易于运算的两点插值方法进行插值处理[15]。

Two interpolations take observations of 2 point *A* and *B* as the reference value, calculating the value of any point, as shown in formula (3).

在两点插值法中，参考值选用相近的两节点A，B的观测值，利用式（3）计算任意点的距离值。

$$y = (x_2 y_1 - x_1 y_2) / L \tag{3}$$

Where y_1 is the observation value of node A and y_2 is observation value of node B. Distance between interpolation points and node A, B are x_1 and x_2. Recent distance between two points is L. Two interpolation method has the advantage of being simple, free from interference of other points, which is often used in the deployment of a network of observation points.

The corresponding service is *double [] DataProcess, getValue (double longitude, double latitude, bool simple)*, of which, *longitude* is longitude of the in the interpolation points and *latitude* is longitude of interpolation points, *simple* is interpolation sign for the two nodes. The return values are point humidity, temperature and light observation of interpolation point.

其中A、B点观测值分别是 y_1 和 y_2，插值点距A、B点距离分别是 x_1 和 x_2，最近两点距离是 L。两点插值法具有简单易行、不受其他点干扰等优点，因而在部署网络时常用来校验观测点传感器的工作情况。

double[]DataProcess, getValue (double longitude, double latitude, bool simple) 是对应服务。其中插值点经度和纬度分别是 longitude 和 latitude，simple 为两点插值标志，插值点湿度、温度和光照观测值就是返回值。

RESULTS AND ANALYSIS

The overall design of control system of water saving irrigation is shown in Fig.7. Light, temperature and humidity of crop in field are viewed and monitored by monitoring station through sensor network and the results are displayed in the main control computer. According to data displayed, the staff decided whether is needed to irrigate.

结果和分析

节水灌溉控制系统整体设计如图7所示，监控站通过传感器网络查看和监控田间作物的温湿度及光照情况，查看结果在主控电脑上显示，工作人员根据显示的数据决定是否进行灌溉。

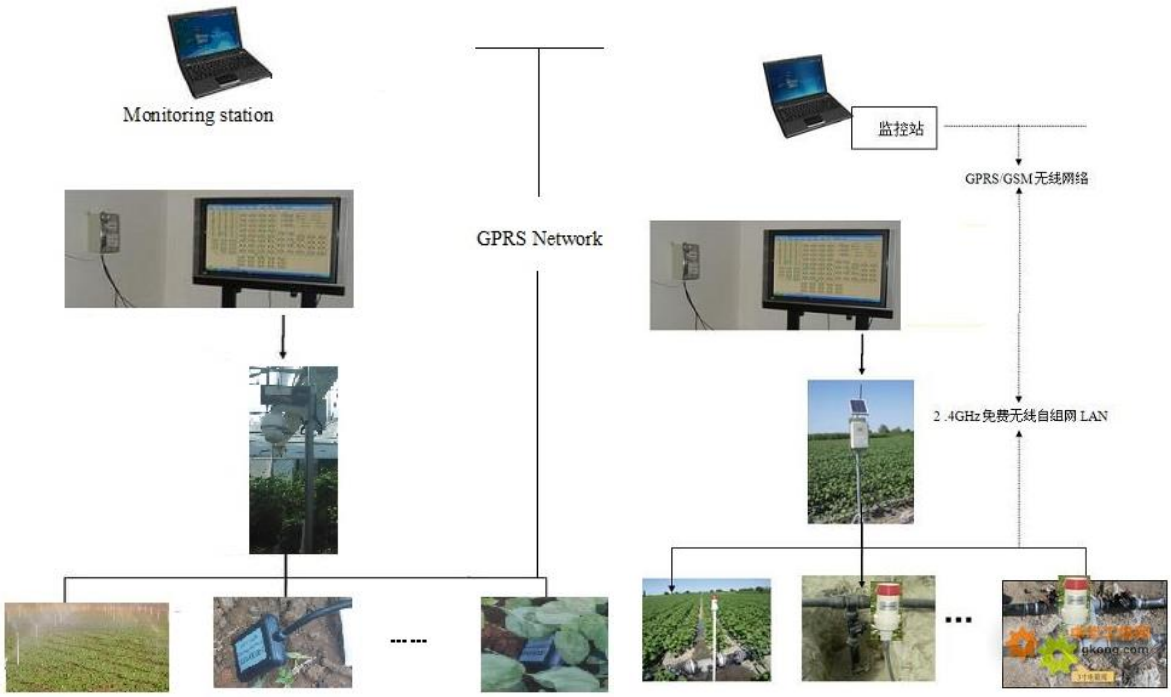

Fig. 7 - System design

The sensor network collected a large amount of data. Through the corresponding service, data curve at any point within the region can be collected. The object observed by user has been transformed into the observation object by sensor nodes. The observation can

传感器网络采集到大量的数据，区域内任意节点的数据曲线可以通过对应的服务采集到。传感器网络节点由用户观测的对象转换成被观测对象，观测值由选择位

be directly obtained by selecting location. Fig.8 shows the latitude and longitude of the soil moisture in acres and light curve of fertile farmland. From October 1, 2014 to October 2nd, Suzhou has experienced a period of rainfall, the light intensity decreased sharply during rainfall, while the soil humidity is rising rapidly until the rain stopped and began to fall at night.

置得到。图 8 展示了宿州千亩良田中经纬度的土壤湿度和光照曲线，在 2014 年 10 月 1 日至 10 月 2 日宿州经历了一场降雨，因而光照强度急剧下降，土壤湿度则随着降雨过程一直升高，当降雨结束时，湿度开始下降。

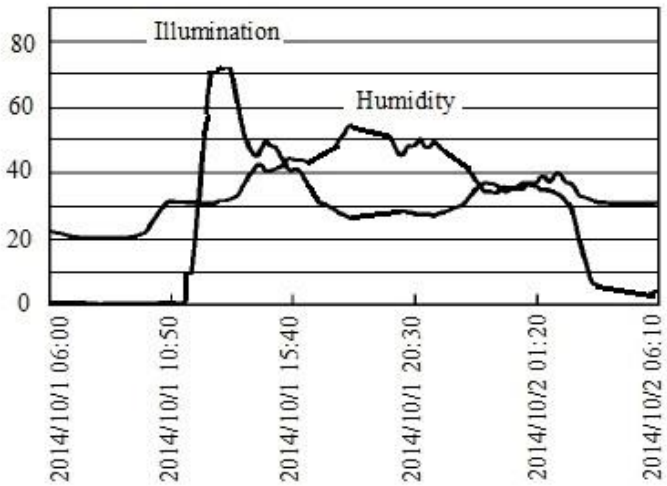

Fig. 8 - Light, soil moisture curve

The limited energy of sensor nodes will reduce the life of the network. In this paper, because the use of filtering methods for data corresponding treatment, it reduces the spread of unwanted data in the network, so it can reduce the burden on the network. It is possible to reduce the energy consumption of the network. The energy consumption of the network is shown in Figure 9, the abscissa represents rounds of the network work and the vertical axis represents the current round of total energy consumption of network operation, unit Joule. It can be seen from the figure, energy consumption of the whole network of this system during the operation is small, so it can ensure that the network has a long life period.

传感器节点能量的有限性会减少该网络的寿命。本文因为采用滤波方法对数据进行了相应的处理，减少了不需要数据在网络中的传播，减少了网络的负担。因而能够降低网络的能量消耗。具体能量的消耗如图 9 所示，纵坐标为当前轮网络运行消耗的总能量，横坐标为网络工作的轮数。从图中可以看出，本文设计的系统在运行期间整个网络能量消耗不大，保证了网络具有较长的生命期。

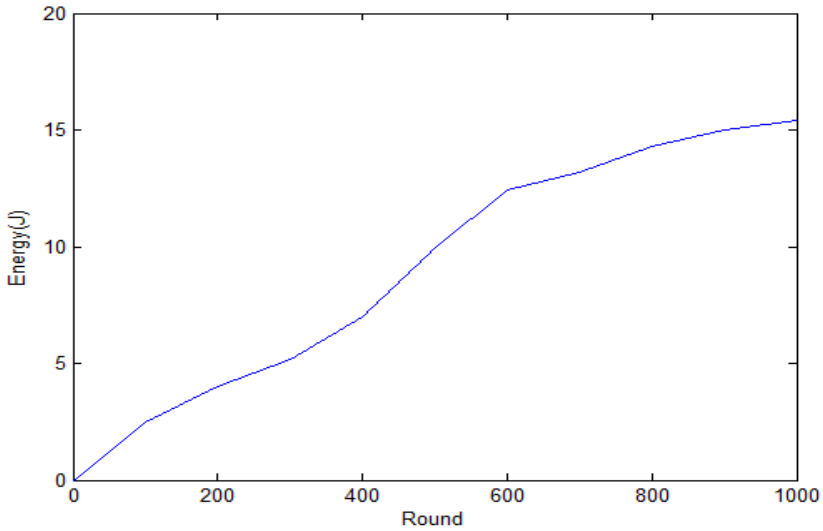

Fig. 9 - Energy consumption of the whole network

CONCLUSION

The system is designed to ease the problem of domestic agricultural irrigation water waste. According to soil temperature and humidity conditions and the demand for agricultural crops in water, the system uses a database system to automatically develop optimal irrigation strategy, both to meet the demand for agricultural crops in water to be more conducive to the growth of the agricultural environment, but also to avoid the waste of excess water, to achieve the purpose of saving and improve the efficiency of agricultural water use. A test on the system was first conducted in a large area of farmland in Suzhou. As the test showed, the system succeeded in collecting and detecting information about soil temperature, soil moisture, light etc, analysing and comparing historical database with the collected data, updating and processing the database in real time, figuring out the optimal water demand for crop growth in the farmland, working out the irrigation sheme that is most suitable for crop growth, and so on. Test experiments in Suzhou acres of fertile land show that in water-saving irrigation system designed in this paper, the sensor nodes collect accurate data-aware layer, transport layer control data transmission in a reliable and less energy consumption. So the system can better complete automatic irrigation tasks and achieve the purpose of saving water.

Acknowledgement

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结论

本文设计的系统是为了缓解国内农业灌溉用水浪费问题。根据土壤温湿度情况和农田中作物对水量的需求情况，系统利用数据库系统自动制订最优的灌溉策略，既能满足农田中作物对水量的需求，使其得到更利于生长的的农田环境，又能避免了多余水量的浪费，达到节水的目的，提高了农田用水的效率。系统研制成功后，首先在宿州千亩良田进行了实验,系统可完成土壤温湿度、光照等信息的收集和检测,利用采集到的数据与历史数据库进行分析比对，实时数据库实时地进行处理，得出农田中作物生长的最佳需水量，制订最适合农田作物生长的灌溉方案。通过在宿州千亩良田实验园的试验表明,本文设计实现的节水灌溉系统中，感知层的感知节点采集数据准确、在控制传输层中数据的传输可靠、而且能耗较小，能较好地完成自动灌溉任务，实现了节水了目的。

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STUDY ON THE SOIL MOISTURE MOVEMENT UNDER INFILTRATION IRRIGATION / 渗灌条件下土壤水分运移规律研究

Prof. Ph.D. Stud. Agr. Feng Yao-zu[1,2)], As. Ms. Agr. Wang Zhi-guo[2)], Prof. Ph.D. Sci. Zhou Jian-bin[1*)], Ph.D. Agr. Yu Dan-lin[3)]

[1)] College of Resources and Environment, Northwest A&F University, Yangling / China,
[2)] Institute of Fertilizer and Agricultural Water Conservation, Xinjiang Academy of Agricultural Sciences, Urumqi / China,
[3)] Department of Earth & Environmental Studies, Montclair State University, New Jersey / U.S.A.
Tel: +86-18939973689, E-mail: fengyaozu@sina.com

Abstract: *To explore moisture movement under infiltrating irrigation and contribute a theoretical basis for agricultural production, we carried out a laboratory simulation experiment to study soil moisture movement under different pore diameters, pressures, and bulk densities. Results showed that the wetting front of both sandy soil and loamy soil increases gradually under three hydraulic head pressures (0.02, 0.01, and 0.005 MPa) as irrigation proceeds. Viewed from the entire shape of the wetting front, the wetting front of Ø*25mm irrigation pipeline with 2.5 mm pore diameter *is uniform. Under two bulk densities (1.54 and 1.43 g·cm^{-3}), given 0.02 MPa pressure, Ø*25mm irrigation pipeline with 2.5 mm pore diameter, *the wetting front of soil rises gradually as irrigation continues. The combination of a 10-year-old root distribution system of fruit trees, 0.02 MPa head pressure, and Ø32mm irrigation pipeline with 2 mm pore diameter could meet the irrigation demand of red dates.*

Keywords: *Infiltrating irrigation; Moisture; wetting front; movement*

INTRODUCTION

Root infiltration irrigation is a new water-saving irrigation technology that has been applied in Xin jiang's forestry and fruit industry in recent years [1,8,11]. This irrigation system has excellent anti-clogging ability and could operate normally under low pressures (2.5–20 KPa). Unlike point water outlet of micro-irrigation, root infiltrating irrigation provides a line water outlet. The root irrigation pipe has two water distribution patterns. One drains water from drainage holes on two sides of the irrigation pipe. The pore diameter generally varies between 2 and 5 mm, it is determined according to practical needs. Blocking these pores is difficult with the use of irrigation water that has been treated simply. The other distribution pattern involves draining water from water seams on two sides of the irrigation pipe. These water seams are formed by neck and trim strips [9] and [12]. Underground drip irrigation systems require strict daily operation management. Such a system has to be examined for defects and has a long maintenance time and high cost. In addition, a large flow of underground drip irrigation system easily causes ponding on the surface, thus resulting in significant evaporation loss of soil water [4]. A root infiltrating irrigation system could solve and avoid these problems. Preliminary research and applications on water and fertilizer management have been conducted Xinjiang's common wood industry based on red dates. [2,3,6]. However, no research has discussed the movement and distribution pattern of water in different types of soil under root infiltrating irrigation and analyzed shape changes of soil wetting front during and after irrigation. To sufficiently serve and contribute to agricultural production in Xinjiang,

摘要： *为了了解渗灌这项微灌技术灌水后的水分运移情况，指导农业生产提供理论依据，为此，在室内通过土壤模拟实验模拟在不同孔径，压力，容重下土壤水分运移规律进行了研究。结果表明三种水头压力下(0.02，0.01，0.005MPa)，随着灌水时间的推移，沙土的湿润峰逐渐增加，从湿润峰的整体性状看，Φ25mm 管2.5mm 孔径渗灌管下湿润锋的性状更加均匀，两种容重 1.54g·cm^{-3} 和 1.43g·cm^{-3} 下，在压力 0.02MPa，Φ25mm 管径 2.5mm 孔径渗灌管的情况下，随着灌水时间的推移，土壤的湿润峰均逐渐增加，结合 10 年果树根系分布状况得知，水头压力采用*0.02MPa*，采用Φ32mm 管2mm 孔径的渗灌管能更好的满足红枣的灌溉需求。*

关键词： *渗灌; 水分; 湿润峰; 运移*

引言

根渗灌是近几年新疆特色林果业应用的新型节水灌溉技术 [1,8,11]。该渗灌系统具有优异的抗堵性能，并能在低压(2.5-20 KPa)条件下正常运行。许多微灌是点出水，而根渗灌是线出水，根灌管是经过两次分配出水，第一次是由灌管壁两边出水孔出水，孔径根据需要一般在2-5 mm，经过简单处理的灌溉水很难堵塞此孔径，第二次是由灌管两侧卡槽与压条形成的出水缝出水 [9][12]。地下滴灌系统日常运行管理要求非常严格，一旦发生故障后需要检查，维修时间长，而且费用高，此外地下滴灌系统流量较大在地表易形成积水而导致土壤水分蒸发损失大[4]，根渗灌系统很好解决和避免这些问题。目前已在新疆特色林果红枣果树等进行了初步水肥管理方面研究与应用 [2][3][6]，但缺乏有关根渗灌新技术在不同类型土壤中水分运移与分布规律，以及灌水过程中和灌水后土壤湿润体形体变化的研究，为了更好结合和服务于新疆农业生产实践，开展不同渗管孔径，不同土壤类型情况下土壤湿润体的变化规律以及灌水后土壤湿润体水分再

studying variation laws of soil wetting front under different irrigation pipe sizes, soil types, and water redistribution patterns is necessary. Optimum irrigation technical parameters were determined, which could help to provide timely and appropriate irrigation to fruit trees and improve water utilization.

In this paper, Ø25 mm was used as the capillary, and Ø32 mm was used as the branch pipe. The pipe network was paved according to the pipe network for the field test. Hence, laboratory soil box simulation was mainly based on Ø25 mm and Ø32 mm. A reasonable pipe size for infiltrating irrigation to red dates was determined through an analysis of the relationship between bulk density of differently sized pipes in different soil types and water advancing distances in soil directions, as well as the water redistribution pattern after irrigation. The test results are expected to provide a theoretical basis for improving infiltration irrigation and its practical applications.

MATERIAL AND METHOD

Test materials

Root irrigation apparatus is shown in Fig.1. Water supply is controlled by the intake pipe, water supply pipe and total intake valve. A stable-voltage water supply device (with drain valve and exhaust valve) is installed between the intake pipe and water supply pipe to keep stable outflow rate. The connected pressure regulating valve and pressure gauge are used for pressure regulating. Finally, water enters into the root irrigation pipes to irrigate farmlands.

Test materials include a soil moisture meter (with 24 probes), a water balancing box, There is a 1.8 m x 0.3m x 1m cuboid soil box which is formed by 1cm-thick steel plates on three sides and 1cm-thick glass plate on one side. The glass place is convenient for observing the wetting front. Please see Fig.2, several 0.2 m long irrigation pipelines (including Φ32mm irrigation pipelines with 2 mm pore diameter and Φ25mm pipelines with 2.5 mm pore diameter), a piece of earth hammer, a spade, a 2 mm sieve, a watering pot, a piece of plastic cloth, an aluminum box, an oven (or ethyl alcohol), a thermometer, a stopwatch, a tape, an electronic balance, some connecting pieces, and valves.

分布情况的研究极为必要,通过研究得到最佳的灌溉技术参数,可以适时适量地对果树进行灌溉并提高水分利用效率。

本研究根据田间试验管网布设以Ø25mm管为毛管,Ø32mm管为支管,为此,室内土箱模拟法主要选择采用Ø25mm管Ø32mm管进行实验,通过分析不同孔径渗管在不同土壤容重和水分在土体中各个方向推进距离的关系,以及灌水停止后水分再分布规律,提出渗灌方式下适合红枣果树灌溉的合理渗管孔径,试验结果以期为完善渗灌技术及其实际应用提供理论依据。

材料与方法

供试材料

根渗灌装置如图 1 所示，供水由进水管、供水管和总控水阀控制,在进水管与供水管之间安装有稳压供水装置（装有泄水阀和排气阀）以保证出水流量的稳定性,之后连接有调压阀和压力表进行调压,最后进入根渗管进行灌溉。

土壤湿度仪(含 24 个探头),恒水箱,1.8m*0.3m*1m的长方体土箱 1 个，三面为 1cm 厚的钢板，另一面为 1cm 厚玻璃板，玻璃版面便于湿润峰的观测，见图 2。0.2 m 长不同管径和孔径（Φ32mm 管 2mm 孔径,Φ25mm 管 2.5mm 孔径）组合的渗灌管若干,夯土锤,铁锹,2mm 筛,洒水壶,塑料布,铝盒,烘箱(或酒精),温度计,秒表,卷尺,电子称,连接件,阀门等。

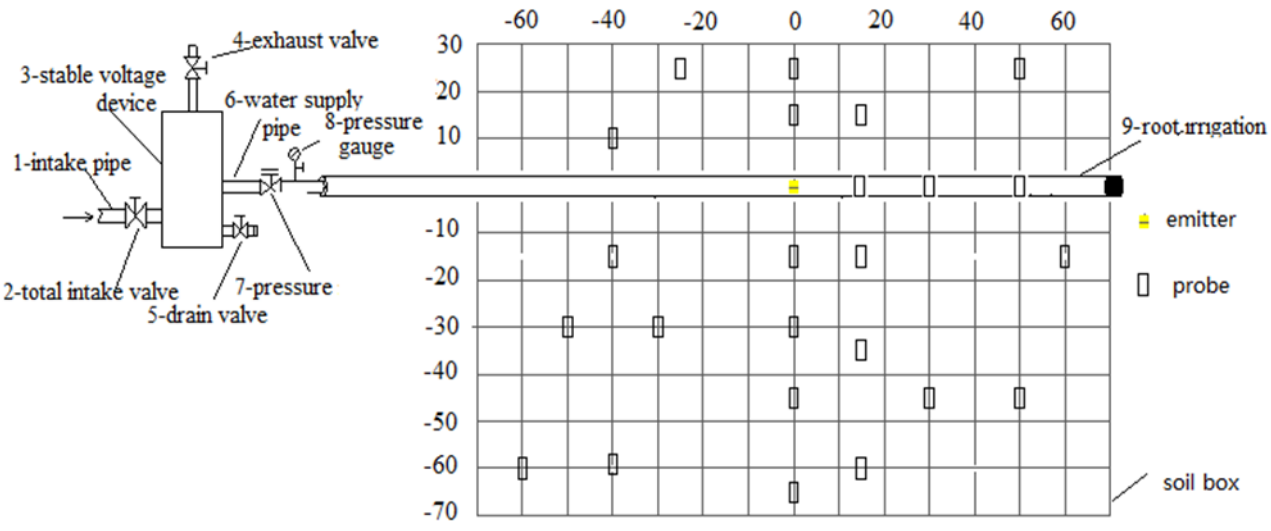

Fig. 1- Test unit

Fig. 2-Testing soil box

Test method

Sandy soils were dried and screened (pore diameter: 2 mm) and then wetted evenly by taking about 50% moisture content of field capacity as the initial soil moisture content. They were layered according to bulk density (each layer is 5 cm thick) and then tamped into the soil box. Differently sized infiltration pipes and probes were buried horizontally during soil filling according to requirements (the infiltration pipe passes through the glass plate). The infiltration pipe is 0.2 m long (with two holes) and is paved 30 cm underneath the earth's surface. Every test applies an infiltration pipe of a permeable pore diameter and constant water supply pressure. The infiltration water was measured every half hour after the test began, and the wetting front was drawn on the glass plate every 10 min (or according to practical infiltration situations). The occurrence time and size range of the saturation circle that surrounds each testing infiltration pipe (soil moisture content exceeds the field capacity) were recorded. If deep leakage occurs 80 cm below the earth's surface, the wetting front has reached 80 cm below the earth's surface. Irrigation shall be stopped at this moment or when water accumulation is observed on the earth's surface. Irrigation time and volume shall be recorded.

Test items

Variation law of the wetting front against time (including the relationship between flow per meter and pressure) under different pressures, pore diameters, and bulk densities were studied. Dynamic changes of soil moisture content were monitored by using SM 100, SM100 is a soil moisture gauge made by the United States, which is mainly used to measure soil water content. It could be connected to meteorological station and data could be read quickly through the reading gauge. The flat shape design makes it easy to be inserted into soil. Watermark water potential probe and Echo water potential probe also could be read from the reading gauge.

测定方法

将沙土分别风干过筛(孔径 2mm), 然后将土按田间持水量的 50%左右的含水率作为土壤初始含水率湿润均匀, 并按容重分层(每层 5cm 厚)夯实填入土箱, 同时在填土的过程中按要求水平埋入渗管与探头(渗管穿过玻璃板), 渗管 0.2m 长(布有两孔), 埋深为 30cm, 每次试验用一种透水孔径的渗管及相应恒定供水压力进行。试验开始后每隔半个小时测量入渗水量,并每隔 10 分钟(或根据入渗情况调整时间间隔) 测定湿润峰并在玻璃板上画出。同时记录各个试验渗管周围饱和圈出现(土壤含水率超过田持)的时间及尺寸范围。如果地表以下 80cm 处土壤发生深层渗漏,则表明湿润峰到达地表以下 80cm，此时停止灌水或土壤表面出现积水时停止灌水,并记录下灌水时间及灌水量。

测定项目

在不同压力, 孔径, 容重条件下的出流情况, (包括米流量与压力关系)观察湿润峰随时间的运移情况,并采用 SM100 动态监测土壤含水率变化情况。SM100 是美国生产的土壤水分测量仪，其主要用途是测量土壤水分含量，可以连接到气象站，也可以用读数表快速读取数据。扁平形状设计可以使其容易插入到土壤当中。读数表也可以读取 Watermark 水势探头和 Echo 水分探头。

RESULTS AND ANALYSIS

Variation law of cumulative infiltration

According to the correlation analysis of pore diameter, pressure, and bulk density of sandy soil, a good linear correlation exists between time and cumulative infiltration (Table 1). Under 0,01 MPa pressure and 1.54 g/cm^3 bulk density, the mean flow in air of Ø32mm irrigation pipeline with 2 mm pore diameter is 61.6 L·(h^{-1}·m^{-1}), while the mean flow in sandy soil is 20.44 L·(h^{-1}·m^{-1}), which is 67% lower than the former. The mean flow in air of Ø25mm irrigation pipeline with 2.5 mm pore diameter is 102.96 L·(h^{-1}·m^{-1}), which is 71% higher than the mean flow in sandy soil at 29.83 L·(h^{-1}·m^{-1}). This finding reflects that a larger pore diameter is accompanied by higher water flow and larger flow losses.

Under 0.02 MPa, the water flow from the Ø32mm irrigation pipeline with 2 mm pore diameter in sandy soils with different bulk densities differs significantly. The water flow in air is 93.9 L·(h^{-1}·m^{-1}). The mean water flow from infiltration pipe under 1.54 g·cm^{-3} bulk density is 49.2 L·(h^{-1}·m^{-1}), which is 48% lower than the water flow in air. The mean water flow from infiltration pipe under 1.43 g·cm^{-3} bulk density is 62.55 L·(h^{-1}·m^{-1}), which is 34% lower. This finding indicates that lower bulk density contributes higher water flow from the infiltration pipe but smaller water flow losses in sandy soil.

Given the same bulk density and pore diameter, the mean flow in sandy soil under 0.02 MPa pressure is significantly higher than that under 0.01 MPa pressure, and the water flow loss in sandy soil under 0.02 MPa pressure is relatively smaller. No significant difference is observed between the mean flow under 0.005 MPa and 0.01 MPa pressure. However, compared with water flow in air, water flow loss in sandy soil under 0.01 MPa pressure is far higher than that under 0.005 MPa pressure.

As shown in Table 1 and Fig. 3, under different conditions (pressure, bulk density, and pore diameter), cumulative infiltration into sandy soil increases as time passes. Cumulative infiltration under low bulk density is higher than that under high bulk density, which indicates the greater water potential that surrounds the permeation irrigation pipe and higher cumulative infiltration under low bulk density. Under fixed 0.01 MPa pressure but different pore diameters, the cumulative infiltration of Ø32mm irrigation pipeline with 2 mm pore diameter is far less than that of Ø25mm irrigation pipeline with 2.5 mm pore diameter. This result implies the existence of greater water potential and higher cumulative infiltration that surrounds the Ø25mm irrigation pipeline with 2.5 mm pore diameter. Cumulative infiltration varies under different pressures, it is significantly higher under 0.02 MPa pressure than under 0.01 MPa pressure. However, cumulative infiltration under 0.01 MPa pressure is similar to that under 0.005 MPa pressure.

结果与分析

累积入渗量的变化规律

沙土条件下对于不同孔径, 压力和容重条件实验数据进行相关性分析发现, 时间和累积入渗量具有较好的线性相关, 结果见表 1。在压力 0.01MPa 和容重 1.54g·cm^{-3} 条件下, Φ32mm 管 2mm 孔径渗灌管在空气中的平均流量为 61.6L·(h^{-1}·m^{-1}), 在沙土中的平均流量为 20.44L·(h^{-1}·m^{-1}), 减少了 67%, Φ25mm 管 2.5mm 孔径渗灌管在空气中的平均流量为 102.96L·(h^{-1}·m^{-1}), 在沙土中的平均流量为 29.83L·(h^{-1}·m^{-1}), 减少了 71%, 说明孔径大, 出水流量大, 但是损失的流量也大。

在压力 0.02MPa, Φ32mm 管 2mm 孔径渗灌管情况下, 不同容重沙土中渗灌管出水流量出现很大差异性, 在空气中出水流量为 93.9L·(h^{-1}·m^{-1}), 在容重 1.54g·cm^{-3} 条件下, 渗灌管出水平均流量为 49.2L·(h^{-1}·m^{-1}), 减少了 48%, 在容重 1.43g·cm^{-3} 条件下,渗灌管出水平均流量为 62.55L·(h^{-1}·m^{-1}), 减少了 34%, 说明低容重条件下渗灌管出水流量大, 在沙土中出水流量损失较小。

在容重和孔径相同的情况下, 压力 0.02MPa 在沙土中的平均流量明显大于 0.01MPa 压力, 且压力 0.02MPa 下出水流量损失也小于压力 0.01MPa, 压力 0.005MPa 下平均流量与压力 0.01MPa 相比较,在沙土中两个压力下渗灌管平均流量相差不大, 然而与空气中流量比较压力 0.01MPa 在沙土中渗灌管流量损失要远远大于压力 0.005MPa。

从表 1 和图 3 得知, 在不同条件下(压力, 容重, 孔径)沙土的累积入渗量随着时间的推移而增大, 不同容重条件下低容重的累积渗水量要高于高容重, 说明在低容重条件下渗灌周围的水势较大, 累积的渗水量就高。在 0.01MPa 压力情况, 不同孔径条件下, Ø32mm 管孔径 2mm 渗灌管的累积入渗量明显小于 Ø25mm 管 2.5mm 渗灌管, 说明 Ø25mm 管 2.5mm 渗灌管周围的水势较大, 累积的渗水量就高。不同压力条件下, 压力 0.02MPa 累积入渗量明显大于压力 0.01MPa, 而 0.01MPa 压力累积入渗量与 0.005MPa 压力累积入渗量相差不大。

Table 1

Fitting results of time and cumulative infiltration in sandy soil

Pressure (MPa)	Pore diameter (mm)	Bulk density(g·cm^{-3})	Mean flow L·(h^{-1}·m^{-1})	Flow in air L·(h^{-1}·m^{-1})	Fitting formula	Determination coefficient(R^2)
0.01	2	1.54	20.44	61.6	y=0.0702x - 0.1483	0.959
	2.5	1.54	29.83	102.96	y= 0.0956x + 0.8719	0.979

Pressure (MPa)	Pore diameter (mm)	Bulk density(g·cm^{-3})	Mean flow L·(h^{-1}·m^{-1})	Flow in air L·(h^{-1}·m^{-1})	Fitting formula	Determination coefficient(R^2)
0.02	2	1.54	49.2	93.9	y = 0.1565x + 1.292	0.949
	2.5	1.43	62.55	93.9	y= 0.0956x + 0.8719	0.959
0.005	2.5	1.54	29.18	71.8	y= 0.0946x + 0.6366	0.969

Note: y is the cumulative infiltration (L), and x is the corresponding time.

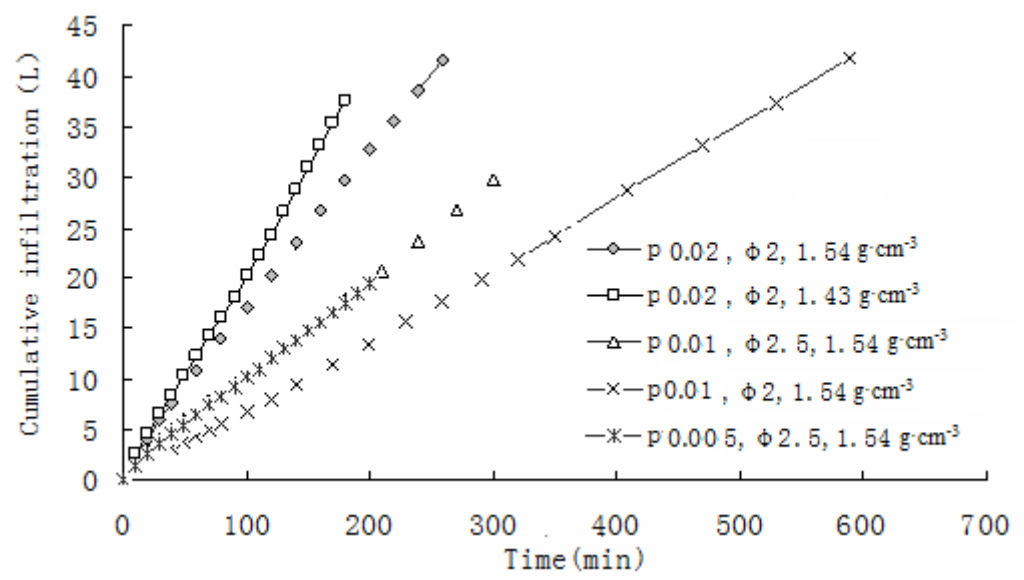

Fig. 3 - Cumulative infiltration into soil

Effect of pressure on soil moisture movement and wetting front

Effect of pressure on soil water movement and wetting front when using Ø32 mm irrigation pipelines with 2 mm pore diameter

During the laboratory simulation, irrigation pressure is a key influencing factor of the wetting front form when texture, bulk density, and pore diameter are fixed. In this paper, the dynamic changes of the wetting front form after 4 h of permeation irrigation using the Ø32 mm irrigation pipelines with 2 mm pore diameter (pressure: 0.02 and 0.01 MPa) were observed (Fig. 4).

The graph on the left shows the wetting front under 0.01 MPa pressure, and the graph on the right is the wetting front under 0.02 MPa pressure. As irrigation continued, the wetting front of the soil increased gradually. However, it changed at different rates in the horizontal, upward, and downward directions. Under 0.02 MPa pressure, the horizontal and downward changes were obviously quicker than the upward change. After 4 h, the upward, horizontal, and downward infiltration diffusion lengths were 30, 46.75, and 50.5 cm, respectively. Under 0.01 MPa pressure, the wetting front changed more quickly in the downward direction than that in the horizontal and upward ones. After 4 h, the upward, horizontal and downward infiltration diffusion lengths were 21.35, 31.22, and 36.69 cm, respectively. Infiltration in different directions under 0.02 MPa pressure is quicker than 0.01 MPa that was 28%, 33%, and 26% higher in the upward, horizontal, and downward directions. This finding means that the infiltration rate under 0.02 MPa pressure is far higher than that under 0.01 MPa pressure.

压力对土壤水分运移和湿润体的影响

在 Φ32mm 管、孔径为 2mm 组合的渗灌管下，压力对土壤水分运移和湿润体的影响

在室内模拟过程中, 在质地, 容重和孔径一定时， 灌溉时的压力大小是影响湿润峰形态的一个关键因子。本试验采用 Ø32mm 管孔径 2mm 渗灌管在两种压力(0.02MPa, 0.01MPa)的情况下, 在试验灌水过程对湿润体在沙土中形态变化进行了 4 小时动态观测, 其变化见图 4。由图 4 可看到, 图的左半边为压力 0.01MPa 灌溉下湿润峰, 右半边为压力 0.02MPa 灌溉下湿润峰, 随着灌水时间的推移, 土壤的湿润峰逐渐增加, 但在水平, 向上, 向下各个方向上的湿润峰变化速度各不相同, 在 0.02MPa 压力下, 水平方向和垂直向下的方向要明显快于向上方向的湿润峰, 4 h 后向上的入渗扩散距离为 30 cm, 水平方向为 46.75cm, 垂直向下方向为 50.5cm, 在压力 0.01MPa 情况的下湿润峰向下的运移的速率高于水平方向和向上方向, 4h 后向上的入渗扩散距离为 21.35cm, 水平方向为 31.22cm, 垂直向下方向为 36.69cm, 压力 0.02MPa 孔径情况下个方向上的入渗速度均比压力 0.01MPa 情况下的快， 向上增加了 28%, 水平方向增加了 33%, 向下方向增加了 26%, 说明 0.02MPa 压力下的入渗速

The movement distance of the wetting front increases with time, which shows a good correlation.

The fitting results are as follows:

Upward:

$$L_1 = 9.26Ln(t) - 30.11 \quad R^2 = 0.996 \tag{1}$$

$$l_1 = 8.41Ln(t) - 14.51 \quad R^2 = 0.9974 \tag{2}$$

Downward:

$$H_1 = 19.69Ln(t) - 69.93 \quad R^2 = 0.99 \tag{3}$$

$$h_1 = 12.70Ln(t) - 21.43 \quad R^2 = 0.99 \tag{4}$$

Horizontal:

$$R_1 = 14.74Ln(t) - 49.49 \quad R^2 = 0.98 \tag{5}$$

$$r_1 = 11.64Ln(x) - 20.10 \quad R^2 = 0.99 \tag{6}$$

L_1, R_1 and H_1 (cm) are the upward and downward movement distances, respectively, and R_1 (cm) is the horizontal diffusion radius of the wetting front under 0.01 MPa pressure. l_1 and h_1 (cm) are the upward and downward movement distances, respectively, and r_1 (cm) is the horizontal diffusion radius of the wetting front under 0.02 MPa pressure. R^2 is a multiple correlation coefficient. The analysis method used was introduced by Wang et al. [5].

率显著高于 0.01MPa 压力情况下。润峰峰运移距离随时间增加而逐渐变大，两者具有较好的相关性，拟合结果如下:

向上：

向下：

水平：

式中L_1, R_1及H_1分别为压力 0.01MPa 情况下向上, 向下垂直湿润峰运移距离, 以及水平扩散半径, cm, l_1, h_1, r_1 分别为压力0.02MPa情况下向上, 向下垂直湿润峰运移距离, 以及水平扩散半径, cm, R^2 为复相关系数, 分析方法参见汪有科等[5]。

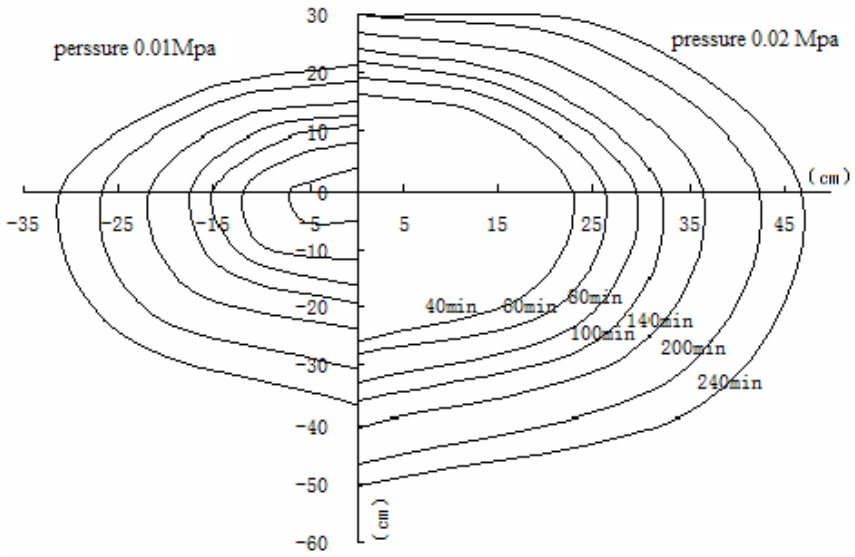

Fig. 4 - Movement curve of the wetting front under different pressure values

Effect of pressure on soil water movement and wetting front when using Ø25 mm irrigation pipelines with 2.5 mm pore diameter

Dynamic changes of the wetting front form in 4 h under infiltration irrigation using Ø25 mm irrigation pipelines with 2.5 mm pore diameter (pressure: 0.01 MPa and 0.005 MPa) were observed (Fig. 5). The graph on the left shows the wetting front under 0.01 MPa pressure, and the one on

在Φ25mm管、孔径为2.5mm组合的渗灌管下，压力对土壤水分运移和湿润体的影响

试验采用Ø25mm管孔径2.5mm渗灌管在两种压力在两种压力(0.01MPa, 0.005MPa)的情况下, 在试验灌水过程对湿润体在沙土中形态变化进行了4小时动态观测, 其变化见

the right is the wetting front under 0.005 MPa pressure. As irrigation continued, the wetting front of the soil increased gradually. However, it changed at different rates in the horizontal, upward, and downward directions. Under 0.01 MPa pressure, the horizontal and downward changes were obviously quicker than the upward change. After 4 h, the upward, horizontal, and downward infiltration diffusion lengths were 29.5, 37.6, and 36.5 cm, respectively. Under 0.005 MPa pressure, the wetting front changed more quickly in the downward direction than in the horizontal and upward ones. The upward, horizontal, and downward infiltration diffusion lengths 4 h later were 27.30, 36, and 36.3 cm, respectively. Infiltrations in different directions under 0.01 MPa and 0.005 MPa pressure agree with each other. The soil wetting fronts under two pressures were relatively even. The movement distance of the wetting front increased gradually with time, which shows a good correlation.

The fitting results are as follows:

Upward:

图5。由图5可看到,图的左半边为压力0.01MPa灌溉下湿润峰,右半边为压力0.005MPa灌溉下湿润峰,随着灌水时间的推移,土壤的湿润峰逐渐增加,但在水平,向上,向下各个方向上的湿润峰变化速度各不相同,在0.01MPa压力下,水平方向和垂直向下的方向要明显快于向上方向的湿润峰,4h后向上的入渗扩散距离为29.5cm,水平方向为37.6cm,垂直向下方向为36.5cm,在压力0.005MPa情况下土壤湿润峰向下的运移的速率高于水平方向和向上方向,4h后向上的入渗扩散距离为27.30cm,水平方向为36cm,垂直向下方向为36.3 cm,压力0.01MPa情况下各方向上的入渗速度与压力0.005MPa情况下的基本一致,两个压力下土壤湿润峰都比较均匀。湿润峰运移距离随时间增加而逐渐变大,两者具有较好的相关性,拟合结果如下:

向上:

$$L_2 = 11.92Ln(t) - 30.26 \qquad R^2 = 0.978 \tag{7}$$

$$l_2 = 2.13Ln(t) - 24.47 \qquad R^2 = 0.979 \tag{8}$$

Downward:

向下:

$$H_2 = 13.22Ln(t) - 37.21 \qquad R^2 = 0.977 \tag{9}$$

$$h_2 = 8.17Ln(t) - 10.95 \qquad R^2 = 0.963 \tag{10}$$

Horizontal:

水平:

$$R_2 = 8.40Ln(t) - 19.05 \qquad R^2 = 0.99 \tag{11}$$

$$r_2 = 8.51Ln(t) - 11.84 \qquad R^2 = 0.96 \tag{12}$$

L_2, H_2, l_2, h_2, r_2, R^2 are the same as the aforementioned equations. The analysis method that was used was introduced by Wang et al. [5].

式中L_2, H_2, l_2, h_2, r_2, R^2同上,分析方法同汪有科等[5]。

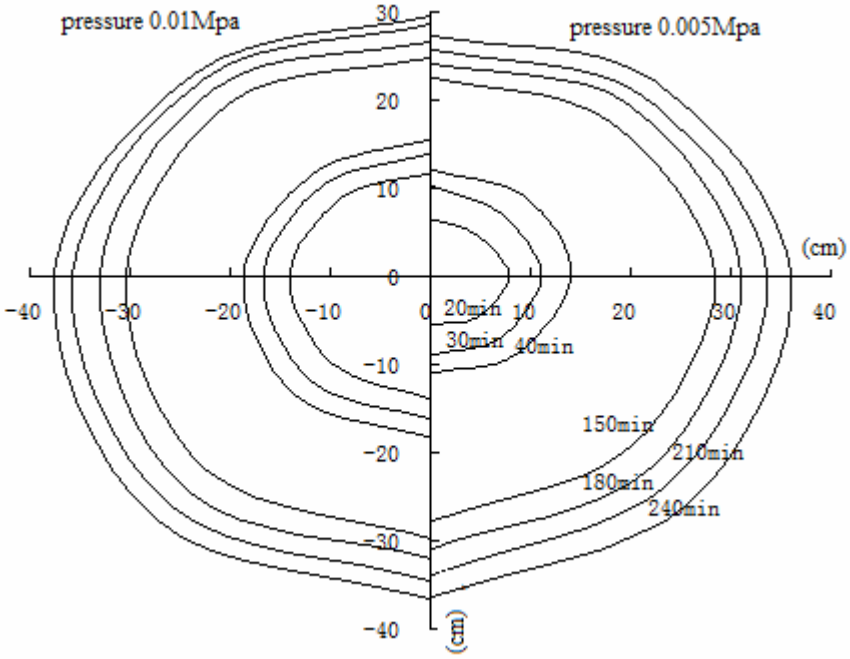

Fig. 5- Movement curve of the wetting front under different pressure values

Effect of different pipeline assembly on moisture movement and wetting front in sandy soil

Pipe size reflects the size of the contact surface between the water supply edges and soil [10]. In the laboratory simulation, given fixed pressure and bulk density, the morphological change of the wetting front is closely related with the infiltration pipe size and pore diameter. This experiment used two different pipeline assemblies (Ø25 mm irrigation pipelines with 2.5 mm pore diameter and Ø32 mm irrigation pipelines with 2 mm pore diameter), During the irrigation test, dynamic morphological changes of the wetting front in sandy soil in 5 h under 0.01 MPa pressure were studied (Fig. 6). The right graph shows the wetting front Ø25 mm irrigation pipelines with 2.5 mm pore diameter, whereas the left graph shows the wetting front Ø32mm irrigation pipelines with 2 mm pore diameter As irrigation continues, the wetting front increases gradually. However, it changes at different rates in the horizontal, upward, and downward directions. Under Ø25 mm irrigation pipeline with 2.5 mm pore diameter, the horizontal and downward changes were obviously quicker than the upward change. The upward, horizontal, and downward infiltration diffusion lengths 5 h later were 30, 40.25, and 40.8 cm, respectively. For the Ø32 mm irrigation pipeline with 2 mm pore diameter, the downward diffusion rate was higher than the horizontal and upward ones. The upward, horizontal, and downward infiltration diffusion lengths 5 h later were 22.45, 33.08, and 39.65 cm, respectively. Therefore, Ø25 mm irrigation pipeline with 2.5 mm pore diameter present quicker upward (25%) and horizontal (17%) infiltration compared withØ32 mm irrigation pipeline with 2 mm pore diameter. However, the infiltration rates under two pore diameters are similar. Viewed from the entire shape of the wetting front, the wetting front of Ø25 mm irrigation pipeline with 2.5 mm pore diameter is more even, which indicates that pore diameter should be changed to irrigate jujube trees. The movement distance of the wetting front lengthens gradually with time, which indicates a good correlation. The fitting results are introduced as follows:

According to the test results in sandy soil, the fitting results of Ø32 mm irrigation pipeline with 2 mm pore diameter are the same in Equations (1), (3), and (5), whereas the fitting results of Ø 25mm irrigation pipeline with 2.5 mm pore diameter are the same in Equations (7), (9) and (11).

Furthermore, water infiltration into soil slows down as time passes, especially in the radial and longitudinal directions. This reaction is due to the fact that at the beginning of irrigation, soil moisture content at the water outlet of the infiltration pipe reaches the saturation state quickly, thereby developing a great water potential difference with the surrounding soil. Consequently, soil water is driven to soil with low water potential. A wetting front with high soil moisture content inside and low moisture content outside is developed. With continuous expansion of the wetting front, the soil moisture gradient decreases, and the soil water potential difference will be reduced accordingly. Therefore, the infiltration rate of the wetting front decreases with the reduction of soil water potential.

不同管径和孔径组合渗灌管对土壤水分运移和湿润体的影响

管径的大小反映了供水边界和土壤接触面的大小[10]。在室内模拟试验时，在压力和容重不变时，沙土湿润峰形态变化与渗管的管径和孔径大小密切相关。本试验采用两种组合方式(Φ25mm管2.5mm孔径和Φ32mm管2mm孔径)的渗灌管， 在压力为0.01MPa的情况下，在试验灌水过程对湿润体在沙土中形态变化进行了5小时动态观测，其变化见图6。由图6可看到，图的右半边为Φ25mm管2.5mm孔径渗灌管的湿润峰，左半边为Φ32mm管2mm孔径渗灌管湿润峰，随着灌水时间的推移，土壤的湿润峰逐渐增加，但在水平，向上，向下各个方向上的湿润峰变化速度各不相同，在Ø25mm管径2.5mm孔径渗灌管下，水平方向和垂直向下的方向要明显快于向上方向的湿润峰，5h后向上的入渗扩散距离为30cm，水平方向为40.25cm，垂直向下方向为40.8cm，Ø32mm管径2mm孔径渗灌管下的湿润峰向下的扩散速度高于水平方向和向上方向，5h后向上的入渗扩散距离为22.45cm，水平方向为33.08cm，垂直向下方向为39.65cm，Ø25mm管径2.5mm孔径渗灌管情况下向上和水平方向入渗速度比Ø32mm管径2mm孔径渗灌管情况下的快， 分别增加了25%和17%，但是两个孔径向下的入渗速度相近,从湿润峰的整体性状看，Ø25mm管径2.5mm孔径渗灌管下湿润峰更加均匀，从这个特点来看在枣树生产实践中应该应用该孔径。润峰运移距离随时间增加而逐渐变大， 具有较好的相关性， 拟合结果如下:

在沙土中测定结果，Ø32mm管径2mm孔径拟合结果同公式(1)，(3)和(5)Ø25mm管径2.5mm孔径拟合结果为(7)，(9)和(11)。

由图6还可以看出，随时间推进水分在土壤中入渗速率逐渐降低，水分在土体径向和纵向各方向推进速度逐渐降低。这是因为在灌溉开始时， 渗管出水口处的土壤含水率快速的达到饱和状态，与周围土壤形成较大的土水势差， 高水势土壤驱使土壤水向低水势土壤运移，形成了内高外低含水率梯度降低的湿润体。随着湿润峰的不断扩大， 内外土壤含水量差减小， 导致土壤水势差降低。因此， 湿润峰入渗速率会随着土壤水势的减小而降低。

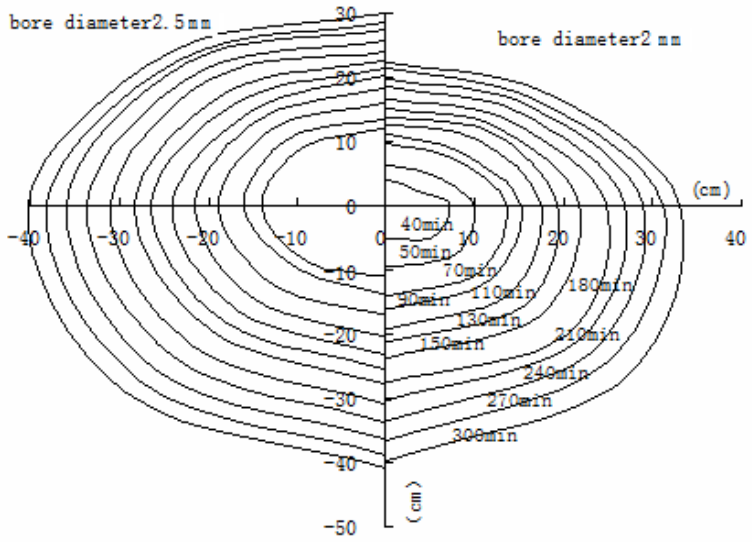

Fig. 6- Movement curve of the wetting front in sandy soil under different pore diameters

Effect of bulk density on moisture movement and the wetting front in sandy soil

Pore development in soil is closely related with the bulk density of soil and influences soil moisture transportation [7]. In the laboratory simulation, given fixed pressure and pore diameter, the bulk density of soil during irrigation is a key influencing factor for the morphology of the wetting front. In this experiment, dynamic morphological changes of the wetting front in sandy soil for 3 h under two bulk densities of soil (1.54 and 1.43 g·cm^{-3}) but fixed 0.02 MPa pressure, Ø25 mm irrigation pipeline with 2.5 mm pore diameter were studied (Fig .7). The graph on the right is the wetting front under 1.43 g·cm^{-3} bulk density, while the graph on the left is the wetting front under 1.54 g·cm^{-3}. As irrigation continued, the wetting front increased gradually. However, it changed at different rates in the horizontal, upward, and downward directions. Under 1.43 g·cm^{-3} bulk density, the horizontal and downward changes were obviously quicker than the upward change. The upward, horizontal, and downward infiltration diffusion lengths 3 h later were 28.8 cm, 43.2 cm, and 49.2 cm, respectively. Under 1.54 g·cm^{-3} bulk density, the downward movement was quicker than the horizontal and upward movements. The upward, horizontal, and downward infiltration diffusion lengths 3 h later were 29cm, 40.5cm, and 45 cm, respectively. Infiltrations in different directions under 1.43 g·cm^{-3} bulk density basically agree with those under 1.54 g·cm^{-3} bulk density, which represents the strong water diversion of sandy soil. The wetting front changed slightly as the bulk density of soil varied. The movement distance of the wetting front increased gradually with time, presenting a good correlation. Fitting results are shown as follows:

The fitting results under 1.54 g·cm^{-3} bulk density are the same in Equations (2), (4), and (6).

The fitting results under 1.43 g·cm^{-3} bulk density are

Upward:

Downward:

容重对渗灌水分运移和湿润体的影响

土壤的孔隙状况与土壤容重密切相关并影响土壤水分传输[7]。室内模拟过程中,在压力和孔径一定时,灌溉时的土壤容重大小是影响湿润峰形态的一个关键因子。本试验采用两种容重(1.54g·cm^{-3},1.43g·cm^{-3}),在压力0.02MPa,Ø25mm管2.5mm孔径渗灌管情况下,在试验灌水过程对湿润体在沙土中形态变化进行了3小时动态观测,其变化见图7。由图7可看到,图的左半边为容重1.43g·cm^{-3}下湿润峰,右半边为容重1.54g·cm^{-3}下湿润峰,随着灌水时间的推移,土壤的湿润峰逐渐增加,但在水平,向上,向下各个方向上的湿润峰变化速度各不相同,在容重1.43g·cm^{-3}下,水平方向和垂直向下的方向要明显快于向上方向的湿润峰,3 h后向上的入渗扩散距离为28.8cm,水平方向为43.2cm,垂直向下方向为49.2cm,在容重1.54g·cm^{-3}情况的下湿润峰向下的运移的速率高于水平方向和向上方向,3 h后向上的入渗扩散距离为29cm,水平方向为40.5cm,垂直向下方向为45cm,容重1.43g·cm^{-3}情况下个方向上的入渗速度与容重1.54g·cm^{-3}情况下的基本一致,说明沙土导水能力比较强,不同容重条件下的湿润锋变化不大,但是湿润峰运移距离随时间增加而逐渐变大,两者具有较好的相关性,拟合结果如下:

在容重1.54g·cm^{-3}情况的下拟合结果同(2),(4)和(6)

在容重1.43g·cm^{-3}情况的下拟合结果:

向上:

$$L_3 = 6.798Ln(x) - 8.055 \qquad R^2 = 0.943 \tag{13}$$

向下:

$$H_3 = 11.738Ln(x) - 15.619 \quad R^2 = 0.943 \tag{14}$$

Horizontal:

水平：

$$R_3 = 10.227Ln(x) - 11.575 \quad R^2 = 0.9867 \tag{15}$$

Where L_3 , H_3 , R_3 and R^2 are the same as the aforementioned equations. The analysis method that was used is that of Wang et al. [5].

式中L_3 , H_3 , R_3和R^2 同上, 分析方法参见汪有科等[5]。

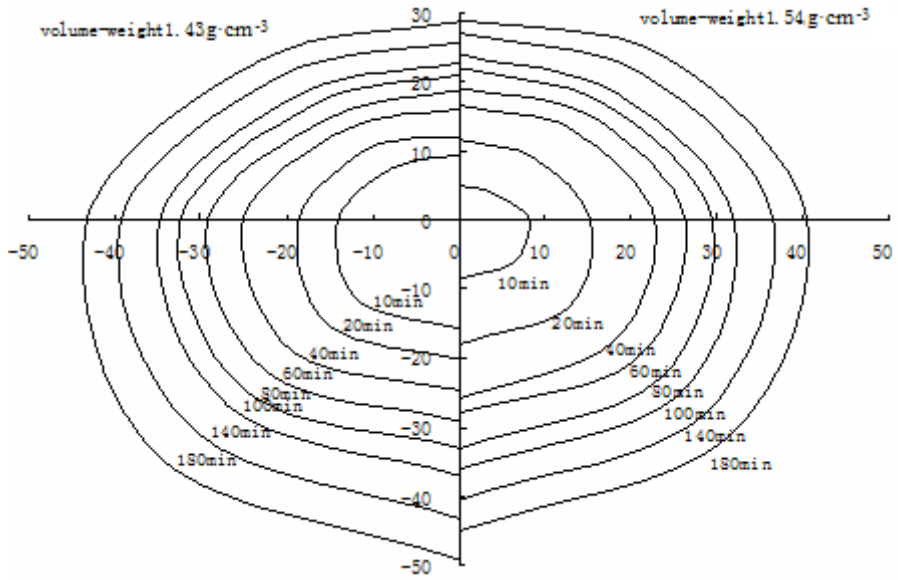

Fig. 7- The spool's rising rate in sand soil

CONCLUSIONS

Arid and semi-arid regions that suffer serious water shortage urgently need water-saving irrigation. Infiltrating irrigation is a new water-saving irrigation method that has attracted significant research attention because of its unique advantages [14,15]. Soil moisture infiltration under infiltrating irrigation is influenced by various factors [13,16]. This paper discussed only the effect of pressure, pore diameter, and bulk density on the wetting front of soil. The experiments obtained the following findings:

(1) Pressure is the key influencing factor for draining water from the infiltration pipe. The wetting front of sandy soil increases gradually under three hydraulic head pressures (0.02, 0.01, and 0.005 MPa) as irrigation continues. Horizontal and downward infiltrations are quicker than upward infiltration. For Ø32 mm irrigation pipeline with 2 mm pore diameter, the wetting front diffuses significantly more quickly under 0.02 MPa head pressure coMPared with 0.01 MPa head pressure. For the Ø25 mm irrigation pipeline with 2.5 mm pore diameter, the wetting fronts under 0.01 MPa and 0.005 MPa m pressure are similar.

(2) Infiltration pipe size and pore diameter affect soil moisture movement. The wetting front of sandy soil increases gradually with time under two pipeline assembly (Ø25 mm irrigation pipelines with 2.5 mm pore diameter and Ø32 mm irrigation pipelines with 2 mm pore diameter). It similarly varies under different pore diameters. The upward and horizontal infiltration rates under the Ø25 mm irrigation pipeline with 2.5 mm pore

结论

在干旱半干旱地区水资源短缺, 节水灌溉刻不容缓, 渗灌作为一种新的节水灌溉方式, 其特有的优点吸引众多学者对此进行研究[14,15], 影响渗灌土壤水分入渗过程受多因素影响[13,16], 本文只探讨了压力, 孔径和容重对等对土壤湿润体的影响, 其结果表明：

(1) 压力是影响渗灌管出水的关键因子。三种水头压力下(0.02,0.01,0.005 MPa), 随着灌水时间的推移, 沙土的湿润峰均逐渐增加, 在水平和向下的入渗运移速率高于向上方向, 在 Ø32mm 管径 2mm 孔径渗灌管, 水头压力 0.02MPa 情况下在各个方向上湿润峰扩散的速度显著高于 0.01MPa 水头压力, 在 Ø25 管径 2.5mm 孔径渗灌管, 水头压力 0.01MPa 情况下各方向上湿润峰与 0.005MPa 水头压力变化差异不大。

(2) 渗管管径和孔径大小影响土壤的水分运动的过程。两种组合方式 (Φ25mm 管 2.5mm 孔径和 Φ32mm 管 2mm 孔径)渗灌管条件下,随着时间的推移, 沙土湿润峰均逐渐增加。在不同孔径下湿润峰变化趋势基本一致。Ø25mm 管径 2.5mm 孔径渗灌管情况下向上和水平方向入渗速度比 Ø32mm 管径 2mm 孔径渗灌管情况下的快, 向下方向两孔

diameter are higher than those under theØ32 mm irrigation pipeline with 2 mm pore diameter. However, no significant difference of downward infiltration rate is detected. The wetting front under the Ø25 mm irrigation pipeline with 2.5mm pore diameter is more even.

(3) Bulk density of soil is the main influencing factor for water movement rate. Under 0.02 MPa pressure, Ø25 mm irrigation pipeline with 2.5 mm pore diameter, the wetting front of soil increases gradually under two bulk densities of soil as irrigation proceeds. The horizontal and downward infiltrations are quicker than the upward infiltration. However, the movement distance of the wetting front remains the same under two bulk densities of soil. This finding reflects that sandy soil has strong water diversion capability, and low bulk density is not the main restriction to soil moisture movement.

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径无明显差异,从湿润峰的整体性状看, Ø25mm 管 2.5mm 孔径渗灌管下湿润锋的性状更加均匀。

(3) 容重是影响水分运移速率的一个主要因子。两种容重(1.54g·cm^{-3}, 1.43g·cm^{-3})下, 在压力0.02MPa,Ø25mm管径 2.5mm 孔径渗灌管的情况下, 随着灌水时间的推移, 土壤的湿润峰逐渐增加, 在水平和向下的入渗运移速率高于向上方向, 但是两种容重(1.54g·cm^{-3}, 1.43g·cm^{-3},)情况下湿润峰相比较, 各方向上的运移距离差异不明显, 说明沙土的导水输水能力较强, 而低容重不是限制水分运移的主因素。

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MATHEMATICAL MODEL CHARACTERIZING THE ANGLE OF SPRAYING JET OF SPRAYERS DESIGNED TO FIELD CROPS
/
MODEL MATEMATIC DE CARACTERIZARE A UNGHIULUI JETULUI DE PULVERIZARE A MAŞINILOR DE STROPIT CULTURILE CAMP

PhD. Stud. Eng. Niţu (Roşu) M.[1)], PhD. Eng. Vlăduţ V.[1)], PhD. Stud. Eng. Matache M.[1)], PhD. Eng. Vlad C.[2)]
[1)]INMA Bucharest / Romania; [2)]ICEADR / Romania

Abstract: *Within the spraying process, the compact jet of solution coming from a limited space, namely the nozzle body or spraying device, is transformed in droplets by liquid dispersion in space, under a certain angle, at a speed able to defeat the internal cohesion forces of liquid dispersed. The jet spraying angle is the angle of cone formed from the tangents to jet contour, which intersect in the nozzle hole. The spraying angle and jet penetration represent the liquid distribution on spraying surface. The spraying angle mostly depends on type and size of the duzzle. Pressure of liquid has a significant effect on size of spraying angle. Within this paper, a mathematical model characterizing the sprayers'nozzle jet angle depending on working process parameters, is presented.*

Keywords: *Nozzles, jet spraying angle, sprayers, dimensional analysis.*

INTRODUCTION

The biphasic flow is a type of flow that appears in immiscible liquid-gas systems. It is a particular case of multiphasic flow. It is often met in nature, the most cogent case being the rain drops fall. In practice, this process is exemplified by the spraying process.

Spraying is the decomposition of the liquid coming in fine droplets (sized between a few micrometers and several hundreds of micrometers, mainly determined by the spraying environment), when the liquid passes through a nozzle at a certain pressure. These droplets leave the spraying nozzle at a certain pressure and then they are decelerated due to friction with air, the liquid superficial tension forces being annulled by internal and external factors, the structure of a sprayed jet being of the form represented in figure 1 [7].

Abstract: *În cadrul procesului de pulverizare, jetul compact de soluţie ce iese dintr-un spaţiu limitat, reprezentat de corpul duzei sau pulverizator, este transformat într-un jet de picături, prin dispersarea lichidului în spaţiu, sub un anumit unghi, la o viteză capabilă să învingă forţele de coeziune internă a lichidului dispersat. Unghiul de pulverizare a jetului este unghiul conului format din tangentele la conturul jetului, concurente în orificiul duzei. Unghiul de pulverizare, ca şi penetraţia jetului, ilustrează distribuţia lichidului pe suprafaţa de stropit. Unghiul de pulverizare depinde în mare măsură de tipul şi mărimea orificiului duzei. Presiunea lichidului are un efect semnificativ asupra mărimii unghiului de pulverizare. În cadrul lucrării se prezintă un model matematic care caracterizează unghiul jetului la duză pentru maşinile de stropit în funcţie de parametrii procesului de lucru.*

Cuvinte cheie: *duze, unghiul jetului de pulverizare, masini de stropit, analiza dimensionala.*

INTRODUCERE

Curgerea bifazică este un tip de curgere ce apare în sisteme lichid-gaz nemiscibile. Este un caz particular de curgere multifazică. Aceasta este întâlnită pe scară largă în natură, cel mai concludent caz fiind căderea picăturilor de ploaie. În practică, este exemplifica prin procesul de pulverizare.

Pulverizarea este procesul de descompunere a unei vâne de lichid în picături fine(dimensionate între câțiva micrometri şi câteva sute de micrometri, determinate în principal de mediul de pulverizare), la trecerea acestuia printr-un ajutaj (duza), la o anumită presiune. Aceste picături ies din duza de pulverizare la o anumită viteză şi sunt apoi decelerate datorită frecării cu aerul, forţele de tensiune superficială a lichidului, fiind anulate de factori interni şi externi, structura unui jet de lichid pulverizat având forma din figura 1 [7].

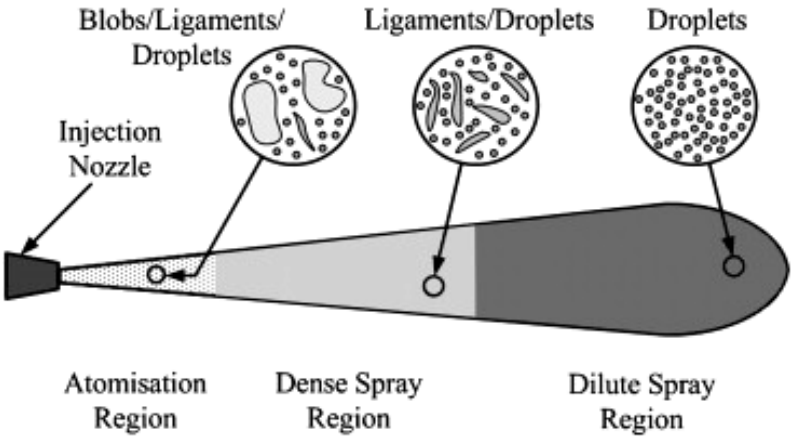

Fig. 1 – Structure of a jet of sprayed liquid [7]

The liquid fraction is dominant in the first area, being decomposed in bubbles and ligaments (non-spherical particles of liquid); in the second area (intermediary), of dense spray, the liquid fraction is less important, because a secondary fragmentation takes place and interactions of droplets/droplets appear, such as collisions. In the third area, that of diluted spraying, the spherical droplets well shaped, which are predominant, powerfully ineract with the air turbulent jet. The spray mostly depends on nozzle pressure, liquid flow, nozzle geometrical charactersitics, viscuousity and density of the liquid [1, 3].

Hydraulic spray is obtained at liquid forced passing through the calibrated orifices (nozzles), in case of machines applying phytosanitary treatments in field being performed:

- Through hydraulic spraying nozzles with projected jet (plane conical jet or nozzles with indirect projected jet);
- Through hydraulic nozzles with two jets that hurt one another, achieving this way the dispersion;

Through vortex nozzles, also named tangential nozzles, where the liquid is allowed to have a circular movement in a chamber located before the calibrated hole. [4, 12].

MATERIAL AND METHOD

The physical spraying phenomenon is not completely elucidated, although it was studied during the last decade, because there is not any general theory that allows to determine the main characteristics of liquid sprayed jet for different types of nozzles [7, 9].

Therefore, the main characteristics of liquid sprayed jet, namely the fine spraying , distribution uniformity according to droplets size, spatial distribution of liquid flow and spraying angle are experimentally expressed using suitable apparata.

In conclusion, the spray studying is experimentally performed, being introduced in model study. Based on similarity theory, the results obtained through dynamic systems, may be generalized.[10] For transposing the models results, it is necessary that numerical values of invariants, that characterize the phenomenon, be identical and the univocity conditions, too. Deduction of invariants is based on a thorough study of phenomenon development, knowing the contour conditions, or starting from the equation of decomposition of liquid sheet and using dimensional analysis method.

This method is based on fundamental theorem of dimensional analysis, theorem Π, referring to the fact that the terms of a physical relation should be homogenous, namely have the same measuring units and the same power of fundamental sizes [12].

The spraying angle is the angle of jet cone and indicates its flaring. The spraying angle dimension depends of density of liquid flow and represents the measure of tangential and axial components of liquid droplets speed [11, 13].

The spraying angle mostly depends on type and size of nozzle hole.

Pressure of liquid significantly influences the size of spraying angle. In practice, the nozzle is also marked with the size of spraying angle [5,6], which is fundamental for dimensional analysis, theorem Π, referring to the fact that the terms of a physical relation should be homogenous, namely have the same measuring units and the same power of fundamental values [12].

Fracţiunea lichidă e dominantă în prima zonă, lichidul fiind descompus în bule şi ligamente (particule de lichid non-sferice), cea de-a doua zonă (intermediară), de pulverizare densă, fracţiunea lichidă are o pondere mai mică, deoarece are loc o fragmentare secundară şi apar interacţiuni picătură/ picătură, cum ar fi coliziunile. În zona trei, cea de pulverizare diluată predomină picăturile sferice, bine formate, care interacţionează puternic cu jetul turbulent de aer. Pulverizarea depinde în mare măsură de presiunea prin duză, de debitul de lichid, de caracteristicile geometrice ale duzei, de vâscozitatea şi densitatea lichidului.[1, 3]

Pulverizarea hidraulică se obţine la trecerea forţată a lichidelor de stropit prin orificii calibrate (duze), în cazul maşinilor de aplicat tratamente fitosanitare în câmp realizându-se:

- prin duze de pulverizare hidraulică cu jet proiectat (jet plat jet conic direct proiectat sau duze cu jet indirect proiectat);
- prin duze hidraulice cu două jeturi care se lovesc între ele, realizându-se astfel dispersia;
- prin duze de turbionare, denumite şi duze tangenţiale, unde se permite lichidului să i se imprime o mişcare circulară într-o cameră plasată înaintea orificiului calibrat. [4, 12]

MATERIAL ŞI METODĂ

Fenomenul fizic de pulverizare nu este pe deplin elucidat, deşi acesta a fost studiat în ultimul deceniu neexistând o teorie generală care să permită determinarea caracteristicilor de bază ale jetului de lichid pulverizat pentru diverse tipuri duze. [7, 9]

De aceea caracteristicile de baza ale jetului de lichid pulverizat, adică fineţea de pulverizare, uniformitatea distribuţiei după dimensiuni a picăturilor, distribuţia spaţială a fluxului de lichid şi unghiul de pulverizare se exprimă experimental folosind aparatură adecvată.

Studierea procesului de pulverizare se face deci pe cale experimentală, introducîndu-se studiul pe model. Pe baza teoriei similitudinii, se pot generaliza rezultatele obţinute pe sisteme dinamice asemenea.[10] Pentru transpunerea rezultatelor de pe modele este necesar ca valorile numerice ale invarianţiilor, care caracterizează fenomenul, să fie identice, iar condiţiile de univocitate asemenea. Deducerea invarianţiilor se face pe baza unui studiu aprofundat al desfăşurării fenomenului, cunoscînd condiţiile de contur, sau pornind de la ecuaţia descompunerii pânzei de lichid şi folosind metoda analizei dimensionale.

Această metodă se bazează pe teorema fundamentală a analizei dimensionale, teorema Π, ce se referă la faptul că termenii unei relaţii fizice să fie omogeni, adică să aibă aceleaşi unităţi de măsură şi aceleaşi puteri ale mărimilor fundamentale [12].

Unghiul de pulverizare este unghiul conului jetului şi indică evazarea acestuia. Mărimea unghiului de pulverizare este dependentă de densitatea fluxului de lichid şi este măsura componentelor tangenţială şi axială ale vitezei picăturilor de lichid [11, 13].

Unghiul de pulverizare depinde în mare măsură de tipul şi mărimea orificiului duzei.

Presiunea lichidului are un efect semnificativ asupra mărimii unghiului de pulverizare. In practică duza are marcată pe ea şi mărimea unghiului de pulverizare [5, 6]. fundamentală a analizei dimensionale, teorema Π, ce se referă la faptul că termenii unei relaţii fizice să fie omogeni, adică să aibă aceleaşi unităţi de măsură şi aceleaşi puteri ale mărimilor fundamentale [12].

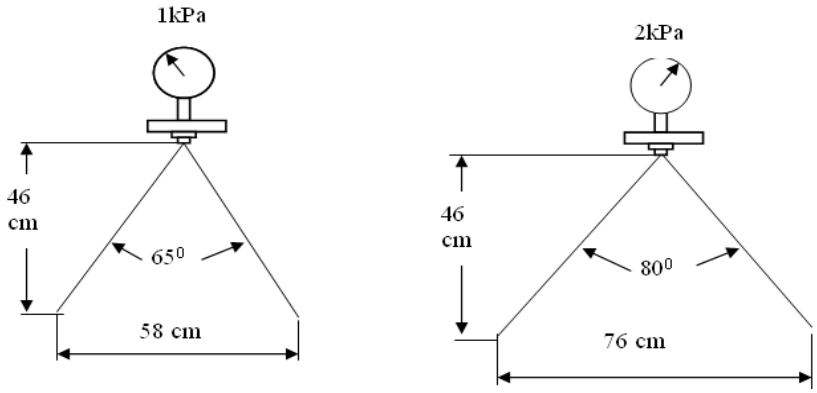

Fig. 2 - Reduction of spraying angle at the same time with pressure diminishing [12]

RESULTS

As a general rule, fluids more viscuos than water form smaller spraying angles, while liquids with lower superficial tension disperse at larger angles.

A diminishing of spraying angle by 2…10% leads to a non-uniformity of distribution along the length of spray gun.

At the same time, the superficial tension size leads to icreasing/diminishing of droplets and spray angle, related to its dimension [2; 8].

The most favourable splitting of jet is given for the ratio:

REZULTATE

In general, lichidele mai vâscoase ca apa formează unghiuri de pulverizare mai mici, în timp ce lichidele cu tensiune superficială mai joasă decât apa se dispersează la unghiuri mai largi. O scădere a valorii unghiului de pulverizare cu 2…10% conduce la o neuniformitate a distribuţiei pe lungimea lăncii de pulverizare.

De asemenea, mărimea tensiunii superficiale conduce la mărirea / micşorarea picăturilor şi a unghiului de pulverizare după cum aceasta este mai mare, respectiv mai mică [2; 8].

Situaţia cea mai favorabilă de descompunere a jetului este pentru raportul:

$$\frac{\lambda}{d_c} = 4.42 \quad (1)$$

where: λ – oscillation wave length

d_c - jet diameter.

Study of decomposition of liquid can be made by the method of smallest perturbations, method of probable hypotheses and method of dimensional analysis.

For establishing the physical relations, of connection between the sizes used to describe the physical phenomena, the dimensional anaysis can be used. This method is based on fundamental theorem of dimensional analysis, theorem *Π*, of Vaschy-Buckingham. According to it, the physical or pysico-chemical processes can be described through functions of independent similarity criteria which can form with variables controlling the process. Those criteria that can not be expressed through arithmetic combinations of other criteria are considered to be independent.[12]

Therefore, if a process is determined by *n* dimensional variables :

$$X_1, X_2, X_3 \ldots X_n$$

It can be expressed by a criteria function of general form:

$$f(\Pi_1, \Pi_2, \Pi_3 \ldots \Pi_{n-m}) = 0$$

Dimensional analysis is the study of relations that describe the physical phenomena. It is based on dimensional homogeneity that must be respected by theory of rational relations and empirical relations. This characteristic refers to the fact that the terms of a physical relation should be homogeneous, namely to have the same measuring units and fundamental measurements power [1].

The general dimensional analysis is connected to cases which, in restricted dimensional analysis lead to equation systems between the dimension exponents and size undetermined exponents.

unde: λ - lungimea de unda a oscilatiei

d_c - diametrul jetului.

Studiul descompunerii pânzei de lichid se poate face prin metoda micilor perturbaţii, metoda ipotezelor probabile si prin metoda analizei dimensionale.

Pentru stabilirea relaţiilor fizice, a legăturii care există între mărimile utilizate la descrierea fenomenelor fizice, poate fi utilizată analiza dimensională. Această metodă se bazează pe teorema fundamentală a analizei dimensionale, teorema *Π*, a lui Vaschy-Buckingham. Conform acestei teoreme, procesele fizice sau procesele fizico-chimice pot fi descrise prin funcţii ale criteriilor de similitudine independente ce se pot forma cu variabilele care controlează procesul. Se consideră că sunt independente acele criterii care nu pot fi exprimate prin combinaţii aritmetice ale altor criterii.[12]

Astfel dacă un proces este determinat de *n* variabile dimensionale:

$$X_1, X_2, X_3 \ldots X_n$$

acesta poate fi exprimat printr-o funcţie criterială de forma generală:

$$f(\Pi_1, \Pi_2, \Pi_3 \ldots \Pi_{n-m}) = 0$$

Analiza dimensională este studiul relaţiilor care descriu fenomenele fizice. Ea se bazează pe proprietatea de omogenitate dimensională care trebuie să fie respectată de toria relaţiile raţionale şi se urmăreşte să fie respectată de relaţiile empirice. Această proprietate se referă la faptul că termenii unei relaţii fizice să fie omogeni, adică să aibă aceleaşi unităţi de măsură şi aceleaşi puteri ale mărimilor fundamentale [1].

Analiza dimensională generală este în legătură cu cazurile care, în analiza dimensională restrînsă conduc la sisteme de ecuaţii între exponenţii de dimensiune şi exponenţii de mărime nedeterminate.

Applying the theorem Π (*number of independent criteria from criteria function is given by the difference n-r, where n is the number of dimensional variables and r is the rank of dimensional matrix, which is equal to number of fundamental measurements, according to which the analyzed variables can be expressed*), the following dimensionless equalities related to average diameter of droplets d_m and distribution constant *n, can be written:*

Aplicându-se teorema Π (*numărul de criterii independente din funcţia criteriala este dat de diferenţa n-r, unde n este numărul variabilelor dimensionale iar r este rangul matricei dimensionale, care este egal cu numărul mărimilor fundamentale în funcţie de care se pot exprima variabilele luate în analiză*), se pot scrie următoarele egalităţi adimensionale relative la diametrul mediu al picăturilor d_m şi constanta de distribuţie *n:*

$$\begin{cases} \dfrac{d_m}{d_0} = F_1\left(\dfrac{\rho_g w^2 d_0}{\sigma}, \dfrac{\rho_l \sigma d_0}{\eta_l^2}, \dfrac{\rho_g}{\rho_l}, \dfrac{\eta_g}{\eta_l}\right) \\ n = F_2\left(\dfrac{\rho_g w^2 d_0}{\sigma}, \dfrac{\rho_l \sigma d_0}{\eta_l^2}, \dfrac{\rho_g}{\rho_l}, \dfrac{\eta_g}{\eta_l}\right) \end{cases} \quad (2)$$

$$\begin{cases} \dfrac{d_m}{d_0} = F_1\left(W_e, L_p, M, N\right) \\ n = F_2\left(W_e, L_p, M, N\right) \end{cases} \quad (3)$$

Restricted dimensional analysis takes into consideration the following function of m* = 8 variables:

Analiza dimensională restrânsă ia în considerare următoarea funcţie de m* = 8 variabile:

$$f(D, v, \rho_l, \alpha, \eta_l, p, \rho_g, \sigma) = 0 \quad (4)$$

where:
- D – nozzle diameter;
- *v* – liquid relative speed to the environmental gas;
- ρ_l – liquid density;
- α – jet angle;
- $\acute{\eta}_l$ – dynamic viscosity of the liquid;
- p – liquid pressure;
- ρ_g –gas density;
- σ – liquid superficial tension.

and, *D, v,* ρ_l are fundamental values.

The following dimensionless complexes were introduced (Π_1, Π_2, Π_3, Π_4, Π_5):

unde:
- D – diametrul duzei;
- *v* – viteza relativă a lichidului faţă de gazul înconjurător;
- ρ_l – densitatea lichidului;
- α – unghiul jetului;
- $\acute{\eta}_l$ – vâscozitatea dinamică a lichidului;
- p – presiunea lichidului;
- ρ_g – densitatea gazului;
- σ – tensiunea superficială a lichidului.

iar, *D, v,* ρ_l sunt mărimi fundamentale.

S-au introdus următorii complexi adimensionali (Π_1, Π_2, Π_3, Π_4, Π_5):

$$\Pi_1 = \alpha; \Pi_2 = \frac{\eta_l}{D^{x_1} v^{x_2} \rho_l^{x_3}}; \Pi_3 = \frac{p}{D^{x'_1} v^{x'_2} \rho_l^{x'_3}}; \Pi_4 = \frac{\rho_g}{\rho_l}; \Pi_5 = \frac{\sigma}{D^{x''_1} v^{x''_2} \rho_l^{x''_3}} \quad (5)$$

Dimensional matrix of variables for the 3 fundamental sizes is:

Matricea dimensională a variabilelor pentru cele 3 mărimi fundamentale este:

	x''_1	x''_2	x''_3					
	x'_1	x'_2	x'_3					
	x_1	x_2	x_3					
	D	v	ρ_l	α	η_l	p	ρ_g	σ
L	1	1	−3	0	−1	−1	−3	1
M	0	0	1	0	1	1	1	1
T	0	−1	0	0	−1	−2	0	−2

(6)

System of dimensional linear equations that expresses the homogeneity condition for dimensionless complex Π_2, is:

Sistemul de ecuaţii dimensionale liniare care exprimă condiţia de omogenitate, pentru complexul adimensional Π_2, este:

$$\begin{aligned} &(L) && x_1 + x_2 - 3x_3 = -1 \\ &(M) && x_3 = 1 \\ &(T) && -x_2 = -1 \end{aligned} \quad (7)$$

Solutions $x_1 = 1$ are obtained ; $x_2 = 1$; $x_3 = 1$ and it results:

Se obţin soluţiile $x_1 = 1$; $x_2 = 1$; $x_3 = 1$ şi rezultă:

$$\Pi_2 = \frac{\eta_l}{D v \rho_l} \quad (8)$$

System of dimensional linear equations that expresses the homogeneity condition for dimensionless complex Π_3, is:

Sistemul de ecuaţii dimensionale liniare care exprimă condiţia de omogenitate, pentru complexul adimensional Π_3, este:

$$\begin{aligned} &(L) \quad x_1' + x_2' - 3x_3' = -1 \\ &(M) \quad x_3' = 1 \\ &(T) \quad -x_2' = -2 \end{aligned} \tag{9}$$

Solutions $x_1' = 0$; $x_2' = 2$ are obtained ; $x_3' = 1$ and it results:

Se obţin soluţiile $x_1' = 0$; $x_2' = 2$; $x_3' = 1$ şi rezultă:

$$\Pi_3 = \frac{p}{v^2 \rho_l} \tag{10}$$

System of dimensional linear equations that expresses the homogeneity condition for dimensionless complex Π_5, is:

Sistemul de ecuaţii dimensionale liniare care exprimă condiţia de omogenitate, pentru complexul adimensional Π_5, este:

$$\begin{aligned} &(L) \quad x_1'' + x_2'' - 3x_3'' = 0 \\ &(M) \quad x_3'' = 1 \\ &(T) \quad -x_2'' = -2 \end{aligned} \tag{11}$$

Solutions $x_1'' = 1$; $x_2'' = 2$ are obtained; $x_3'' = 1$ and it results:

Se obţin soluţiile $x_1'' = 1$; $x_2'' = 2$; $x_3'' = 1$ şi rezultă:

$$\Pi 5 = \frac{\sigma}{Dv^2 \rho_l} \tag{12}$$

So that: $\varphi_1(\Pi_1,\Pi_2,\Pi_3,\Pi_4,\Pi_5) = 0$.
or

aşa încât: $\varphi_1(\Pi_1,\Pi_2,\Pi_3,\Pi_4,\Pi_5) = 0$.
sau

$$\Pi_1 = \varphi_1(\Pi_2,\Pi_3,\Pi_4,\Pi_5) \qquad (*) \tag{13}$$

namely:

adică:

$$\alpha = \varphi_2\left(\frac{\eta_l}{Dv\rho_l}, \frac{p}{v^2\rho_l}, \frac{\rho_g}{\rho_l}, \frac{\sigma}{Dv^2\rho_l}\right) \tag{14}$$

Dimensionless complex Π_1:

Complexul adimensional Π_1:

$$\Pi_1 = k\Pi_2^a \Pi_3^b \Pi_4^c \Pi_5^d \tag{15}$$

Combinations between dimensionless complexes are made so that a physical value, easily to vary in a single complex, appears, namely *v*, which can be varied. So, the dimensionless complexes Π_2, Π_3 şi Π_5, aiming to eliminate *v*, are combined and then the new complexes Π_2, Π_3 şi Π_5 appear:

Se fac combinaţii între complexii adimensionali, astfel încât să apară o mărime fizică uşor de variat într-un singur complex, în cazul de faţa *v*, care poate fi variată. Astfel, se combină complexii adimensionali Π_2, Π_3 şi Π_5, care să-l elimine pe *v* şi apar noii complexi Π_2, Π_3 şi Π_5:

$$\Pi_2' = \frac{\Pi_2^2}{\Pi_5} = \frac{\eta_l^2}{D^2 v^2 \rho_l^2} \cdot \frac{Dv^2\rho_l}{\sigma} = \frac{\eta_l^2}{D\rho_l\sigma} \tag{16}$$

$$\Pi_3' = \frac{\Pi_3}{\Pi_5} = \frac{p}{v^2\rho_l} \cdot \frac{Dv^2\rho_l}{\sigma} = \frac{pD}{\sigma} \tag{17}$$

$$\Pi_5' = \frac{\Pi_5}{\Pi_3} = \frac{\sigma}{Dv^2\rho_l} \cdot \frac{v^2\rho_l}{p} = \frac{\sigma}{pD} = \frac{1}{\Pi_3} \tag{18}$$

Relation (13) becomes:

Relaţia (13) devine:

$$\Pi_1 = k_1 \Pi_2'^a \Pi_3'^b \Pi_4^c \Pi_5'^d \tag{19}$$

but

dar

$$\Pi_4 = \frac{\rho_a}{\rho_l} = const. \Rightarrow k_1 \left(\frac{\rho_a}{\rho_l}\right)^c = k \tag{20}$$

So

deci

$$\Pi_1 = k\Pi_2'^a \Pi_3'^b \Pi_5'^d = k\Pi_2'^a \Pi_3'^b \left(\frac{1}{\Pi_3'}\right)^{-d} = k\Pi_2'^a \Pi_3'^{b-d} \tag{21}$$

It is noted: b-d = e = ct. and it results:

Notam: b-d = e = ct. si rezulta:

$$\Pi_1 = k\Pi'^{a}_{2}\,\Pi'^{e}_{3} \tag{22}$$

namely:

adică:

$$\alpha = k\left(\frac{\eta_l{}^2\sigma}{D\rho_l}\right)^a \cdot \left(\frac{pD}{\sigma}\right)^e \tag{23}$$

When the liquid used is the water, then the values of parameters η_l, σ, ρ_l, can be considered as being constant, so that the angle size depends only on working pressure and nozzle diameter, according to the following relation:

În ipoteza că lichuidul utilizat este apă, valorile parametrilor η_l, σ, ρ_l, se considera constante, astfel încât, marimea unghiului va depinde doar de presiunea de lucru şi diametrul duzei, conform urmatoarei relaţii:

$$a = kp^x D^y \tag{24}$$

Starting from relation (24) and data obtained from tests, using the same liquid, the function (25), with two variable working values, namely the working pressure and nozzle diameter, results:

Pornind de la relaţia (24) şi datele obţinute din experimentări, utilizând acelaşi lichid, rezultă funcţia (25), cu două mărimi de lucru variabile: presiunea de lucru şi diametrul duzei:

Table 1

Evolution of jet depending on working pressure and nozzle diameter

No of measurements, N	Nozzle diameter [m]	Pressure [bar]	Angle [°]
0	1×10^{-4}	1	83.8
1	1×10^{-4}	2	102.644
2	1×10^{-4}	3	109.548
3	1×10^{-4}	4	112.634
4	1×10^{-4}	5	118.442
5	2×10^{-4}	1	85.05
6	2×10^{-4}	2	106.736
7	2×10^{-4}	3	115.796
8	2×10^{-4}	4	127.972
9	2×10^{-4}	5	129.756
10	3×10^{-4}	1	87.566
11	3×10^{-4}	2	100.174
12	3×10^{-4}	3	110.546
13	3×10^{-4}	4	114.38
14	3×10^{-4}	5	118.464
15	4×10^{-4}	1	90.632
16	4×10^{-4}	2	102.404
17	4×10^{-4}	3	112.91
18	4×10^{-4}	4	117.652
19	4×10^{-4}	5	122,254
20	5×10^{-4}	1	84.284
21	5×10^{-4}	2	94.832
22	5×10^{-4}	3	105.61
23	5×10^{-4}	4	113.744
24	5×10^{-4}	5	117.974
25	6×10^{-4}	1	88.654
26	6×10^{-4}	2	99.27
27	6×10^{-4}	3	108.3
28	6×10^{-4}	4	114.668
29	6×10^{-4}	5	122.364

$$F(k,x,y,P,D) = k\left(\frac{P}{P_0}\right)^x \frac{D}{D_0}^y \tag{25}$$

In order to emphasize the dimensionless character of nozzle angle size, the working pressure and nozzle diameter were expressed in equation (25) as a report of respective values per their initial values P_0 şi D_0:

Pentru a se evidenţia caracterul adimensional al mărimii unghiului la duză, presiunea de lucru şi diametrul duzei au fost exprimate în ecuaţia (25) ca un raport al mărimilor respective pe valorile lor iniţiale P_0 şi D_0:

$$\begin{cases} P_0 = 1 & (26) \\ D_0 = 0.0001 & (27) \end{cases}$$

In order to obtain the values of coefficients k, x and y we propose the functional N(k,x,y) as a sum of differences between the values obtained applying function F and real values measured α_i, all squared.

It results the function as :

În scopul obţinerii valorilor coeficienţilor k, x şi y propunem funcţionala N(k,x,y) ca o sumă a diferenţelor dintre valorile obţinute aplicând funcţia F şi valorile reale măsurate α_i, toate ridicate la pătrat.

Rezultă functia de foma :

$$N(k,x,y)=\sum_{i=1}^{N}\left[f(k,x,y,p_i,d_i)-(a_i)\right]^2 \quad (28)$$

Initial calculation conditions are: x = 1; y = 1; k = 1.5. Using Mathcad program, the function N(k,x,y) is minimized:

Conditiile initiale de calcul sunt: x = 1; y = 1; k = 1,5. Utilizând programul Mathcad, se minimizează funcţia N(k,x,y):

$$F_m = MINIMIZE\,(N,k,x,y) \quad (29)$$

And it results:

şi rezultă:

k = 1,537

x = 0,21

y = - 9,956 x 10^{-3}

In the following table, the value of spraying angle, measured by comparison with spraying jet angle value estimated, is shown, by applying function F with calculated coefficients k, x and y

In tabelul următor se prezintă valoarea unghiului jetului de pulverizare măsurată comparativ cu valoarea unghiului jetului de pulverizare estimat prin aplicarea funcţiei F cu coeficienţii calculaţi k, x şi y.

Table 2

Measured and estimated values of spraying jet angle

Den. No.	α_i (°)	$\alpha_{calculated}$ [°]
0	83.8	88.07
1	102.644	101.898
2	109.548	110.973
3	112,634	117.897
4	118.442	123.565
5	85.05	87.464
6	106.736	101.197
7	115.796	110.209
8	127.972	117.086
9	129.756	122,.715
10	87.566	87.112
11	100.174	100.789
12	110.546	109.765
13	114.38	116.615
14	118.464	122.22
15	90.632	86.863
16	102.404	100.501
17	112.91	109.452
18	117.652	116.281
19	122.254	121.871
20	84.284	86.67
21	94.832	100.278
22	105.61	109.209
23	113.744	116.023
24	117.974	121.6
25	88.654	86.513
26	99.27	100.096
27	108.3	109.011
28	114.668	115.813
29	122.364	121.38

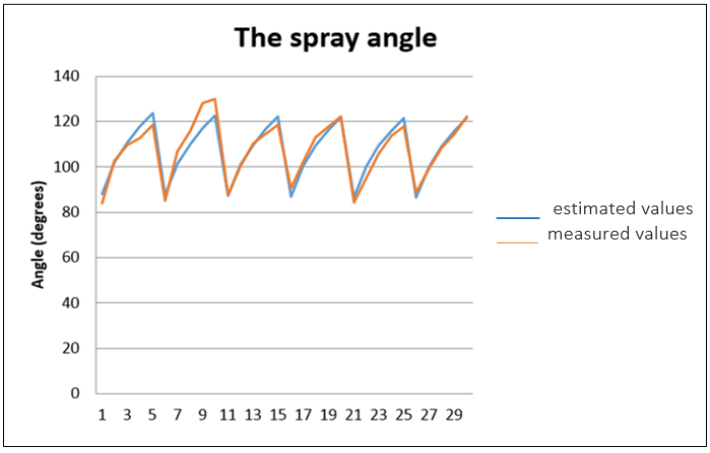

Fig. 3 – Evolution of jet angle for the two values (estimated and measured)

Definition of correlation coefficient:

Definitie coeficient de corelatie:

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \quad (30)$$

În figure 3 are presented as graphic the values of jet angle obtained experimentally and which were estimated. Calculating the value of correlation coefficient R between the two sets of data, the value of 0.95579 is obtained, indicating a direct correlation between them, fact confirmed by diagrams from figure 4.

Module of difference between the value obtained experimentally and minimized value, is calculated according to formula (31) and introduced in formula (32) for calculating the maximum deviation resulted between the two sets of data:

În figura 3 se prezintă grafic valorile unghiului jetului obţinute experimental şi estimate. Calculând valoarea coeficientului de corelaţie R între cele două seturi de date se obţine valoarea de 0,95579 ceea ce indică o corelare directă între ele, fapt confirmat şi de diagramele din figura 4.

Modulul diferenţei dintre valoarea obţinută experimental şi valoarea minimizată se calculează conform formulei (31) şi se introduce în formula (32) pentru calculul abaterii maxime rezultate între cele două seturi de date:

$$\Delta_i = \sqrt{(\alpha_{calculat} - \alpha_i)^2} \quad (31)$$

$$\frac{\max(\Delta)\cdot 100}{\min(\alpha_i)} = 12.99\% \quad (32)$$

In the following figures, the dependence of spraying jet angle, eperimentally measured and estimated afterwards depending on input data (working pressure and nozzle diameter) is presented as a graphic.

În figurile următoare se prezintă grafic dependenţa unghiului jetului de pulverizare măsurat experimental şi mai apoi estimate în funcţie de datele de intrare: presiune de lucru şi diametrul duzei.

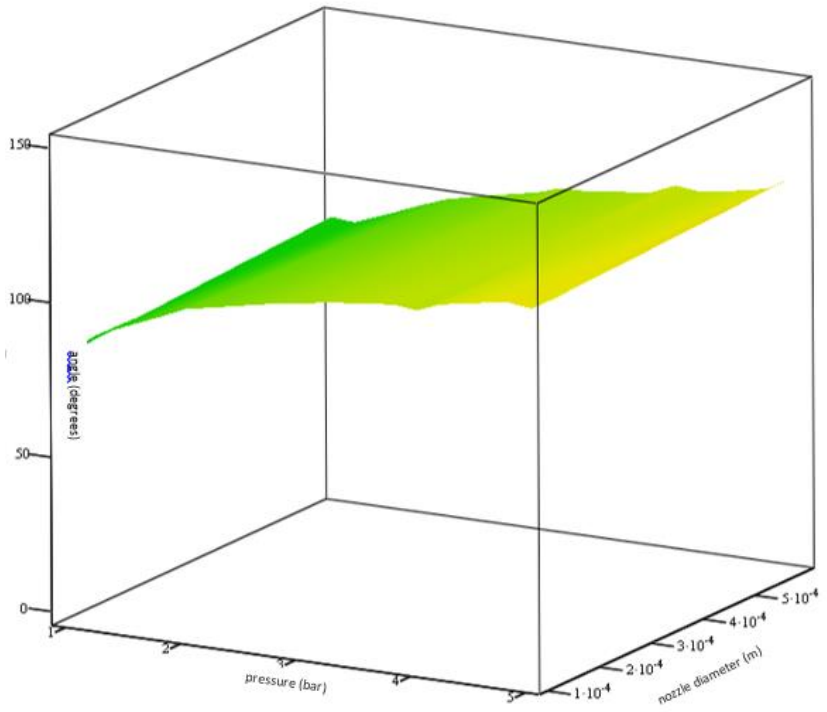

Fig. 4 - Variation of spraying jet angle according to working pressure and nozzle diameter (data experimentally obtained)

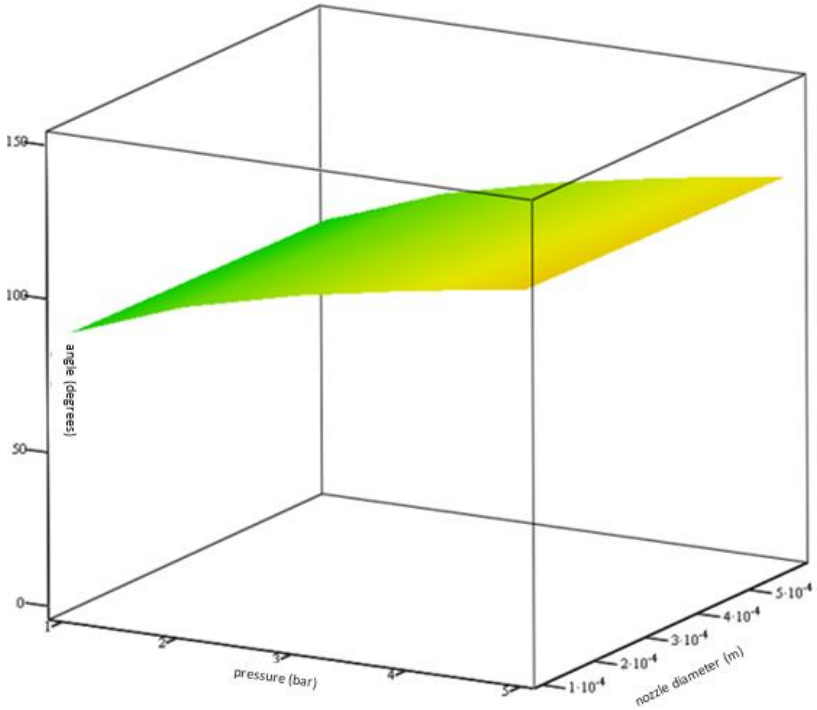

Fig. 5 - Variation of spraying jet angle according to working pressure and nozzle diameter (interpolated data)

CONCLUSIONS

Assuring a mximum efficiency of phytosanitary treatments in agricultural crops is possible by manufacturing sprayers equiped with high performance parameters spraying systems.

The repartition deviations at stand test are inherent even for a new nozzle, but they must frame within the suitable limits that should not affect the fragmentation repartition on working width of ramp, where nozzles repartitions are overlapping, and deviation of overlapping values should not surpass ±5%.

Using the function proposed, it can be estimated with high precision the evolution of spraying jet according to working pressure and nozzle diameter. Therefore, this information can be useful when calculating the covering degree and rate of phytosanitary substance used for different crops.

For the present model, only two values have been taken into account, namely nozzle pressure and flow, measurements being performed with water as liquid. In order to continue the researches, three variable sizes will be introduced in the model: viscosity and density of the liquid and its temperature, in this case using the phytosanitary solutions for tests.

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CONCLUZII

Asigurarea unei eficiente maxime a tratamentelor cu substanţe fitosanitare în culturile agricole de câmp este posibilă prin realizarea unor maşini de stropit echipate cu sisteme de pulverizare cu parametri superiori în procesul de lucru.

Abaterile de repartiţie, la încercarea pe stand, sunt inerente chiar şi pentru o duză nouă însă acestea trebuie să se înscrie în limite care să nu afecteze repartiţia fragmentaţiei pe lăţimea de lucru a rampei, unde repartiţiile duzelor se suprapun, iar abaterea valorilor de suprapunere să nu depăşească ±5%.

Folosind funcţia propusă se poate estima cu o precizie destul de ridicată evoluţia unghiului jetului de pulverizare în funcţie de presiunea de lucru şi de diametrul duzei. Astfel această informaţie poate fi utilă în calculul gradului de acoperire şi al normei de substanţă fitosanitară folosită de utilizator pentru diverse culturi.

În modelul luat în calcul s-au presupus ca variabile în timp doar două mărimi: presiunea şi debitul duzei, măsurătorile realizându-se prin utilizarea ca lichid a apei. Pentru continuarea cercetărilor se vor introduce în model trei mărimi variabile: vâscozitatea şi densitatea lichidului şi temperatura acestuia folosindu-se pentru experimentări, în acest caz, soluţii fitosanitare.

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ORGANIC PLANT AND ANIMAL WASTE MANAGEMENT SYSTEM
/
SISTEM ECOLOGIC DE GESTIONARE A DEŞEURILOR VEGETALE ŞI ANIMALE

PhD. Eng. Ciupercă R., PhD. Stud. Eng. Lazăr G., PhD.Eng.Popa L., PhD. Eng. Nedelcu A., PhD. Stud. Ştefan V., PhD. Stud. Eng. Zaica A., PhD. Stud. Eng. Petcu A.
INMA Bucharest / Romania
E-mail: ciupercaradu@yahoo.com

Abstract: *The paper presents some theoretical and practical considerations related to environmental management of plant and animal waste by aerobic composting, this being the most effective way of treating waste from agricultural activities.*
Treatment of this waste by composting having a deep impact both economically, on one hand, compost being a very good and valuable organic fertilizer used in crop production, greenhouses and solariums and on the environment, on the other hand, by reducing the impact on main negative environmental factors (air, water, soil).
Basically, four methods of composting are known, classified by location and aeration method, as follows:
- passive open composting heap;
- stack composting in the platform with the use of technical reshuffling equipment for ventilation;
- composting in aerated static stacks, using the culverts or pipes;
- composting in container.
Ecological waste management system, subject of this paper, uses static stacks method, using an aeration system consisting of culverts and pipes, integrated in composting platform, and aeration system is powered by a photovoltaic system.

Keywords: *environmental management of organic waste, composting platform*

INTRODUCTION

Environmental pollution is a major problem of the modern world, this being the main factor that generates global warming of the atmosphere with serious present and future repercussions on health and life on planet Earth.

Therefore, it must be analysed, with great responsibility pollution sources, their influence on the main environmental factors (air, water, soil) and on life, identify and implement appropriate measures to reduce or even eliminate environmental pollution.

Also in agricultural activities, basic branch in all economies of the world, are known countless factors that pollute the environment, one of the most important being non-food by-products from agricultural and livestock farming in particular.

In fact, it is about wastes coming from crop production, animal manure from livestock farms or individual farms and other plant and animal wastes, resulting from the activities of production units mentioned above.

Although there are specific rules, applying especially on manure, related to good agricultural practices, biological safety of the treatment applied and other products based on manure processed, in Romania have not been yet generalized these rules by practical measures at local or general management.

Rezumat: *În lucrare se prezintă câteva consideraţii teoretice şi practice referitoare la gestionarea ecologică a deşeurilor vegetale şi animale prin compostare aerobă, aceasta reprezentând cea mai eficientă modalitate de tratare a deşeurilor provenite din activităţile agricole.*
Tratarea prin compostare a acestor deşeuri are un profund impact benefic atât economic, pe de o parte, compostul fiind un foarte bun și valoros îngrășământ organic utilizat în producția agricolă vegetală, sere și solarii cât și asupra mediului, pe de altă parte, prin reducerea impactului negativ asupra principalilor factori de mediu(aer, apă, sol).
În principiu sunt cunoscute patru metode de compostare, clasificate după modalitatea de amplasare şi aerare, astfel:
- compostarea pasivă în grămadă deschisă;
- compostarea pe platformă în șire, cu utilizarea de echipamente tehnice de remaniere pentru aerare;
- compostarea în grămezi statice aerate, folosind sisteme de rigole sau conducte;
- compostarea în container.
Sistemul ecologic de gestionare a deșeurilor care face obiectul prezentei lucrări, utilizează metoda în grămezi statice, folosind un sistem de aerare alcătuit din rigole şi conducte, integrate în platforma de compostare, iar instalația de aerare este acționată de un sistem cu panouri fotovoltaice.

Cuvinte cheie: *gestionare ecologică deșeuri organice, platformă de compostare*

INTRODUCERE

Poluarea mediului înconjurător reprezintă o problematică majoră a lumii moderne, aceasta fiind principalul factor care generează încălzirea globală a atmosferei cu repercusiuni grave actuale și de perspectivă asupra sănătății și vieții pe planeta Pământ.

De aceea trebuie analizate cu mare responsabilitate sursele de poluare, influenta acestora asupra principalilor factori de mediu(aer, apă, sol) şi asupra vieții, identificate și implementate măsuri adecvate pentru reducerea sau chiar eliminarea poluării mediului.

Și în activitățile din agricultură, ramură de bază în toate economiile țărilor lumii, se cunosc nenumărați factori care poluează mediul, unul dintre cei mai importanți constituindu-l deșeurile sau produsele secundare nealimentare rezultate din activitatea agricolă în general şi zootehnică în special.

Este vorba de fapt de resturile rezultate din producția agricolă vegetală, dejecțiile animalelor din fermele zootehnice sau gospodăriile individuale precum și alte resturi vegetale și animale rezultate din activitățile unităților de producție menționate.

Deşi există norme specifice, aplicabile în special gunoiului de grajd, legate de bunele practici agricole, de siguranța biologică a tratamentelor aplicate acestuia şi a altor produse pe bază de gunoi de grajd transformate, în România nu s-a reușit încă generalizarea acestor norme prin măsuri practice de gestionare la nivel local sau general.

The main factors favouring the aerobic composting and guide values [3,4].

Oxygen from the air - specialty literature refers in detail to the importance of oxygen in the air contained in the compost heap for aerobic fermentation process, but there are few scientists who give values, and these are: 25-35% pore volume of air; oxygen requirements 2g O_2 / g dry air or 2 l air / g fresh material [ICIM].

Water - the optimal moisture percentage of 50-60% is recommended for fermentation.

Waste composition - the optimum carbon/nitrogen (C/N) between 25-30: 1. *PH value*- must be between 7 ... 9.

Auxiliary factors that favour the aerobic fermentation:

- homogeneity of the mixture;
- waste grain size subject to fermentation - approx. 90% of compost having dimensions less than 35 mm;
- how to place in stacks the waste ground;
- ratio of aerating stack;
- size of stack of composting;
- ambient conditions (temperature, wind, moisture etc.).

MATERIAL AND METHOD

The ecological waste management coming from plants and animals which is subject of this paper, fig.1 is designed as a complete system that fully comply with the requirements of national and European rules currently in this area and includes the following main assemblies: concrete platform, item.1, aeration system, item 2, drainage and collection, item 3, measuring and monitoring system of composting parameters, item 4.

- concrete platform - has three functional areas, namely:

Pre-treatment zone - is the storage, handling, preparation, mixing and transfer area to the composting area (the green area, fig. 1). The area is provided with boarding ramp for mechanical means used to manage the compost. Its surface is approx. by 1.5 greater than the composting area. In this case, when in this area is provided also an area where you can make effective composting platform is designed to make comparative research on the composting process.

Area treatment (composting) - is located in the centre of the platform and is divided, in this case in two areas in order to achieve and monitor the composting process in two comparative ways , respectively with and without tarp covering and different conditions of aeration (the red area, fig. 1). In this area is performed composting process being provided with culverts for aeration and gutters for collecting liquid leakage resulted in the composting process.

Composting area size is calculated according to the amount and composting technology, density and moisture content of compost.

Final compost storage area - is designed for temporary storage of compost to their capitalization or transfer to another designated area (the orange area, fig. 1). It has a surface area greater than treatment area.

Concrete platform provides an inclination angle of 2...40^o and is provided around with gutters to collect leakage from stack composting and rainwater.

- Aeration system - fig.2, is performed in order to aerate the compost stack.

It consists of aeration gutters, performed in concrete platform, a centrifugal fan, pos.1, a system of pipes,

Factorii principali care favorizează compostarea aerobă şi valorile orientative ale acestora [3,4].

Oxigenul din aer – literatura de specialitate face referiri detaliate la importanța oxigenului din aerul conținut în grămada de compostat pentru procesul de fermentare aerobă, însă sunt puțini cei care dau valori, iar acestea sunt: volumul porilor de aer 25-35%; necesarul de oxigen 2gO_2/g substanță uscată sau 2 l aer/g material proaspăt [ICIM].

Apa - procentul de umiditate optim pentru fermentare recomandat este de 50-60%.

Compoziția deșeurilor - raportul optim carbon/azot (C/N) între 25-30:1.

Valoare pH-ului - trebuie să se situeze între 7…9.

Factorii auxiliari care favorizează fermentarea aerobă:

- omogenitatea amestecului;
- granulația deșeurilor supuse fermentării – cca. 90% din compost să aibă dimensiuni sub 35 mm;
- modul de așezare a deșeurilor măcinate în grămezi;
- rata de aerare a grămezii;
- mărimea grămezii de compostare;
- condițiile mediului ambiant (temperatura, vânt, umiditate etc.).

MATERIAL ŞI METODĂ

Sistemul ecologic de gestionare a deşeurilor vegetale şi animale care face obiectul prezentei lucrări, fig.1 este conceput ca un sistem complet care să corespundă în totalitate cerințelor normelor actuale naționale şi europene în domeniu şi are în componență următoarele ansambluri principale: platforma betonată, poz. 1, instalația pentru aerare, poz. 2, sistem de scurgere şi colectare, poz. 3, sistemul de măsurare şi monitorizare a parametrilor de compostare, poz. 4.

- platforma betonată - are trei zone funcționale și anume:

Zona de pre-tratare – este zona de stocare, manevrare, pregătire, amestecare si transfer spre zona de compostare (zona careului verde, fig. 1). Zona este prevăzută cu rampă de urcare pentru mijloacele mecanice utilizate la gestionarea compostului. Suprafața acesteia este de cca. 1,5 ori mai mare decât zona de compostare. În cazul de față în această zonă este prevăzută și o zonă unde se poate face compostarea efectivă, platforma fiind destinată efectuării de cercetări comparative asupra procesului de compostare.

Zona de tratare (compostare) - este amplasată în zona centrală a platformei și este împărțită, în cazul de fată, în două spatii pentru a putea realiza și monitoriza procesul de compostare în două moduri comparative, respectiv cu și fără acoperire cu prelată şi condiții diferite de aerare (zona careului roşu, fig. 1). In această zonă se realizează efectiv procesul de compostare fiind prevăzută cu rigole pentru aerare și colectare a scurgerilor lichide rezultate în procesul de compostare.

Mărimea zonei de compostare este calculată în concordanță cu cantitatea și tehnologia de compostare, densitatea si umiditatea compostului.

Zona de depozitare a compostului final - este destinată depozitării provizorii a compostului până la valorificarea acestuia sau transferarea în altă zonă special amenajată (zona careului portocaliu, fig. 1). Are suprafața mai mare decât a zonei de tratare.

Platforma betonată asigură un unghi de inclinare de 2...4^0 și este prevăzută de jur împrejur cu rigole pentru colectarea scurgerilor și levigatului din grămada compostată și a apelor pluviale.

- instalația pentru aerare – fig. 2, este realizată în vederea aerării grămezii de compost.

Este alcătuită din rigole de aerare, prevăzute în platforma betonată, un ventilator centrifugal, poz.1, un

couplings, elbows and three check valves, pos. 2, which facilitates closing - opening of the suction three circuits.

Fan drive is done with electricity produced by a photovoltaic system with the necessary accessories pos. 3 (inverter, controller, two batteries, cables, connectors), electrical control panel etc., all of which are placed in a container, pos. 4 to be protected from the weather.

Fan drive can be achieved with electricity from the national network.

- ***Drainage and collection system*** – Fig. 3 is designed to allow draining compost and liquid fraction collection (garbage mash), leachates and waters resulting from rainfall. This system consists of aeration and collection gutters, pos. 1, which is located in the composition of the concrete platform of composting, a removable system of pipes, couplings, elbows, caps, pos. 2, marginal gutters of the concrete platform, pos. 3 and a collection basin, pos. 4.

sistem de conducte, mufe de legătură, coturi precum şi trei clapete de reținere, poz. 2, care facilitează închiderea – deschiderea la alegere a celor trei circuite de aerare.

Acționarea ventilatorului se realizează cu energie electrică produsă de un sistem de panouri fotovoltaice cu accesoriile necesare poz. 3 (invertor, controler, două acumulatoare, cabluri, conectori), tabloul electric de comandă etc., toate acestea fiind amplasate într-un container, poz. 4 pentru a fi protejate de intemperii.

Acționarea ventilatorului se poate realiza şi cu energie electrică de la rețeaua națională.

- sistemul de scurgere şi colectare – fig 3, este realizat pentru a permite scurgerea şi colectarea fracţiei lichide din compost (mustul de gunoi), a levigatelor şi apelor rezultate în urma ploilor. Acest sistem este alcătuit din rigolele de aerare şi colectare, poz. 1, care se află amplasate în componența platformei betonate de compostare, un sistem demontabil de conducte, mufe, coturi capace, poz. 2, rigolele marginale ale platformei betonate, poz. 3 şi un bazin de colectare, poz. 4.

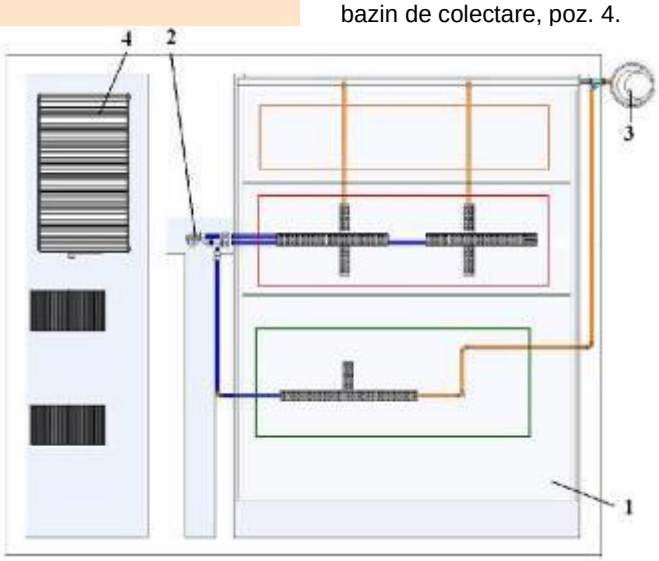

Fig.1 – Organic waste management system of vegetable and animal waste -SEG
1- concrete platform; 2 - aeration system; 3 - drainage and collection; 4 - measuring and monitoring system of composting parameters process

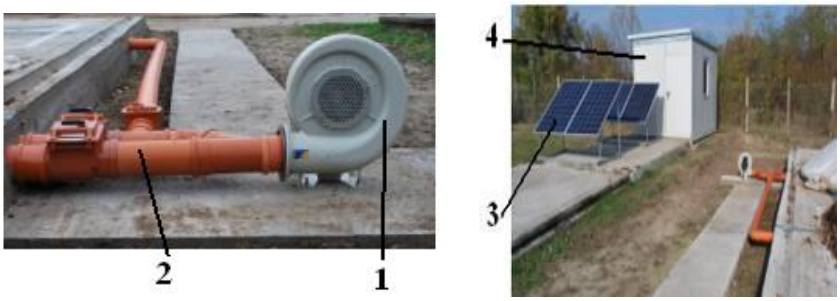

Fig. 2 - The device for aerating
1 - centrifugal fan; 2 - pipes, bands, check valves; 3 - photovoltaic panels; 4 - Container + accessories

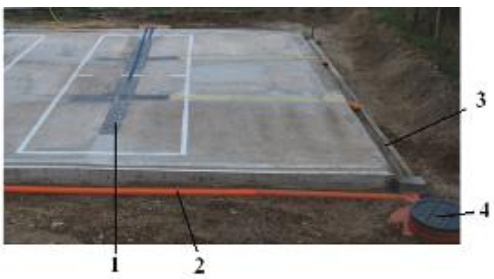

Fig. 3 - Drainage and collection system
1 - Suction gutters and collection; 2 - pipes, couplings, elbows; 3 - marginal gutters; 4 - collection basin

- ***measuring and monitoring system of parameters of composting*** - is designed to perform measurement and monitoring of parameters of the composting process and consists of: instruments for measuring temperature, humidity, air velocity generated by the fan, penetration resistance in compost, a date logger with data acquisition system and eight-channel recording with graphic display and built-in analysis functions and laptop;

Apparatus and instruments for measuring and monitoring are mounted or kept inside the container, Fig. 2 pos. 4.

Constructive and functional characteristics:

Concrete platform
- total length [m] ……..12.4
- total width [m] …… 9.3
- height [m] …….. 0.25
- pre-treatment surface area [m^2] ……..about 35
- composting surface area [m^2] ……20…25
- composting capacity [t]…… approx. 10
- storage area surface, [m] …… about 35

The device for aerating
- fan
  - power driving [kW] …….. 1.1
  - maximal air flow [m^3/h] ……1790
  - voltage [V] ……220
- The fan driving
  - 4 photovoltaic panels LxWxH [m] ……1,6x1x0,04
  - inverter - VITRON MULTIPLUS ……..24V / 1200W
  - controller - VITRON BLUE SOLAR …….. 24V / 50A
  - 2 solar batteries: ……12V, 220Ah, [kW] 1

Drainage and collection system
- pipe dimensions [mm] …….. 125; 110
- volume of collection tank [m^3] ……1.8

Making stack for composting, **fig. 4**

- **first stage** – plant and animal wastes were transported and stored temporarily in the pre-treatment platform of compost (manure from horses, cattle, sheep, poultry, rabbits and sawdust fir, mixed + dried leaves, branches, straw).
- **In the second step** - the compost material is placed in alternating layers as follows: the first layer is composed of branches that carry out a porous layer that allows an easier ventilation and uniform air distribution over the entire surface area of the actual composting; than a layer of garbage over dry leaves and straw mixed with each other and watered is put over.

The operation has continued, alternating the placement, mixing and wetting the layers of garbage, straw and leaves, until the platform was ready, set dimensions.

Repeatedly, the mixture humidity in different areas, was measured to ensure that the final stack will have optimal humidity and distributed as uniform as possible, fig.5.

Monitoring the composting process was done in two ways, fig. 4, namely:

- For an area of stack covered with a geo-textile foil and aerated both naturally and artificially by forced aeration with a centrifugal fan at set intervals and wetted when necessary depending on the evolution of composting parameters - **active composting**;
- for another area of uncovered stack with aeration and wetting only natural - **passive composting.**

- sistemul de măsurare şi monitorizare a parametrilor de compostare – este realizat pentru a efectua măsurarea și monitorizarea parametrilor principali ai procesului de compostare și este alcătuit din: instrumente pentru măsurarea temperaturii, umidității, vitezei aerului generat de ventilator, rezistenței la penetrare în compost, un data logger cu sistem de achiziție şi înregistrare date cu opt canale cu afișaj grafic şi funcții de analiză încorporate şi laptop;

Aparatura şi instrumentele de măsurare şi monitorizare sunt monate sau păstrate în interiorul containerului, fig. 2, poz. 4.

Caracteristici tehnice constructive şi funcționale:

Platforma betonată
- lungime totală, [m]……12,4
- lățime totală, [m]……9,3
- înălțime, [m] …… 0,25
- suprafața zonei de pretratare, [m^2] …….. cca.35
- suprafața zonei de compostare, [m^2]……20…25
- capacitatea de compostare, [t] …… cca.10
- suprafața zonei de depozitare, [m]…… cca.35

Instalația pentru aerare
- ventilator
  - puterea de acţionare, [kW] ……1,1
  - debitul de aer maxim, [m^3/h] 1790
  - tensiunea, [V]..... 220
- sistemul de acţionare ventilator
  - 4 panouri fotovoltaice Lxlxh [m] 1,6x1x0,04
  - inverter - VITRON MULTIPLUS 24V/1200W
  - controler - VITRON BLUE SOLAR 24V/50A
  - 2 acumulatori solari: .....12V,220Ah, [kW] 1

Sistemul de scurgere şi colectare
- dimensiuni conducte, [mm] 125;110
- volum rezervor de colectare, [m^3] ……1,8

Realizarea grămezii (şirei) pentru compostare, fig. 4

- în prima etapă - au fost transportate şi depozitate provizoriu, deşeurile de natură vegetală şi animală în zona de pretratare a platformei de compostare (gunoi de grajd de cabaline, bovine, ovine, păsări, iepuri şi rumeguş de brad, în amestec+ frunze uscate, crengi, paie).

- în etapa a doua – se aşează materialele de compostat, în straturi alternative, după cum urmează: primul strat este alcătuit din crengi care realizează un strat poros ce permite o aerare mai facilă şi o distribuţie uniformă a aerului pe toată suprafaţa zonei de compostare efectivă; urmează un strat de gunoi peste care se aşează frunze uscate şi paie care se amestecă între ele şi se udă.

Operaţiunea a continuat, alternând aşezarea, amestecarea şi udarea straturilor de gunoi, paie şi frunze, până când platforma a fost gata, la dimensiunile stabilite.

In mod repetat, s-a verificat umiditatea amestecului, în diferite zone, pentru a ne asigura că în final grămada va avea o umiditate optimă şi distribuită cât mai uniformă, fig.5.

Monitorizarea procesului de compostare s-a realizat în două moduri , fig. 4 şi anume:

- pentru o zonă a grămezii acoperită cu o folie de Geotextil şi aerată atât natural cât şi artificial prin aerare forţată cu un ventilator centrifugal la intervale stabilite şi umectată la nevoie, în funcţie de evoluţia parametrilor de compostare - **compostare activă;**
- pentru altă zonă a grămezii neacoperită, cu aerare şi umectare doar naturală - **compostare pasivă.**

Fig. 4- Aspects of the compost stack while performing

Fig. 5 – Aspects during measurement of composting parameters

The apparatus used in experiments

- roman weigh 20t;
- non-automatic weighing machine, 0-6100 g;
- measuring tapes 0-5m;
- digital thermometre: -50 ° C ... + 200 ° C
- thermal resistance Pt 100- SC CAOM PASCANI;
- soil moisture meter HH-2 14/82;
- oven;
- penetrometer Meter SC 900 - Spectrum;
- testovent 4000 SPECTRUM Technologies.

RESULTS

The variation in time of the physical parameters of the compost stack is shown in Table 1.

Composting parameters were measured and continuous monitoring measurement points are shown in the diagram of fig. 6.

Parameters at the beginning of composting

- Humidity ……..65…70%
- Temperature ……28 ... 350C
- Degree of compaction ……70 ... 140 kPa

The speed of the air flow realized by the fan (output) - 29.5 m/s.

Aparatura utilizată la experimentări

- basculă romană 20t;
- aparat de cântărit cu funcţie neautomată 0-6100 g;
- ruletă de măsură 0-5m;
- termometru digital: -50°C…+ 200°C
- termorezistenţă Pt 100- S.C. CAOM PASCANI;
- umidometru pentru sol HH-2 14/82;
- etuvă;
- penetrometru Meter SC 900 – Spectrum;
- testovent 4000 SPECTRUM Technologies.

REZULTATE

Variaţia în timp a parametrilor fizici ai grămezii compostate este prezentată în tabelul 1.

Parametrii de compostare au fost măsuraţi şi monitorizaţi continuu, punctele de măsurare fiind prezentate în schema din fig. 6.

Parametrii de compostare la începutul procesului

- umiditatea ..... 65…70%
- temperatura ..... 28…35^{0}C
- gradul de compactare ..... 70…140 kPa

Viteza curentului de aer realizată de ventilator (la ieşire) – 29,5 m/s.

Table 1

Temporal variation of physical composted stack parameters

Nr. Crt.	Parameter	M.U.	Composting period [days]			
			1	10	15	35
1	Length	m	8.8	8.8	8.8	8.8
2	Width	m	3	3	3	3
3	Height	m	1.7	1.6	1.5	1.25
4	Volume	m^3	19	17.9	16.8	13.4
5	Mass	t	8.8	8.55	8.6	8.7
6	Specific weight	t/m^3	0.46	0.48	0.51	0.625
7	Natural slope angle	degrees	51	49	47	42

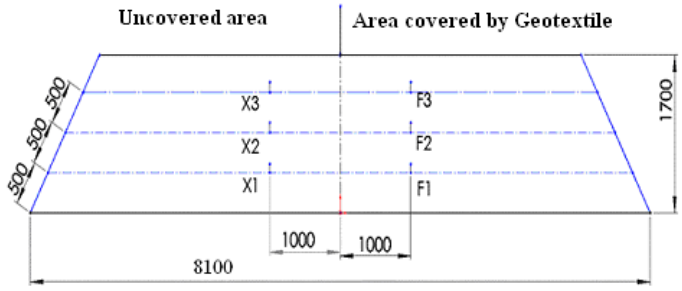

Fig. 6 – The distribution of measurement points of the composting parameters

The temperature and humidity of the compost stack was continuously measured at the points shown in Fig. 6, the distribution of values over time is shown in diagram 1; 4. In the diagrams were presented variations of composting parameters only in representative points and depths so you can draw the following conclusions for the composting process.

Evolution of compaction in time for the two areas of compaction (covered and uncovered) is shown in diagrams 5, 6.

Temperatura şi umiditatea grămezii compostate au fost măsurate continuu, în punctele prezentate în fig. 6, distribuția valorilor în timp, fiind prezentată în diagramele 1; 4. În diagrame s-au prezentat variațiile parametrilor de compostare doar în punctele şi adâncimile mai reprezentative, astfel încât să se poată desprinde câteva concluzii importante pentru procesul de compostare.

Evoluția gradului de compactare în timp, pentru cele două zone de compactare(acoperită şi neacoperită) este prezentată în diagramele 5, 6.

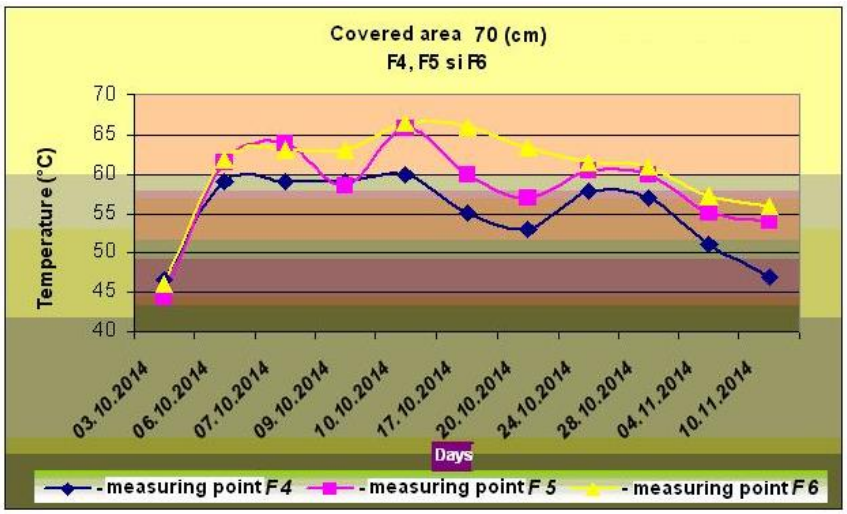

Diagram 1 - Variation in time of temperature in covered area

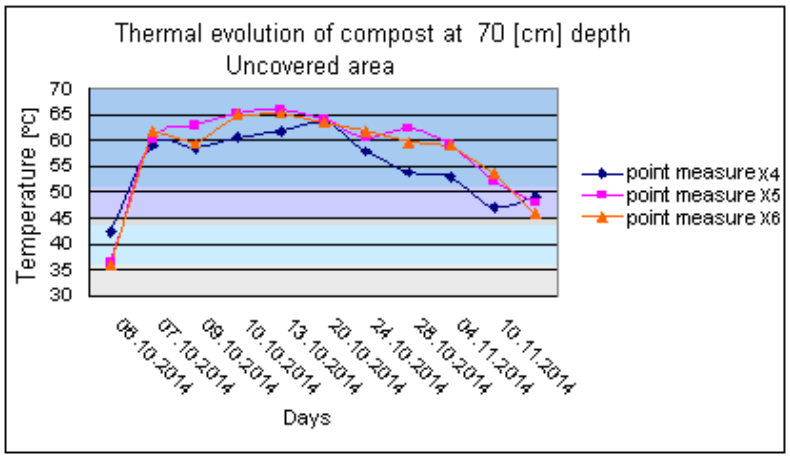

Diagram 2 - Variation in time of temperature in uncovered area

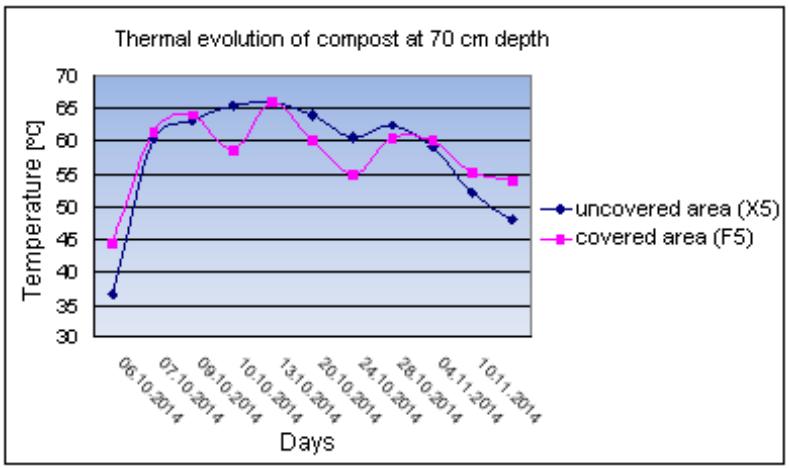

Diagram 3 - Variation in time of compost temperature in covered and uncovered areas at 70 cm depth

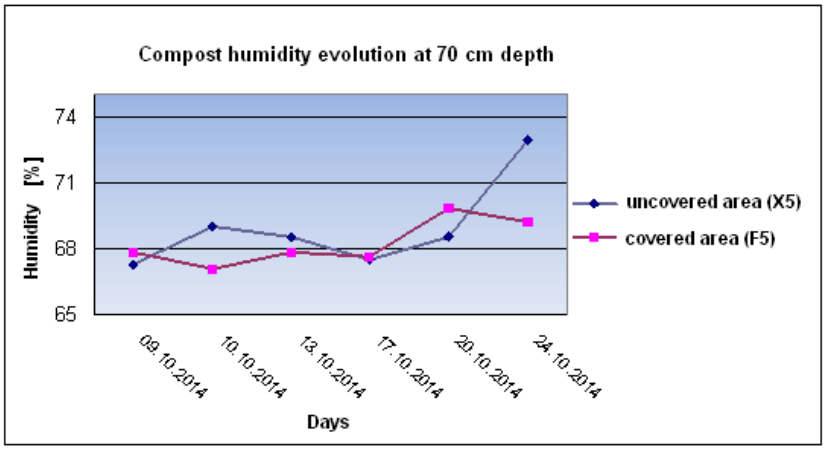

Diagram 4 - Variation in time of compost humidity at 70 cm depth

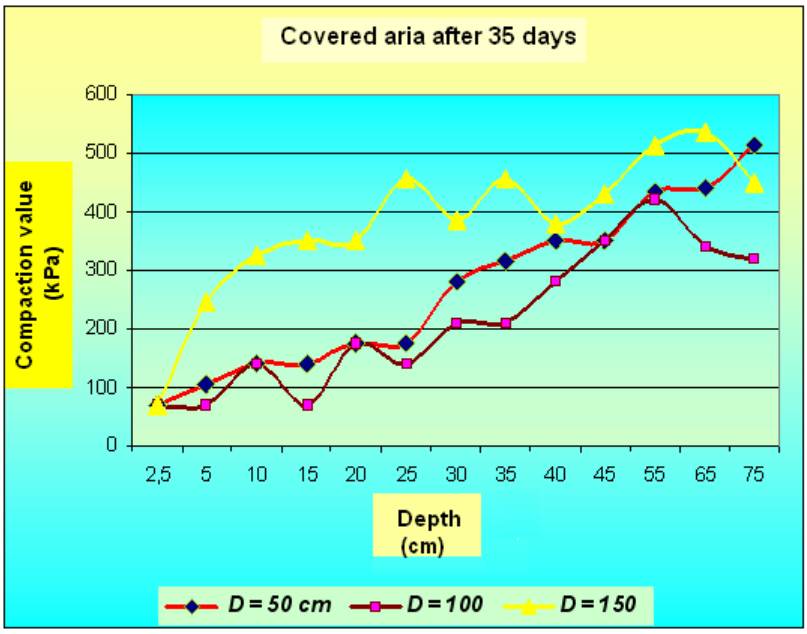

Diagram 5 - Evolution in time of compaction degree in covered area

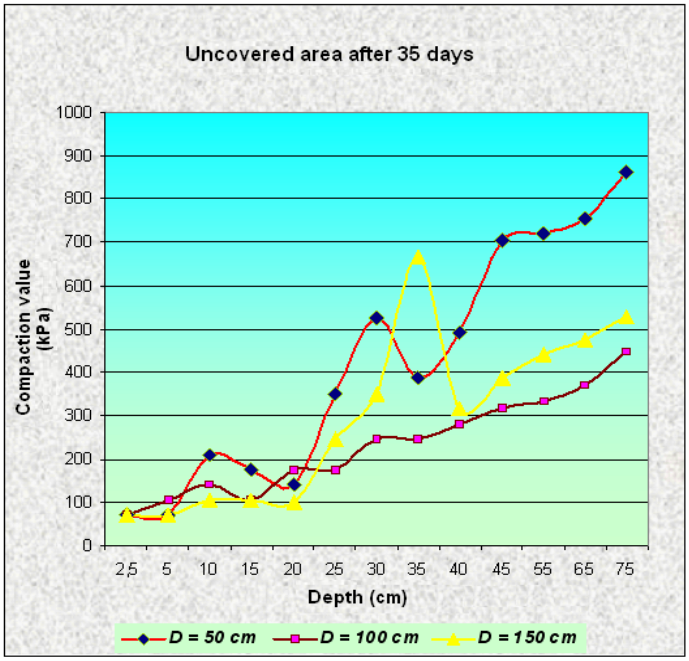

Diagrama 6 - Evolution in time of compaction degree in uncovered area

CONCLUSIONS

- The greenest way to manage plant and animal waste, generally, organic waste, is aerobic composting;
- With carrying out the composting process, in addition to temperature and humidity variation, piles changed their other physical parameters (size, volume, mass, density, angle of slope);
- In diagrams 1 and 2 it is shown that, starting from an initial stack temperature of 28 -35^{0}C, in approx. 4 days, the temperature reached values of approx..60^{0}C (growth phase), the temperature of the composting process and the actual start time of approx. 26 days being maintained in the range of 55 ... 65^{0}C (thermophilic phase) suitable to fermentation temperature. After the thermophilic phase temperature drops to 45 ... 50^{0}C and maintains for a longer period, ripening period corresponding to phase of compost. Temperatures have significantly higher values at the top of the pile.
- For the covered area were observed some greater decreases in temperature, 1.3 diagrams, this fact being manifested during the periods in the aerated pile. Nevertheless, temperatures remain within limits suitable to the fermentation;
- Pile humidity in the uncovered area, is maintained approximately within the initial limits for approx. 20 days, with sensitive increase of the area covered by watering, respectively following the rains the uncovered area;
- Composting temperature is slightly higher to the top of the pile;
- The degree of compaction increases from the outside to the inside of the pile, both for geo-textile covered are and uncovered area, as a result of specific weight increment by transforming the original material into compost;
- Degree of compaction is continuously increasing in general, from the outside to inside, but there were deviations caused by unevenness of compost composition or process running;
- Degree of compaction increases from bottom to top of the pile in the area covered, diagram 5. For the uncovered area, variation of compaction is uneven because of a time variation of moisture due to rains during the monitored period, Chart 6.

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CONCLUZII

- cea mai ecologică modalitate de gestionare a deșeurilor agricole vegetale şi animale, în general a deșeurilor de natură organică, este compostarea aerobă;
- odată cu desfășurarea procesului de compostare, pe lângă variația temperaturii şi umidității, grămada își modificat și alți parametri fizici(dimensiuni, volum, masa, densitatea, unghi de taluz);
- din diagramele 1 şi 2 se observă că, pornind de la o temperatură inițială a grămezii de 28 -35^{0}C, în cca. 4 zile, temperatura a ajuns la valori de cca.60^{0}C(faza de creștere), temperatură la care procesul de compostare începe efectiv iar timp de cca. 26 de zile se menține în intervalul de 55...65^{0}C(faza termofilă), temperaturi propice fermentării. După faza termofilă temperatura scade la valori cuprinse între 45…50^{0}C şi se menține o perioadă mai îndelungată la aceste temperaturi, perioadă care corespunde fazei de maturare a compostului. Temperaturile au valori sensibil mai ridicate spre vârful grămezii.
- pentru zona acoperită se observă câteva scăderi mai mari ale temperaturii, diagramele 1,3, acest fapt manifestându-se în perioadele în care grămada a fost aerată. Cu toate aceste, temperaturile se mențin în limite propice fermentării;
- umiditatea grămezii, în zona neacoperită, cca. 20 de zile, se menține aproximativ în limitele inițiale, cu creșteri sensibile după udarea zonei acoperite, respectiv în urma ploilor căzute, în zona neacoperită;
- temperatura de compostare este sensibil mai mare spre partea superioară a grămezii;
- gradul de compactare crește, de la exteriorul spre interiorul grămezii, atât pentru zona acoperită cu geotextil cât și pentru zona neacoperită, urmare a creșterii greutății specifice prin transformarea materialelor inițiale în compost;
- gradul de compactare crește continuu în general, de la exterior spre interior, dar s-au înregistrat şi abateri, cauzate de neuniformitatea compoziției compostului sau a desfășurării procesului;
- gradul de compactare creşte de la bază spre vârful grămezii la zona acoperită, diagrama 5. La zona neacoperită, variația compactării este mai neuniformă, cauza principală fiind variația în timp a umidității datorate ploilor căzute în perioada monitorizată, diagrama 6.

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THE INFLUENCE OF PHYSICAL CHARACTERISTICS OF SOLID ORGANIC FERTILIZERS ON QUALITY OF LAND SPREADING

/

INFLUENŢA CARACTERISTICILOR FIZICE ALE ÎNGRĂŞĂMINTELOR ORGANICE SOLIDE ASUPRA CALITĂŢII LUCRĂRII DE ÎMPRĂŞTIERE

PhD.Stud. Eng. Ştefan (Popa) V., PhD. Eng. Ciupercă R., PhD. Eng. Popa L., PhD. Eng. Nedelcu A., PhD. Stud. Eng. Lazăr G., PhD.Stud. Eng. Petcu A.S., PhD.Stud. Eng. Zaica A.
INMA Bucharest / Romania
Tel: 0722 245 443; E-mail: valle_vali@yahoo.com

Abstract: *Article presents the experimental researches results regarding the influence of physical characteristics of solid organic fertilizers on quality of spreading, performed with machines with vertical spreading apparatus of spire rotor type. These researches are required by the fact that spreading machines should assure a certain shredding degree of material for ensuring a suitable fertilization according to agro-technical requirements respecting the standards in force.*

Keywords: *organic fertilizers, humidity, shredding degree, spreading.*

INTRODUCTION

Soil fertilization with organic fertilizers takes a very important part within the plants cultivating technologies, as it directly influences the soil quality and conditions of plants growing. Increased and sustainable agricultural productions will be obtained if the fertilization is appropriately and in due time performed.

Quality of operation of applying organic fertilizers is considered as optimum, when the land is uniformly covered and material applied does not remain in aggregates bigger than 4…6 cm [2,6,12].

The spreading uniformity, whether the operation is manual or mechanized, must surpass 75% [3,12].

In terms of the influence of humidity of spread material on spreading uniformity on soil, from previous researches [4,5,8,10,11], it has found that, if the material has an average humidity it can be easily broken and minced and thus, allows to obtain a high uniformity.

When spread material, especially manure has a bigger humidity, when it is without litter or litter is not uniformly mixed with dejections, the fertilizer spreading is made in big pieces, determining concentrations on certain surface parts [1, 2]. When the material humidity is higher, it sticks to machine working parts, damaging the operation quality [1,7,12].

For a mechanized applying of solid organic fertilizers–manure, stocked on storing or composting platforms, specialized machines, namely technological trailers equipped with horizontal feeding conveyor on the body's floor and dislocation –mincing and distribution parts, are used. Certain machines are also endowed with uniformization parts, for example rotors with fingers [2]. The spreading parts can be rotors with helical spire with indented edges or rotors with fingers that can be arranged horizontally or vertically on the machine. When manure is mechanically spread, the material has to be well homogenized during loading, free of impurities and foreign

Rezumat: *Articolul prezintă rezultatele cercetărilor experimentale privind influența caracteristicilor fizice ale îngrășămintelor organice solide asupra calității lucrării de împrăștiere, realizată cu mașini cu aparat de distribuție vertical tip rotor cu spiră. Necesitatea realizării acestor cercetări reiese din faptul că mașinile de împrăștiat trebuie să asigure un anumit grad de mărunțire al materialului pentru ca fertilizarea să fie conform cerințelor agro-tehnice cu respectarea standardelor în vigoare.*

Cuvinte cheie: *îngrășăminte organice, umiditate, grad de mărunțire, împrăștiere*

INTRODUCERE

Fertilizarea solului cu îngrășămintelor organice ocupă un rol foarte important în cadrul tehnologiilor de cultivare a plantelor deoarece influențează în mod direct calitatea solului și condițiile de dezvoltare a plantelor cultivate. Se pot obține producții sporite și o durabilitate a producției agricole dacă operația de fertilizare se efectuează corect și la timp.

Calitatea lucrării de administrare a îngrășămintelor organice se consideră a fi optimă atunci când terenul este acoperit uniform iar materialul administrat nu rămâne în agregate mai mari de 4…6 cm [2,6,12]. Uniformitatea de împrăștiere, indiferent dacă aceasta operație se efectuează manual sau mecanizat, trebuie să depășească 75% [3,12].

În ceea ce privește influenta umidității materialului împrăștiat asupra uniformității distribuției pe suprafață solului, din cercetările anterioare [4,5,8,10,11], s-a constatat că daca materialul are o umiditate moderata acesta poate fi ușor destrămat si mărunțit și prin urmare permite obținerea unei uniformități ridicate. Când materialul împrăștiat, în special gunoiul de grajd, are o umiditate mai mare, mai ales daca este fără așternut sau așternutul nu este uniform amestecat cu dejecțiile, împrăștierea îngrășământului se face in bucăți mari, provocând concentrări pe anumite porțiuni de suprafață[1,2]. Cu cât materialul este mai umed acesta se lipește de organele de lucru ale mașinii, înrăutățind si mai mult calitatea lucrării [1,7,12].

Pentru administrarea mecanizată a îngrășămintelor organice solide - gunoi de grajd, stocate pe platforme de depozitare sau compostare, se folosesc mașini specializate, in genul remorcilor tehnologice ,echipate cu un transportor orizontal de alimentare pe podeaua benei și cu organe de dislocare-mărunțire și distribuție a îngrășămintelor. Unele mașini au prevăzute in plus și organe de uniformizare a materialului, de exemplu rotoare cu degete [2]. Organele de distribuție pot fi de tipul unor rotoare cu spira elicoidala cu muchii dințate sau rotoare cu degete care pot fi dispuse orizontal sau vertical pe mașină. Atunci când aplicarea gunoiului se face mecanizat, materialul trebuie bine omogenizat în timpul încărcării, liber

bodies (stones, clods, metallic waste, wire etc.), and manure layer from the machine hopper must have a constant thickness.

MATERIAL AND METHOD

In order to perform the tests, the machine of spreading solid organic fertilizers MG 5 [3,7] was used (Fig.1) whose spreading apparatus is made of four vertical rotors placed at a 10° angle to the vertical, for allowing an easy driving of body's material according to its natural slope angle.

Each rotor comprises a central shaft on which 3 spires are placed, on which mincing knives are set, and at the lower part centrifugal discs allowing the spreading of material remained in blades or of material not taken by the first rotor spire, are endowed. Spreading apparatus is driven by the PTO and has the transmission ratio 1:1.

de impurități și corpuri străine (pietre, bulgări, deșeuri metalice, sârmă, etc.), iar stratul de gunoi din buncărul mașinii de administrat să fie uniform ca grosime.

MATERIAL ŞI METODĂ

Pentru realizare experimentărilor s-a utilizat mașina de administrat îngrășăminte organice solide MG 5 [3,7] (fig.1) al cărui aparat de împrăștiere este alcătuit din patru rotoare verticale dispuse la un unghi de 10° față de verticală, pentru a permite antrenarea cu ușurință a materialului din benă, conform unghiului de taluz natural al acestuia.

Fiecare rotor este alcătuit dintr-un ax central pe care se află 3 spire pe care sunt dispuse cuțite de mărunțire a materialului, iar la partea inferioară sunt prevăzute discuri centrifugale care să permită împrăștierea materialului rămas în racletele transportorului sau a materialului nepreluat de prima spiră a rotorului. Aparatul de împrăștiere este acționat prin priza de putere şi are raportul de transmitere 1:1.

a)

b)

Fig. 1 – Manure spreader MG 5
a) rear view; b) machine during work

Table 1

Characteristics of machine used in tests

Capacity of body [m³]	Spreading apparatus type	Rotors height [m]	Spire pace [m]	Spire external diameter [m]	No. of mincing knives/rotor [pcs]	Distance between rotors [m]	Transmission Ratio at PTO-rotors
5	with 4 vertical rotors	1.1	0.3	0.345	28	rotor 1-rotor 2: 0.47 rotor 2-rotor 3: 0.47 rotor 3-rotor 4: 0.47	1:1

Uniformity of spreading width greatly depends on type, composition and state of fertilizer to be spread (humidity, straw content, and age). For obtaining evenly fertilized surfaces, the fertilizer must be spread by overlapping the marginal areas (at two successive passages) where quantities are smaller [6, 9]. From the transversal spreading analysis, performed with 41 spreading machines with different spreading apparatus, presented in specialty literature [8] 3 types of profiles were emphasized (Fig.2), namely:

- triangle profile with maximum dosage in centre and a regular decreasing in the two distribution semi-width;
- trapezoidal profile with a central part where the dose is maximum and constant and then rapidly diminishes toward the two sides;
- „M"-shaped profile with a central part sub-dosed and sides overdosed.

It can be noticed that the most tested equipment (19) has had a trapezoidal profile for all the materials spread. But, these shapes are only theoretical, frequently overdosing or sub-dosing appearing.

Uniformitatea de împrăștiere pe lățime depinde într-o mare măsura de tipul, compoziția şi starea îngrășământului împrăștiat (umiditate, conținut de paie, vârstă). Pentru a avea suprafețe uniform fertilizate, îngrășământul trebuie să fie împrăștiat prin suprapunerea zonelor marginale (la doua treceri succesive) unde cantitățile sunt mai mici [6,9]. Din analiza distribuției transversal, efectuate cu 41 de mașini de distribuit cu diferite aparate de distribuție, prezentate în literatura de specialitate [8] s-au evidențiat 3 tipuri de profile (fig.2) și anume:

- profilul triunghiular cu un maxim de dozare la centru şi o descreștere regulată pe cele două semilăţimi de distribuție;
- profilul trapezoidal cu o parte centrală unde doza este constantă și maximă, apoi descrește rapid în cele două laterale;
- profilul în „M" cu o parte centrală subdozată și lateralele supradozate.

Se observă că cele mai multe echipamente testate (19) au realizat profil in formă de trapez pentru toate materialele distribuite. Aceste forme sunt însă teoretice, de cele mai multe ori existând supradozaje sau subdozaje.

	Triangle profile	Trapezoid profile	"M" profile
Vertical rotors spreaders	11 **spreaders**	9 **spreaders**	8 **spreaders**
Centrifugal discs spreaders	0 **spreaders**	10 **spreaders**	3 **spreaders**

Fig. 2 - Transversal distribution profile obtained with different spreaders [8]

Modern spreaders should be able to offer a better and more precise uniformity of organic fertilizers spreading on desired surface. An increased control of operator could enhance the spreading process quality.

In order to analyze the spreading quality, the material physical qualities have to be first determined. The most important are type and oldness of material, volumic mass, components and humidity.

Volumic mass of organic fertilizers is defined as being the material mass in comparison with total volume occupied by material in its natural state. In order to find out the volumic mas, the graded cylinder method was used. In practice, the volumic mass of material to be spread is calculated by weighing the mass of fertilizer loaded into spreader, referring to machine body volume.

Aparatele de distribuție moderne ar trebui să ofere o uniformitate mai bună și mai precisă la împrăștierea îngrășămintelor organice pe suprafața dorită. Creșterea controlul operatorului ar duce la creșterea calității procesului de împrăștiere.

Pentru a putea analiza calitatea lucrării de împrăștiere trebuie determinate mai întâi caracteristicile fizice ale materialului supus împrăștierii. Cele mai importante sunt tipul și vârsta materialului, masa volumică, componența şi umiditatea.

Masa volumică a îngrășămintelor organice este definită ca fiind masa materialului raportată la volumul total pe care acesta îl ocupă acesta în starea sa naturală. Pentru aflarea masei volumice s-a utilizat metoda cilindrului gradat. In practică, masa volumică a materialului care urmează a fi împrăștiat se calculează cântărind masa de îngrășământ încărcat în mașina de împrăștiat, raportata la volumul benei mașinii.

$$\gamma = \frac{m}{V_m} \quad [kg/m3] \tag{1}$$

where
γ is volumic mass, [kg/m^3];
m – manure mass, [kg];
V_m – volume of graded cylinder, [m^3].

Volumic mass is a qualitative index which constructively influences the choice of body volume, but also gives clear indications on material humidity.

Greater the material density is, higher the humidity content will be.

Humidity or liquid content is expressed by mass of liquid lost by material during drying.

It is determined by the relation:

unde
γ este masa volumică, [kg/m^3];
m - masa de gunoi, [kg];
V_m - volumul cilindrului gradat, [m^3].

Masa volumică este un indice calitativ care influențează constructiv alegerea volumului benelor dar ne dă şi indicații clare asupra umidității materialului. Cu cât densitatea materialului este mai mare vom avea şi un conținut crescut de umiditate.

Umiditatea sau *conținutul de lichid* este exprimat de masa de lichid pierdută de material în timpul uscării.

Se determină prin relația:

$$U = \frac{m_i - m_f}{m_i} \cdot 100 \quad [\%] \tag{2}$$

Where:
U is humidity in percentages [%]
m_i – initial mass of sample before drying, [kg];
m_f – final mass of sample obtained after drying, [kg].

Humidity has been determined by method of drying at 105º, where the sample is kept for 2 hours, afterwards maintaining in desiccator for 30 minutes. Operations of drying, cooling and weighing are performed till the difference between two weighings does not surpass 0.004g. In this moment, it is considered to have reached the steady mass and evaporated the whole water from the sample.

Manure shredding degree

Manure shredding degree is the qualitative working index which shows the percentage of manure particles less than 6 cm [10], distributed, comparing to total quantity of spread manure.

Determination of shredding was made by separately weighing the particles smaller than 6 cm, relating their whole weight to the whole weight of sample of manure.

Relation used for breakage finding is:

Unde:
U este umiditatea în procente [%]
m_i - masa inițială a probei înainte de uscare, [kg];
m_f - masa finală a probei obținută după uscare, [kg].

Umiditatea s-a determinat prin metoda uscării la 105º, unde se ține timp de 2 ore, urmată de menținerea in exsicator timp de 30 de minute. Operațiile de uscare, răcire si cântărire se efectuează până când diferența dintre doua cântăriri succesive nu este mai mare de 0,004g. In acest moment se considera ca s-a ajuns la masa constanta și s-a evaporat toata apa din proba.

Gradul de mărunțire a gunoiului de grajd

Mărunțirea gunoiului de grajd este indicele calitativ de lucru care arată procentul distribuit de particule de gunoi cu dimensiuni mai mici de 6 cm [10], față de cantitatea totală de gunoi împrăștiat.

Determinarea mărunțirii s-a efectuat prin cântărirea separată a particulelor cu dimensiuni mai mici de 6 cm, raportând greutatea lor la greutatea totală a probei de gunoi.

Relația folosită pentru determinarea mărunțirii este:

$$m = \frac{g}{G} \cdot 100 \ [\%] \tag{3}$$

where: *m* is the mincing in %;
g – mass of particles smaller than 6 cm in grams;
G – total mass of sample in grams.

For determining the mincing degree, the material *granulometric analysis* after spreading must be performed. If particles are in big aggregates, then fertilization is not suitably achieved, being excedentary in those areas, according to [3, 5, 12].

For a detailed observation of mincing degree, the particles size was determined by means of system of sifters with meshes of 6 cm, 4 cm, 2 cm, 1 cm, 0.5 cm. Material put on sifter is shaken for 90 seconds and the remained material quantity on sifter is weighed, the ratio between the total quantity and that remained on sifter being calculated.

RESULTS

Experiments were performed with two types of fertilizers, namely: fermented manure old of 3 years and compost, achieved by intensive aeration method during 7 months, the latest comprising manure, chopped branches, wheat straw and leaves.

în care: *m* este mărunţirea în %;
g - masa particulelor cu dimensiuni sub 6 cm în grame;
G – masa totală a probei în grame.

Pentru a putea determina gradul de mărunțire trebuie realizată *analiza granulometrică* a materialului după împrăștiere. Dacă particulele se află în agregate mari, fertilizarea nu se realizează corespunzător, ea fiind excedentară în acele zone, conform [3, 5,12].

Pentru observa mai în detaliu gradul de mărunțire s-a determinat dimensiunile particulelor cu ajutorul sistemul de site cu ochiuri de 6 cm, 4 cm, 2 cm, 1 cm, 0,5 cm. Materialul așezat pe sită se cerne timp de 90 de secunde și se cântărește cantitatea de material rămasă pe sită, făcându-se apoi raportul între cantitatea totală şi cantitatea rămasă pe sită.

REZULTATE

Experimentările au fost efectuate cu doua tipuri de îngrășăminte și anume: gunoi de grajd bine fermentat (mraniță) vechi de 3 ani și compost, realizat prin procedeul de aerare intensivă în decurs de 7 luni, care are în componența gunoi de grajd, tocătura de crengi, paie de grâu și frunze.

In order to find out the humidity and volumic mass, 5 samples were taken from manure and compost platforms.

Results obtained are shown in tables 2 and 3.

Pentru determinarea umidității și masei volumice s-au prelevat 5 probe din platformele de gunoi de grajd și compost.

Rezultatele obţinute sunt prezentate in tabelele 2 şi 3.

Table 2

Values of humidity

Den. No	Material	Umiditatea [%]					Average [%]
		Sample I	Sample II	Sample III	Sample IV	Sample V	
1	Fermented manure	55.51	54.81	56.79	59.54	53.78	56.08
2	Compost	75.34	70.33	74.15	61.49	80.35	72.33

Fig. 2- Aspects during measurements
a) determination of mass, b) utilization of drying chamber

Table 3

Values of bulk density

Den. No	Material	Bulk density [kg/m^3]					Average [kg/m^3]
		Sample I	Sample II	Sample III	Sample IV	Sample V	
1	Fermented manure	397.45	411.78	358.68	455.32	400.75	404.79
2	Compost	524.60	552.87	640.44	510.62	565.76	558.85

From the analysis of tests results, the following were noticed:

- for fermented manure, the average humidity was of approx. 56.08, and the volumic mass of 404.79 kg/m^3;
- for compost, the average humidity was of approx. 72.33% and volumic mass of 558.85 kg/m^3;

Tests were performed on plane land (stubble), wind being in average of 1.3 m/s, value accepted by STAS 12836:1990, value which does not negatively affect the distribution curve. For achieving the spreading were used 3 rotative speeds at a 65 HP tractor' PTO, namely 365, 445 and 530 rpm and material real spreading width and mincing degree were monitored. Forward speed of tractor-machine aggregate was maintained constant at 3.26 [km/h] and scraper conveyor speed was of 0.0416 [m/s]. When spreading the two types of materials, the following results were obtained:

Din analiza rezultatelor obţinute în urma experimentărilor s-a constatat următoarele:

- pentru gunoiului de grajd fermentat, umiditatea medie a fost de cca. 56,08% şi masa volumică 404,79 kg/m^3;
- pentru compost umiditatea medie a fost de cca. 72,33% şi masa volumică 558,85 kg/m^3;

Încercările s-au efectuat pe teren şes (mirişte), vântul având o valoare medie de 1,3 m/s, valoare acceptată de STAS 12836:1990, valoare care nu afectează negativ curba distribuției. Pentru realizarea distribuției s-au utilizat 3 turații la priza de putere a unui tractor de 65 CP și anume 365, 445 şi 530 rpm şi s-a urmărit determinarea lățimii efective de împrăștiere, uniformității de împrăștiere și gradul de mărunțire al materialului. Viteza de deplasare a agregatului tractor-mașină a fost menținută constantă la valoarea 3,26 [km/h] şi viteza transportorului cu raclete a fost 0,0416 [m/s]. La împrăștierea celor două tipuri de materiale s-au obținut următoarele rezultate:

Table 4

Values of spread width and shredding degree

Material type	Rotative speed of spreading apparatus [rpm]	Maximum distribution width [m]	Total mass of sample [kg]	Mass of particles sized of< 6cm [kg]	Shredding degree [%]
Fermented manure	365	8.5	14.08	10.78	76.56
	445	10	15.95	12.52	78.49
	530	13	20.05	17.56	87.58
Compost	365	9	17.79	16.85	94.71
	445	11.5	19.23	18.12	94.22
	530	14	24.11	24.11	100

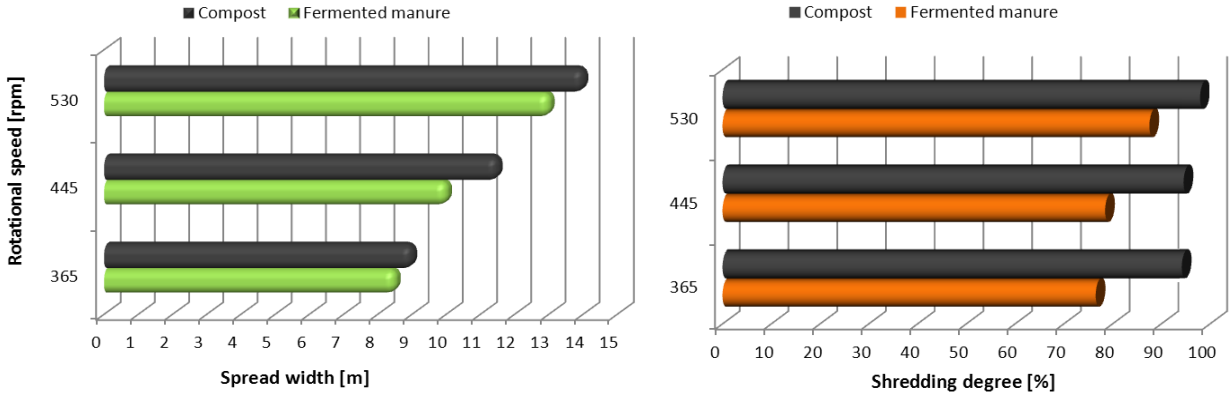


Fig.3 - Graphic representation of spread width and shredding degree

From data obtained, it has concluded that spread width is directly influenced by rotative speed of spreading apparatus, increasing along with it.

As for the shredding degree, the compost values were better than fermented manure ones, although these two product categories are somehow similar. For fermented manure, the spreading degree was about 80.87% and for compost 94.77%, value largely superior to the first one. This is explained first by the fact that obtaining compost has been achieved by a controlled intense process of forced aeration, while the manure has been obtained by passive composting in open heap. The latest had many pieces of material of small humidity of approx. 55% (dried crusts), coming from superficial layer of heap which was not appropriately minced.

In order to find out the granulometric composition from each material fraction, different size sifters were used (6 cm, 4 cm, 2 cm, 1 cm, 0.5 cm).

For measurements, the sample was harvested on a surface of 1 m^2 situated in the middle of spreading width, obtained at a spreading apparatus rotative speed of 530 rpm.

Din datele obținute reiese că lățimea de distribuție este influențată direct de turația aparatului de distribuție aceasta crescând odată cu creșterea turației.

În ceea ce privește gradul de mărunțire se constată că la compost am obținut valori mai bune decât la gunoiul fermentat, deși aceste două categorii de produs sunt oarecum similare. Pentru gunoiul de grajd fermentat s-a obținut un grad de mărunțire în jurul valorii de 80,87% iar la compost 94,77%, valoare mult superioară primei. Acest lucru se datorează în primul rând faptului că obținerea compostului s-a realizat printr-un proces controlat, intens si forțat de fermentare cu aerare forțată, pe când gunoiul fermentat a fost obținut prin compostare pasivă în grămadă deschisă. Acesta din urmă a prezentat multe bucăți de material cu umiditate mică de cca. 55% (cruste uscate), provenite din stratul superficial al grămezii care nu au fost mărunțite corespunzător.

Pentru a determina compoziția granulometrică din fiecare fracție de material s-au utilizat site de diverse dimensiuni (6 cm, 4 cm, 2 cm, 1 cm, 0,5 cm).

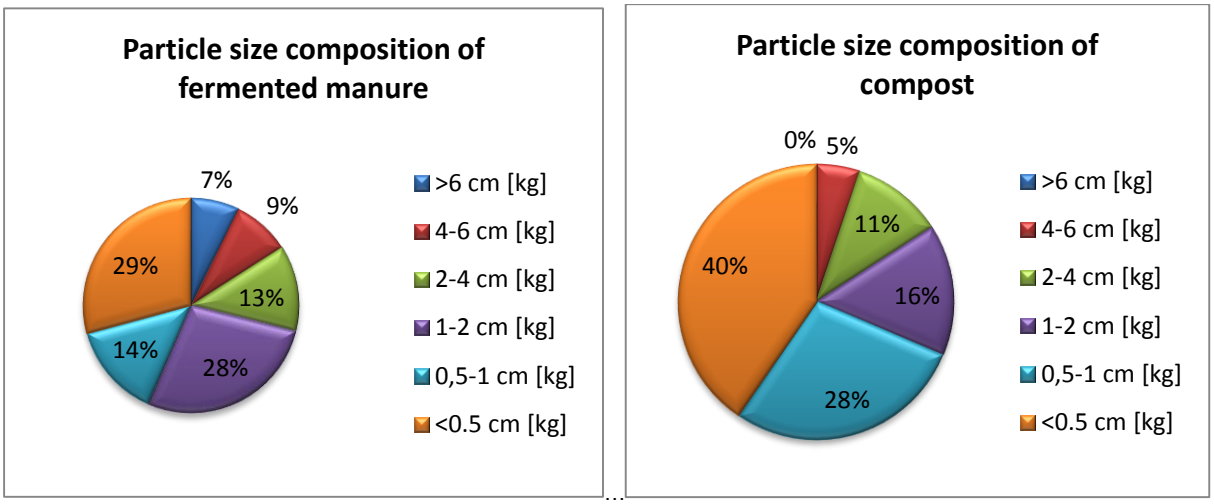
Pentru măsurători s-a recoltat proba de pe suprafața de 1 m^2 aflată la mijlocul lățimii de împrăștiere, obținută la turația aparatului de distribuție de 530 rpm.

Fig.4 – Obtaining the fractions by separation on sifters

Table 5

Particle size distribution of tested materials

Material	Rotational speed [rpm]	Total sample mass [kg]	Particle size distribution of each material fraction [kg]					
			>6 cm	4-6 cm	2-4 cm	1-2 cm	0,5-1 cm	<0.5 cm
Fermented manure	530	3.45	0.250	0.300	0.446	0.954	0.492	1.008
Compost	530	4.82	0	0.245	0.520	0.745	1.360	1.950



a) b)

Fig. 5 - Graphic representation of particle size distribution
a) fermented manure b) compost

In figure 5 is shown that fractions obtained after material spreading have closed values, the biggest quantity being sized under 0.5 cm at both types of material.

CONCLUSIONS

From analysis of tests results, the following were found out:

- compost had a bigger humidity than fermented manure (72.33% compared to 56.08%);
- manure crust which was drier than the rest of material did not minced uniformly, pieces of bigger size than recommended standard dimension remaining;
- shredding degree depends both on type and construction of spreading apparatus and material physical properties (humidity);
- compost mincing degree was of approx.95% while fermented manure was of about 80%, both materials having a good behaviour from this point of view, as values of over 75 % were obtained, according to norms in force.

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Din fig.5 reiese că fracțiile obținute după împrăștierea materialului au valori apropiate remarcându-se că cea mai mare cantitate a avut dimensiuni sub 0,5 cm la ambele tipuri de material.

CONCLUZII

Din analiza rezultatelor obținute în urma experimentărilor s-au constatat următoarele:

- compostul a avut o umiditate mai mare decât gunoiul de grajd fermentat (72,33% față de 56,08%);
- crusta gunoiului de grajd, mai uscată decât restul materialului, nu s-a mărunțit uniform, rămânând bucăți cu dimensiuni mai mari decât recomandările standardelor;
- gradul de mărunțire depinde atât de tipul şi construcția aparatului de distribuție cât și de proprietățile fizice ale materialului testat;(umiditate);
- gradul de mărunțire al compostul a avut valori de cca.95% în timp ce gunoiul fermentat a avut valori de cca 80%, per ansamblu, ambele materiale s-au comportat bine din acest punct de vedere, deoarece s-au obținut valori de peste 75 % așa cum impun normele in vigoare.

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SYSTEM DESIGN AND IMPLEMENTATION OF A NOVEL ROBOT FOR APPLE HARVEST / 一种新型苹果采摘机器人系统设计与实现

Lect. Ph.D Haifeng Luo[1)] , Lect. Ph.D Guowu Wei[2)]
[1)]The Technology School of Beijing Forest University, Beijing / China; [2)] University of Salford, Manchester/ United Kingdom
Tel:+8601062338144; Email: luohaifeng@bjfu.edu.cn

Abstract: *The mechanical design of a novel robot system for apple harvest in orchards is introduced in this paper. A description of the working environment is first provided. The robot system is operated in a master–slave manner, which is widely used in surgical robots. The robot makes use of human judgment and the precise positioning, stable, and tireless manipulability of the slave robot to mechanize apple harvest. The slave robot is constructed with an under-actuated end effector and a modified Selective Compliance Assembly Robot Arm (SCARA) manipulator. Two passive joints are set at the end effector to adjust its capture gesture according to the branch of the target apple. An additional joint is set at the SCARA arm to point the end effector at the tree trunk during harvest period. The dexterity of the manipulator is analyzed with the geometrical method, and a preferred initial harvest position is obtained. A joystick is employed as the master device for the operator to generate the control command, which is utilized to control the motion of the slave arm and end effector. A PC-based control system is established to integrate the pieces of equipment. Initial test results validate the design concept of this apple harvest robot system.*

Keywords: *Master-slave; Under-actuated; Modified SCARA; Harvest; PC*

摘要：*本文介绍了一个用于果园中苹果采摘的新型机器人系统的机械设计。文中首先介绍了该机器人系统工作的果园环境。这个机器人系统采用的是在外科机器人中广泛采用的主-从控制模式。这个机器人综合利用人工判断与从操作机器人精确定位、稳定和不知疲倦的工作能力，以实现苹果采摘的机械化。从操作机器人由欠驱动末端工具和改进的 SCARA 机械臂构成。末端工具设置有两个被动式关节来调整其相对于目标苹果所在枝条的姿态。本文在 SCARA 构型机械臂末端增设了一个转动关节，使末端工具在采摘过程中可始终指向树干方向。本文采用几何方法分析了机械臂灵活度并得到了其优选采摘初始位置。工作人员操作控制手柄来产生控制命令用来控制从操作机械臂和末端工具的动作。控制系统采用 PC 工控机为平台集成了机器人系统的其他硬件。初步的测试结果验证了该苹果采摘机器人系统的设计概念。*

关键词：*主-从；欠驱动；改进型 SCARA；采摘；工控机*

INTRODUCTION

In China, large amounts of apples and pears are produced in orchards. These fruits play an important role in the fruit economy. Total apple production reached 35 million tons in 2014. An unavoidable social course in China at present is that a decreasing number of laborers stay in the countryside. This phenomenon affects agriculture and the fruit industry. Labor in orchards is in serious demand, especially during harvest season. Hence, mechanization of fruit harvest is required.

With the development of machine vision, robots, and artificial intelligence, many important achievements have been obtained in the automation of fruit cultivation and harvest. Schertz first proposed the concept of harvest robot in 1968 [11]. The success rate of this robot when used in harvesting was approximately 70%. Kondo developed a tomato harvest robot in 1993 [8]. The robot comprised a manipulator, an end effector, a vehicle unit, and a vision and control system. Its success rate was approximately 70%. Zhou presented a 7-DOF robot for cucumber harvest in greenhouses in 1998 [16]. A Charge-Coupled Device (CCD) was embedded inside the end effector for quick and precise positioning. The harvest speed was approximately 10 s for each target. Edan presented a robot system for melon harvesting in 2000 [2]. The robot body was set on a mobile platform, and a black and white image was utilized to locate the target fruit; the success rate was about 85%. Van introduced an

引言

在中国，果园中每年生产大量的苹果和梨，这两种水果在水果经济中占据重要的地位。水果的年产量，以苹果为例在 2014 年达到了 3500 万吨。在中国社会化进程中一个不可逆的现象是农村劳动力变得越来越少，这会明显影响农业和水果业。果园中的人工劳动力会变得越来越紧缺，特别是在果实收获季节。这是水果收获机械化在近些年变得越来越迫切的一个非常重要的原因。

得益于机器视觉、机器人和人工智能的发展，在水果培育和采摘自动化方面近年来取得了许多重要的成就。舍尔茨于 1968 年首次提出了收获采摘机器人的概念[11]，他们研发的采摘机器人的收获成功率大概在 70%。近藤春雄等在 1993 年研制了番茄收获机器人[8]，该机器人包括机械臂，末端工具，车辆单元，图像和控制系统。其采摘成功率约为 70%。周在 1998 年推出了用于温室内的 7 自由度黄瓜采摘机器人[16]，机器人末端工具里面嵌入了用于快速和准确定位的 CCD 摄像头。每个目标果实的收获速度大概是 10 秒钟。埃德娜于 2000 年开发了用于收获甜瓜的机器人[2]，这个机器人安装在移动平台上，该机器人采用黑白图像来定位目标果实，采摘的成功率大概是 85%。范于 2002 年开发了在温室里自动采摘收获黄瓜的机器人[14]，

autonomous robot for cucumber harvest in greenhouses in 2002 [14]. The robot had 7 DOF, and the end effector was equipped with a hot cut unit for antivirus. In 1994, Setiawan designed an apple gripper that is highly capable of picking up an apple without scratching its skin [12]. Foglia introduced a cost-effective robotic arm for the harvest of radicchio; the robotic arm employed visual localization of the plants in the field [3]. The harvester was composed of a double four-bar linkage manipulator and a gripper, which fulfilled the requirement for a plant cut approximately 10 mm underground. Han proposed a fruit and vegetable picking robot in 2007 [6]. The robot was jointed with 4 DOF and fulfilled the requirements for eggplant picking in greenhouses. Baur developed a redundant modular multipurpose agriculture robot for the harvest of sweet pepper, apple, and so on [1].

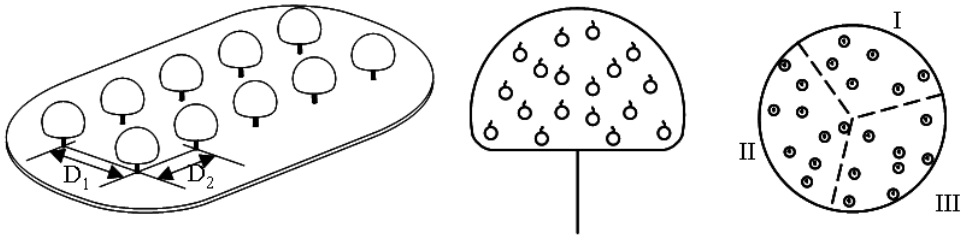
The uncertainty and non-structural environment in orchards, the random and complicated distribution of apples in a tree, illumination variation, and other factors significantly affect the efficiency of the vision system, amount of time consumed, and success rate of robot harvest. The amount of time required for a robot to harvest a single fruit varies from 7 s to 55 s [10, 13], and the success rate is approximately 43% to 95% [7, 15].

Robots for fruit harvest have been investigated for decades. Most of the studies mentioned above are based on the vision-navigated autonomous robot method. To date, no commercial products for orchards are available. The concept of master–slave robot for the mechanization of apple harvest was presented in 2013 [5]; this work is developed in the present study. The master–slave robot was first employed in a radioactive station in the 1950s in the USA [4]. It was widely used in surgery robots by the end of the 1990s [9]. The similarities of surgery and fruit harvest are the complexity of the environment and the uncertainty of target manipulation. The task for fruit harvest is less difficult compared with that in surgery; this fact may reduce the cost and difficulty involved in introducing the master–slave robot to fruit harvest.

这个机器人有 7 自由度机械臂，该机器人末端执行器上设置有高温剪切单元来消除病菌对果实切口的影响。赛蒂亚万设计了低成本的苹果采摘工具[12]，这个采摘工具可以高效率的采摘苹果，同时不会刮伤目标果实的果皮。福利亚开发了用于采摘菊苣的高效费比的机器人机械臂[3]，这个机器人采用机器视觉的方法来定位田野里的目标果实。这个机器人由双四连杆机构机械臂和特殊设计的采摘手爪构成，这个机械臂可满足地下 10㎜ 左右深度的植物剪断要求。韩在 2007 年推出了蔬菜和水果采摘机器人[6]，这个机器人为 4 自由度转动关节构型，可满足在温室内的茄子采摘要求。鲍尔开发了冗余式模块化多功能农业机器人[1]，可用来采摘甜椒，苹果等果实。

由于不确定性因素以及果园非结构化环境特点，以及果树上苹果分布的随机和复杂性，加之环境光线亮度变化以及其他因素影响，采摘机器人图像系统的效率会受到干扰，并进一步影响图像系统所需的处理时间以及采摘成功率。机器人采摘单个果实所需的时间大概是 7 到 55 秒[10, 13]，采摘成功率是 43%到 95%[7, 15]。

采摘机器人的研究已经发展了几十年的时间，前述提到的大部分研究工作都是基于图像导航的自动化机器人，然而直到目前还没有出现可实际用于果园的商用化机器人产品。本文作者于 2013 年提出一种主-从式遥操作控制的苹果采摘机器人概念[5]，本文所述内容在此基础上深化得到。主-从式遥操作机器人技术于 1950 年代在美国核电站中得到首次应用[4]，然而最终将其大范围商业化推广却是在 1990 年代的外科医学机器人领域[9]。外科医学机器人和采摘机器人的相同点是它们作业环境的复杂性和操作目标不确定性。同时果实采摘难度不及外科手术操作，因此可降低机器人成本，也可降低将主-从遥操作技术引入果实采摘的难度。



(a) Apple tree in orchard (b) Apple distribution (c) Top view of tree

Fig.1 - Orchard and apple distribution

MATERIALS AND METHODS

Working environment of a harvest robot

With several exceptions excluded, apple trees in China are typically grown in orchards with a similar layout. Apple trees are planted in lines at a distance D1 of about 4 m to 4.6 m; the trees are maintained within the same line at a distance D2 of about 3.3 m to 3.8 m, as shown in Figure 1(a). The space around the trees is for laborers to cultivate the apple trees and harvest their fruits; it also allows a vehicle to cross the orchard. Sufficient space between trees also benefits photosynthesis for better production. An ordinary mature apple fruit is 80 mm to 100 mm in

材料和方法

采摘机器人工作环境

在中国除了一些特殊的情况外，果园里的苹果树都是以类似的布置方式种植。苹果树种植成行列形式，每列之间的行距 D_1 为 4 到 4.6 米，同列中两棵树之间的间距 D_2 为 3.3 到 3.8 米，如图 1（a）所示。果园工人利用树周围的空间来培育果树以及采摘果实，同时车辆可以在果树之间的空隙穿行过往。果树之间足够宽松的空间还可以使果树的光合作用更高效以提高果实产量。正常成熟苹果的直径约为 80 至 100㎜，重量约为 180 至 250g。苹果树的果实几乎分

diameter, with a weight of 0.18 kg to 0.25 kg. Fruits are distributed on almost all branches of an apple tree in different height layers, as shown in Figure 1(b). Most of the branches radially extend from the center of the tree trunk to the outer edge direction, providing an apple tree a nearly spheroid shape. The body of an apple tree is likely to point toward the ground direction because of gravity. When the apple fruits are mature, laborers pick them from around a tree along sector areas I, II, and III, as shown in top view in Figure 1(c). The preferred harvest sequence is from the bottom of a tree to its top and from the outside circle to the center tree trunk; in this manner, laborers encounter the least obstacle from radially structured branches and avoid unnecessary damage to other apples.

Mechanical design and analysis of the slave robot

1). Manipulator of the harvest robot

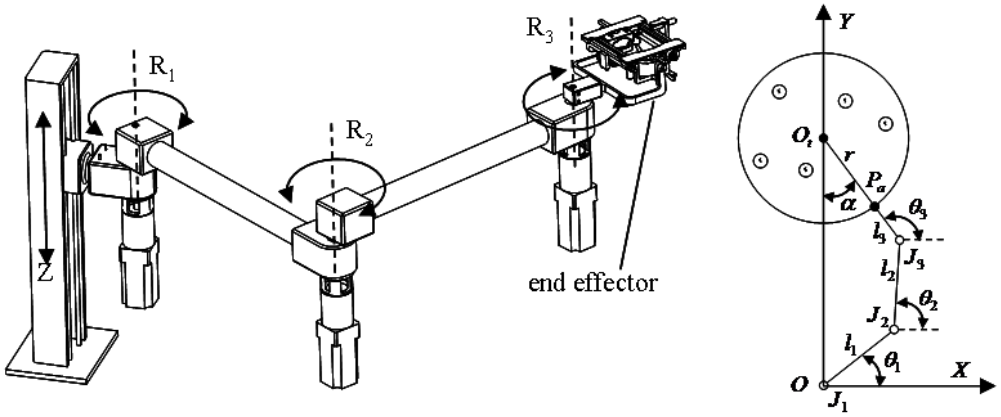
A master–slave robot for apple harvest is proposed. The slave robot is meant to be set on a common vehicle in an orchard, which is not discussed in this paper. The slave robot for apple harvest is composed of a modified SCARA manipulator and an under-actuated end effector, as shown in Fig. 2(a). The manipulator of the robot is from an ordinary SCARA robot with a third rotation joint R3 added to its distal. The end effector is connected to joint R3. The manipulator has a vertical translational joint Z set inside the base column. Joint Z is driven by a screw mechanism (KA140A-C5) and lifts the robot arm up and down. Joints R1, R2, and R3 are driven by servo motors (YZ-ACSD60) to move the end effector on a plane.

布于果树树身周围不同高度层的所有部位枝条，如图 1（b）所示。果树的多数枝条呈放射状从树干伸向外侧边缘方向，这样果树整体呈现为一个近似球形的轮廓。苹果树的果实由于重力的作用，大部分朝向地面的方向生长。当苹果成熟以后，从果树的正上方俯视果树，如图 1（c）所示，果园的工人可以沿着果树周围分别在区域 I，II，III 来采摘苹果。采摘时从果树的底部向果树的树尖方向采摘，从树的边缘部位向树干方向是比较好的顺序。这样采摘时工人不会遇到放射状分布枝条的太多阻碍，同时可以避免对其他需采摘果实的不必要伤害。

从操作机器人机构设计及分析

1）. 采摘机器人机械臂

本文提出主-从式苹果采摘机器人，从操作机器人装置在果园车辆上，关于车辆本文未做描述。如图 2 所示，该苹果采摘从操作机器人由改进型 SCARA 机械臂和欠驱动末端执行器构成。该机器人机械臂由一般 SCARA 机器人改进而来，如图 2（a）所示，通过在 SCARA 机械臂末端增加第三个转动关节 R_3 实现。末端工具安装在关节 R_3 上。该机械臂在基座立柱内部设置了竖直运动的移动关节 Z，关节 Z 由丝杠机构驱动(KA140A-C5)，带动机器人机械臂上下运动。关节 R_1，R_2 和 R_3 由伺服电机(YZ-ACSD60)驱动，使末端执行器在平面内运动。



(a) Modified SCARA manipulator (b) Pointing at tree trunk

Fig.2 - Slave manipulator for apple harvest

To reduce the obstacle from branches and damage to other mature apples in sectors I, II, and III of the apple tree, joint R3 must align the end effector to the center of the tree trunk all the time during harvest, as shown in Figure 2(b). The origin of coordinate O is set on point J_1 of joint R1, and the positions of joints R2 and R3 are marked as J_2 and J_3. The coordination of the tree trunk (O_t) is $(0,L)$, and the location of the target apple is labeled with P_a by radial r and angle α of the branch, as shown in Figure 2(b). Thus, lines J_3P_a and P_aO_t are expected to be collinear all the time.

With joint angle variations $\theta_1,\theta_2,\theta_3$ and arm lengths l_1,l_2,l_3 of the manipulator, we have：

为了减少果树枝条对于机械臂的阻碍，同时为了减少对于其他成熟果实的损伤，在果树周围的区域 I，II 和 III 里，如图 2（b）所示，机械臂的关节 R_3 应该让欠驱动末端工具在采摘工作的全过程中始终指向果树的树干方向。平面坐标系 O-XY 的原点 O 设置在关节 R_1 的 J_1 点，关节 R_2 和 R_3 的位置标记为 J_2 和 J_3。采摘对象果树的树干坐标 O_t 标记为 $(0,L)$，采摘对象苹果的位置点标记为 P_a，如图 2（b）所示，P_a 可以由所在枝条到树干的距离 r 和角度 α 确定，这样线段 J_3P_a 和 P_aO_t 应该一直保持共线。

根据关节变量 θ_1、θ_2和θ_3，以及机械臂的各段长度值 l_1、l_2和l_3，可得到：

$$\begin{cases} l_1\cos\theta_1 + l_2\cos\theta_1 + l_3\cos\theta_3 = r\sin\alpha \\ l_1\sin\theta_1 + l_2\sin\theta_1 + l_3\sin\theta_3 = L - r\cos\alpha \end{cases} \quad (1)$$

Incorporating $\theta_3 = \pi/2 + \alpha$ into Equation (1) yields

将 $\theta_3 = \pi/2 + \alpha$ 代入公式（1）可得：

$$\theta_1 = 2\arctan\frac{-4[L-(r+l_3)\cos\alpha]l_1}{2[E+2l_1(r+l_3)\sin\alpha]} + \frac{\sqrt{(4Ll_1)^2+16(r+l_3)^2l_1^2-4E^2-32L(r+l_3)l_1^2\cos\alpha}}{2[E+2l_1(r+l_3)\sin\alpha]} \quad (2)$$

where $E=(r+l_3)^2+L^2+2L(r+l_3)\cos\alpha$.
Incorporating Equation (2) into Equation (1) yields

这里 $E=(r+l_3)^2+L^2+2L(r+l_3)\cos\alpha$，将公式（2）代入公式（1）可得：

$$\theta_1 = 2\arccos\frac{(r+l_3)\sin\alpha - l_1\cos\theta_1}{l_2} \quad (3)$$

To ensure that the end effector has sufficient dexterity, k is regarded as an index with

为了保证末端执行器具有足够的灵活度，这里将 k 作为一个指数：

$$k = 1 - \left|\frac{\theta_3 - \theta_2}{\theta_3'}\right| \quad (4)$$

where θ_3' is the angle range of joint R3 and k is distributed to r and α, as shown in Figure 3.

The result shows that dexterity is highly sensitive to angle α of a branch, and the r behaviors have a minimal effect on dexterity. The nearer to the tree trunk, the better dexterity is. The angle around $\alpha = \pi/6$ is a preferred position for the slave manipulator to have the best dexterity.

这里 θ_3' 是关节 R_3 的关节活动范围，k 相对于 r 和 α 的变化情况如图 3 所示。

从结果可以看出该机器人末端执行器的灵活性受枝条角度 α 的影响较大，而 r 对于灵活性的影响较小，同时越靠近树干的采摘位置，机器人末端工具的灵活性越好。在 $\alpha = \pi/6$ 角度附近机器人灵活度最好，可以作为机器人一个优先初始位置。

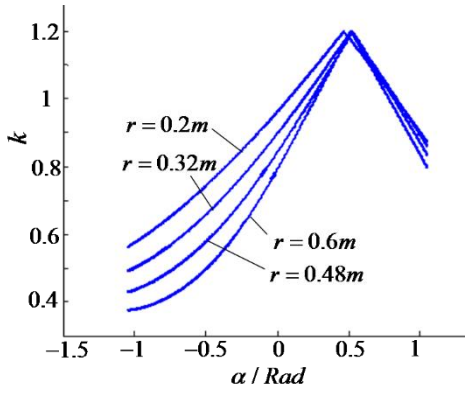


Fig.3 - Variation of k to α and r

2). Under-actuated end effector for the robot

The end effector is installed in the manipulator with two passive joints, R4 and R5, as shown in Figure 4(a). The end effector is basically constructed on a square frame. The side lengths of the frame are b and c. A local coordinate $o-xy$ is set on the frame plane, as shown in Figure 4(b). The ideal condition for harvest is that the branch is horizontal and the apple is vertical. However, in most cases, the branch is gradient oriented [marked as line L_R in Figure 4(b)]. The gradient angle of L_R relative to the frame plane is β, which is measured with a parallel auxiliary line l_B of L_B. The direction of projection

2). 机器人欠驱动末端工具

机器人欠驱动末端工具通过两个被动式关节 R_4 和 R_5 安装到机械臂上，如图 4（a）所示。这个末端工具基本上构建在一个长方形的框架上，该长方形的两个边长分别为 b 和 c。可在这个长方形框架上设置一个局部坐标系采摘果实的最佳情况是枝条水平生长，苹果垂直悬吊。然而，大多数时候枝条是倾斜分布，如图 4（b）中标记为 L_B 的线所示。枝条 L_B 相对于末端工具长方形框架平面倾斜的角度标记为 β，该角度值由 L_B 的平行辅助线 l_B 测得。在长方形框架平面内 L_B 的投影线 l 相对于 $o-y$ 轴的角度标记为

line l of L_B relative to the $o-y$ axis on the frame is marked as δ.

Joints R4 and R5 are expected to adjust the gesture of the end effector relative to the apple and branch, with angles labeled as θ_4 and θ_5. The end effector rises to meet the target apple, with a vertical translation by joint Z marked as z in Figure 4 (b). The frame edge of the end effector thus meets the gradient branch first at point P. The gravity of the branch and apple pushes against the frame and rotates it at joints R4 and R5 until the apple is inside the end effector, where the frame plan meets the bottom of the apple stem with vertical distance a to the branch. Thus, with displacement and moment balanced, the equations are

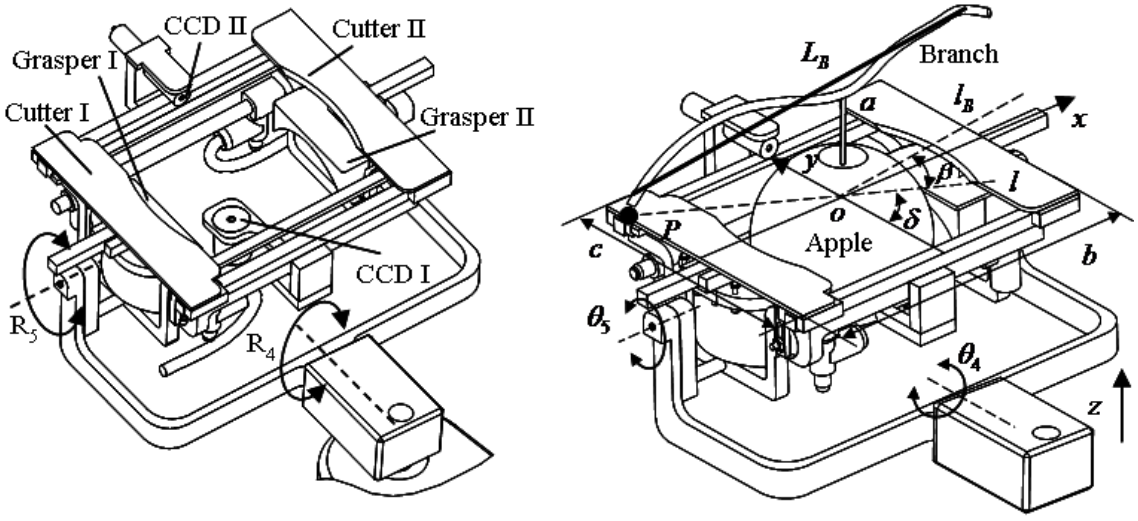
δ。

末端执行器相对采摘果实和枝条的姿态通过关节 R_4 和关节 R_5 调整，标记为 θ_4 和 θ_5。末端执行通过垂直升降关节 Z 上升到目标苹果，其行程标记为图 4（b）中的 z。这个过程中末端执行器的长方形框架的边缘会首先在 P 点接触到倾斜枝条。对于采摘机器人，目标苹果 L_B 和所在枝条的重力会在 P 点推着末端执行器的长方形框架边缘，使长方形框架绕着关节 R_4 和 R_5 旋转直到目标果实进入末端执行器的内部，此时长方形框架平面接触到苹果果梗的根部，果梗从果实到枝条的长度标记为 a。在这个位置，关于末端执行器的位移和力矩平衡公式为：

$$\begin{cases} \dfrac{b\sin\beta}{2\sin\delta\cos\beta} - a = \dfrac{b}{2}(\sin\theta_4 + ctg\delta\sin\theta_5\cos\theta_4) \\ \dfrac{Fb}{2\sin\delta} = (\sin\theta_4 \cdot l_4 + \sin\theta_5 \cdot l_5)\cdot mg \end{cases} \tag{5}$$

where m is the mass of the end effector and F is the force from the branch to the frame. l_4 and l_5 are the vertical distances of the end effector mass center to the axis of joints R4 and R5.

此处 m 为末端执行器的重量，F 为枝条作用到框架上的力。l_4 和 l_5 是末端执行器质心到关节 R_4 和 R_5 轴线的距离。



(a) Under-actuated end effector (b) Gesture adjustment

Fig.4 - End effector of the slave robot

Cutters I and II are set on two separate sliders along the axis direction of joint R5 and driven by two separate micro cylinders. Graspers I and II are installed with springs in cutters I and II separately and move together with them; they are set to an initial position where they are sure to come in contact with and grasp the apple before cutters I and II operate. With a proper capture gesture by the end effector, the cutters and graspers are driven by micro cylinders together. When graspers I and II hold the apple steadily, they stop moving. Cutters I and II keep sliding toward the center and cut the apple stem with their sharp edge when they meet each other. In this manner, the number of drive units for the cutters and graspers can be reduced for the benefit of the mechanism structure and improvement of harvest art.

沿着关节 5 的轴线方向，切刀 I 和切刀 II 分别装在两个滑块上面，这两个滑块由两个单独微型气缸驱动。夹持器 I 和夹持器 II 分别通过弹簧机构安装在切刀 I 和切刀 II 上并且各自跟随它们一起运动，夹持器 I 和夹持器 II 设置的初始位置可以确保它们在切刀 I 和切刀 II 之前先抓持苹果。当末端执行器到达合适采摘姿态后，两组微型气缸同时驱动切刀和夹持器机构向中间运动。当夹持器 I 和夹持器 II 稳定抓住苹果后它们停止移动，切刀 I 和切刀 II 继续向中心方向移动直到它们相互接触，它们各自的锋利刀刃共同挤压切断苹果果梗。利用这种结构，可以减少末端执行器的切刀和夹持器驱动单元数量，不仅可以使机械结构紧凑，同时可以优化采摘工艺。

Control method for the apple harvest robot

1) PC-based control system

The control system of the apple harvest robot is based on a PC platform, as shown in Figure 5. The operator holds the master joystick and sends control signals via the stick and a button on it to the PC and PLC controller (FX2N). PCI 1020H is a PCI-installed motion controller; it is used to receive the motion command and control the motors of the slave manipulator simultaneously. The PLC controller is employed to trigger the solenoid valves of the micro cylinders of the end effector to generate an under-actuated grasping and cutting movement. The views of the target apple are captured by CCD I and II. The video signals of CCD I and II are processed by a vision card (VCER-89) and shown on an LCD screen set in front of the operator for feedback.

苹果采摘机器人的控制方法

1) 基于PC的控制系统

本文所述的苹果采摘机器人控制系统目前基于 PC 平台集成，如图 5 所示。操作者抓持主控制手柄，通过这个手柄向 PC 和 PLC 控制器（FX2N）发送控制信号。PCI1020H 是一个 PCI 总线安装的运动控制器，本文采用它来接收运动命令然后控制从操作机械臂的驱动电机协调运动。PLC 控制器用来触发控制采摘机器人末端执行器微型气缸动作的电磁阀，微型气缸可以推动夹持器和切刀完成欠驱动运动。摄像头 CCD I 和 CCD II 用来采集目标采摘果实的图像场景信息。视频采集卡用来接收 CCD I 和 CCD II 采集的视频信号，然后将其在置于操作者面前的 LCD 显示器中显示出来。

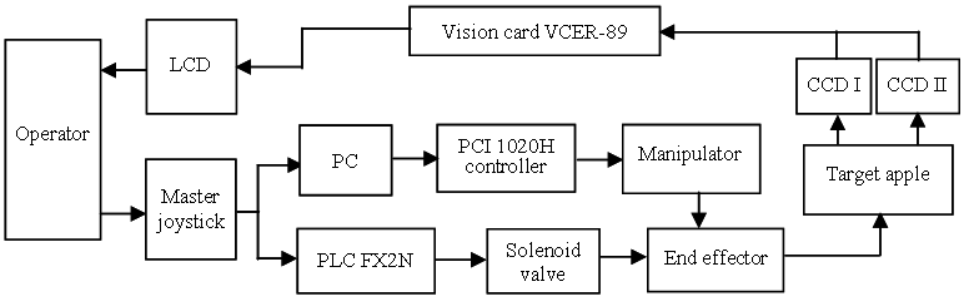


Fig.5 - Architecture of the control system

2) Vision system

CCD I (SUNWAY-500A) is vertically set at the bottom center of the end effector frame similar to the arrangement of “eye in hand,” as shown in Figure 4(a). CCD I is expected to capture views under the target apple and “guide” the apple to the center of the LCD screen, as shown in Figure 6(a). CCD II (CSTE-10) is horizontally set at the frame side of the end effector and is expected to help the operator check whether the apple has fallen into the end effector properly, as shown in Figure 6(b). The scenes captured by CCD I are the first to be shown on the LCD screen. When an apple is positioned well in CCD I, joint Z of the manipulator begins to raise the end effector. The LCD changes to show the scenes captured by CCD II to help the operator decide whether to cut the apple stem.

2）图像系统

摄像头 CCD I（SUNWAY-500A）以“眼在手中”的方式竖直安装于末端执行器方形框架中心点的正下方，如图 4（a）所示。摄像头 CCD I 在目标苹果下方获取目标苹果图像，然后将苹果“导引”到图像中心位置，如图 6（a）所示。摄像头 CCD II（CSTE-10）水平安装于末端执行器方形框架边缘，用来帮助操作者确定苹果是否“下落”到末端执行器的合适位置，如图 6（b）所示。摄像头 CCD I 所采集的视频信息首先显示在 LCD 上。当苹果处于合适位置后，机械臂 Z 关节向上驱动末端执行器，此时 LCD 切换显示摄像头 CCD II 所采集的图像帮助操作者确定是否切断果梗。

(a) Scene of CCD I (b) Scene of CCD II

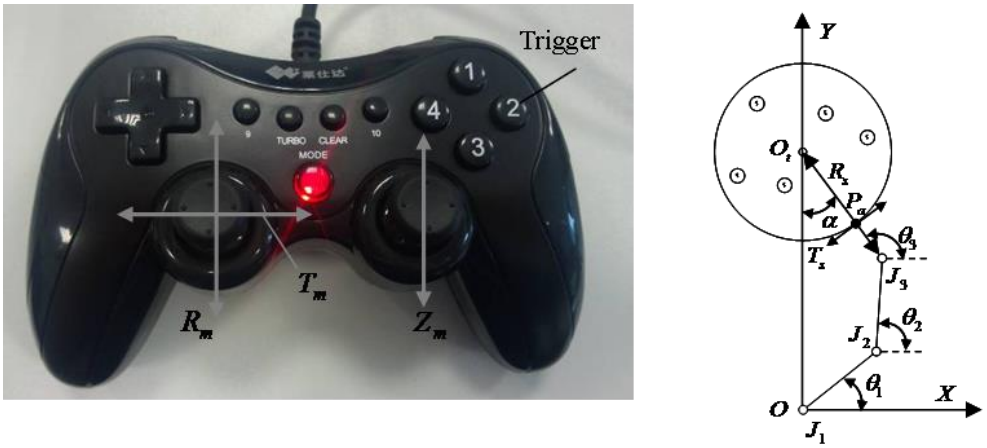
Fig.6 - The scenes on the LCD

3) Master–slave mapping

The apple harvest robot operates in a master–slave style. The master device (Litestar) is a commercial joystick, as shown in Figure 7(a). It is composed of two sticks and several buttons. The left stick can produce two planar absolute values marked as R_m and T_m. The right stick is utilized to generate absolute control value Z_m. R_m used is to control the distance of P_a to O_t, which is marked as R_s, as shown in Figure 7(b). T_m is employed to control the direction of arm J_3P_a, which is labeled as T_s, and keep lines J_3P_a and P_aO_t collinear and rotating together relative to O_t. Z_m of the joystick is used to directly control the translational joint Z_s of the slave manipulator in Figure 2(a). Button 2 of the joystick functions as a switch to set off the grasper and cutter mechanism of the end effector.

3）主-从映射

苹果采摘机器人的工作模式为主-从遥操作形式，主控制设备(Litestar)是商用手柄，如图 7（a）所示。该控制手柄由两个控制操纵杆和若干按钮构成，左操纵杆可输出两个平面绝对值信号，标记为 R_m 和 T_m。右操纵杆可产生绝对控制信号 Z_m。R_m 可控制 P_a 到 O_t 的距离，该距离在图 7（b）中标为 R_s。T_m 用来控制机械臂 J_3P_a 方向，该方向标为 T_s，这个方向应保证线段 J_3P_a 和线段 P_aO_t 处于共线，即保证它们绕着树干中心 O_t 转动。控制手柄信号 Z_m 用来控制图 2（a）中的关节 Z_s。控制手柄的按钮 2 作为触发开关启动末端工具的夹持器和切刀机构的动作。



(a) Master joystick (b) Slave manipulator

Fig.7 - Master-slave mapping

The master–slave control system operates in a continuous circulation mode. In the beginning of each control loop, the output of the master joystick is captured by the PC and analyzed to control joint angles θ_1, θ_2, and θ_3 of the slave manipulator as in the following equation.

主-从控制系统工作的时候处于一种连续循环状态。在每一个工作循环的初始，PC 机获取主控制手柄的输出信号，该输出信号经过处理后用来控制从操作机器人机械臂的关节角度 θ_1、θ_2 和 θ_3，公式为：

$$\begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \Delta\theta_3 \\ \Delta z \end{bmatrix} = J\left[R_s, \alpha\right] \cdot \begin{bmatrix} \Delta R_m \\ \Delta T_m \\ \Delta Z_m \end{bmatrix} \tag{6}$$

where $J\left[R_s, \alpha\right]$ is a mapping function derived from Equations (2) and (3). $\left[\Delta\theta_1, \Delta\theta_2, \Delta\theta_3, \Delta z\right]^T$ are the micro displacements of slave manipulator joints; they are sent to the PCI motion controller to determine and drive the motors of the manipulator within the present control loop.

这里 $J\left[R_s, \alpha\right]$ 是由公式（2）和公式（3）得到的映射函数。$\left[\Delta\theta_1, \Delta\theta_2, \Delta\theta_3, \Delta z\right]^T$ 是从操作机器人机械臂的关节微位移，这些微小位移量传到 PCI 运动控制卡后作为本次控制周期内的目标位置，用来控制驱动机械臂的关节电机。

RESULTS AND DISSCUSSION

Before the harvest experiment in the orchard, a phantom test was conducted in a laboratory to initially evaluate the master–slave robot system. Three aspects of the system, namely, the manipulator route, gesture adjustment, and apple capture ability of the end effector, were considered.

结果分析与讨论

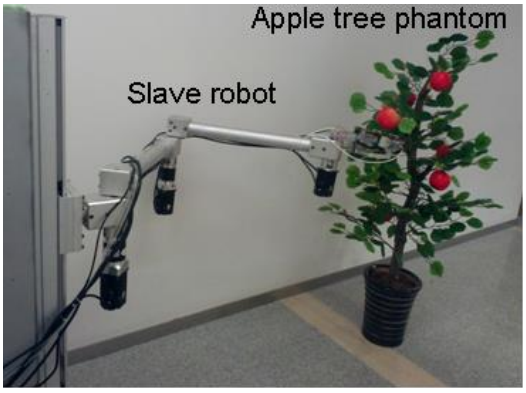
机器人在进行果园测试之前，为了对主-从式采摘机器人进行初步的测试，本文在实验室进行了仿体实验测试。机器人从操作臂的采摘路径，末端执行器的姿态调整和欠驱动末端工具的果实采摘是测试的三个方面。

Arc route of the manipulator

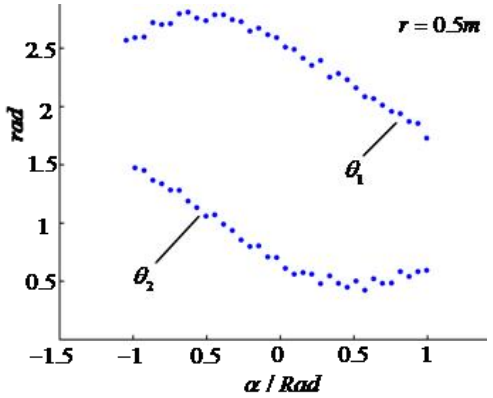
To validate the concept of the modified SCARA manipulator, a circle arc with $r = 0.5m$ was set as the harvest route for the robot. Within the range of $\alpha \in [-\pi/3, \pi/3]$, the manipulator can point the end effector to the tree trunk along the arc route as expected, as shown in Figure 8(a). The joint angles of R1 and R2 during this process are plotted in Figure 8(b).

机械臂弧形轨迹

为了证明本文改进型 SCARA 机械臂的概念，本文设定了一个半径 0.5m 的圆弧段作为采摘机器人机械臂的动作路径。在 $\alpha \in [-\pi/3, \pi/3]$ 区域内，从操作机械臂可按照预期将末端执行器沿着弧形轨道移动，并保证末端工具始终指向树干方向，如图 8（a）所示。在此过程中，关节 R_1 和 R_2 的变化情况如图 8（b）所示。



(a) Phantom test



(b) Joint variation of slave manipulator

Fig.8 - Test of the slave manipulator

Gesture adjustment of the end effector

Joints R4 and R5 are equipped with potentiometers ($5k\Omega$) to measure the variation of joint angles θ_4 and θ_5 as the end effector approaches the target apple. With the branch of angles $\beta = \pi/6$, $\delta = \pi/4$, the plane of the end effector frame is rotated to adapt to the branch gesture.

The variations in θ_4 and θ_5 are indicated in Figure 9. The passive joints for the end effector basically achieved the expectation for gesture adjustment. Owing to a mechanical reason, the effects of the two passive joints are not similar. Joint R4 is more sensitive to rotation by the gradient branch, and joint R5 has more friction and behaves below expectations.

末端工具的姿态调整

关节 R4 和关节 R5 分别安装了电位器（5kΩ）来测量角度 θ_4 和 θ_5 在末端执行器趋近目标苹果过程中的变化情况。本实验目标苹果枝条的角度约为 $\beta = \pi/6$, $\delta = \pi/4$，机器人末端工具的方形框架平面转动以适应该枝条姿态。

图 9 显示了关节角度 θ_4 和 θ_5 的变化情况。从测试结果可看到末端执行器的被动式关节可基本达到调整其姿态的目的。由于机械系统的原因，两个关节的姿态调整效果并不完全相同。关节 R_4 更为敏感容易转动，关节 R_5 由于自身的摩擦较大，因此其姿态调整能力未能达到其应有的预期效果。

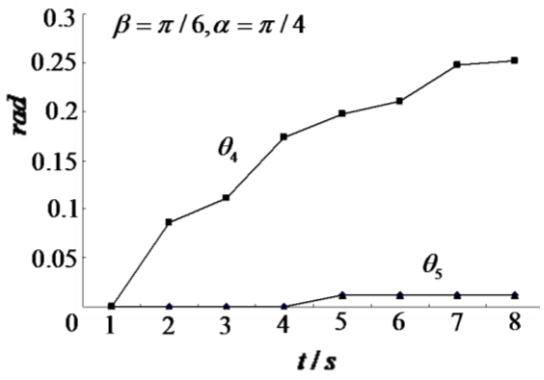


Fig.9 - Angle variation of θ_4 and θ_5

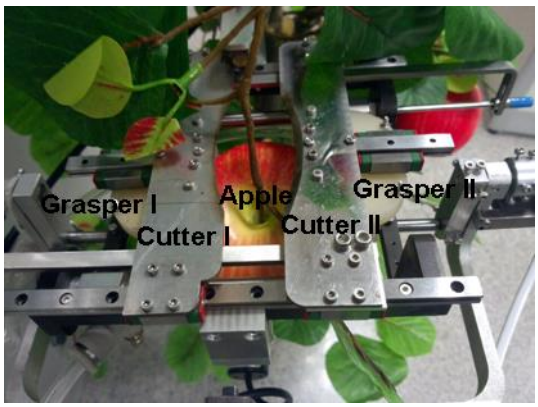


Fig.10 - Grasp and cut the apple phantom

Apple harvest with the end effector

Apple harvest is directly carried out with the end effector. The maximum diameter of the phantom target apple is approximately 80 mm. The motion of the graspers and cutters are driven pneumatically in an under-actuated mode. The cylinders for the end effector work with a

末端工具采摘苹果

苹果的采摘实验由机器人末端工具直接完成。仿体目标苹果的最大直径约为 80mm。末端工具的夹持器和切刀的动作由气缸以欠驱动的方式推动完成。末端工具所用的气缸

pressure of 0.6 MPa, and the maximum travel distance of the cylinder is 60 mm. Given the dimension of the other mechanical parts, the maximum apple diameter that the end effector can deal with is 80 mm, as shown in Figure 10.

CONCLUSIONS

To address the reduction in available labor in orchards, a novel harvest robot system that operates in a master–slave style was comprehensively studied. The robot system integrates human judgment and the precise motion of the slave robot to mechanize apple harvest. After introducing the working environment, the mechanical design for the slave robot was presented. The slave robot is composed of an under-actuated end effector and a modified SCARA manipulator. An additional rotation joint is set to an ordinary SCARA arm to point the end effector at the tree trunk during harvest. The dexterity of the manipulator was studied, and a preferred position was obtained. The passive joints on the end effector adjust its capture gesture according to the branch of the target apple. The control system was established based on a PC platform to integrate the pieces of equipment. The operator obtains video feedback from a CCD embedded inside the end effector. A joystick is employed as the master device to generate the control command and further control the slave robot. Test results show that the new robot system meets the initial design expectation in terms of the modified SCARA manipulator, gesture adjustment of passive joints, and apple harvest with the end effector.

Nevertheless, the control system and end effector need to be improved. For the control system, a dedicated system instead of a PC platform is preferred in the field test and final usage, which will be conducted in the next stage. As for the end effector, the mechanical design needs to be modified for better weight and dimension to be capable of harvesting bigger apples than those harvested at present.

ACKNOWLEDGEMENTS

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正常工作压力为 0.6Mpa，该气缸的最大位移行程为 60mm。由于末端工具其他机械零件的尺寸影响，本文机器人末端工具目前可采摘的最大苹果直径为 80mm，如图 10 所示。

结论与研究展望

为了适应果园中劳动力越来越少的社会发展现状，本文详细研究了一种用于果实采摘的新型主-从控制模式机器人系统。这个机器人集成了人工判断和机器人精确运动能力来实现机械化采摘作业。本文首先分析了采摘的工作环境，之后介绍了从操作机器人的机械结构设计。从操作机器人由欠驱动末端工具和改进的 SCARA 机械臂构成。从操作机械臂在常规 SCARA 结构末端增加了一个转动关节以使末端工具在采摘过程中始终指向树干。本文分析了采摘机器人从操作机械臂灵活性并得到了其优选初始采摘位置。末端工具上设置的被动关节可根据苹果所在枝条方位调整末端工具的姿态。目前该采摘机器人的控制系统建立在 PC 平台上并集成了各种相关设备。操作人员从内置于末端执行器的两个 CCD 摄像头获取机器人采摘果实的实时视频信息。本文采用控制手柄作为主操作设备发送命令控制从操作机器人的动作。初步测试结果显示本文设计的新型采摘机器人系统可达到预期的目标，包括改进的 SCARA 机械臂，末端工具姿态调整及欠驱动末端工具的果实采摘动作。

目前本文机器人在控制系统及末端工具两个方面仍需改进。对于控制系统，在下一阶段进行户外测试及最终应用的时候应使用专用控制系统而不是基于 PC 平台的开放式系统。对于机器人的末端工具的机械结构设计，需在重量和尺寸等方面对其进行优化，使其可采摘比现在更大尺寸的果实。

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THEORETICAL REASONING OF THE COUPLANT EQUIPMENT DRUM POSITION RESPECTIVE TO THE CUT PLANTS
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ОБҐРУНТУВАННЯ ПОЛОЖЕННЯ БАРАБАНУ КОНТАКТНОГО ПРИСТРОЮ ВІДНОСНО ЗРІЗУ СТЕБЛА РОСЛИНИ

Ass. Ph.D. Eng. Bundza O.Z., Prof. Ph.D. Eng. Kravets S. V., Prof. Ph.D. Eng. Nalobina O.O., Assoc.Prof. Ph.D. Eng. Nikitin V.G.
National University of Water Management and Nature Resources Use, Soborna str., 11, Rivne / Ukraine
E-mail: olegbundza@gmail.com

Abstract: *The work deals with the results of theoretical research of the process of interaction of the couplant equipment with the plants. The equations for calculating the cutting height and the drum position respective to the cut plants were developed within the present work.*

Key words: *drum, herbicide application, plant stem, couplant method*

INTRODUCTION

The machines for herbicide application by couplant method are ones of the ecologically advantageous kind of machines for eliminating the undesirable vegetation in the agricultural lands and grazings [3, 8, 10]. Their use allows almost to eliminate the unproductive herbicide loses, which can achieve 40-60% while spraying [4, 9]. The chief matter of couplant method is in herbicide solution application by direct contact of a working tool with the herb top. The herbicide effect can be higher because of the simultaneous performance of two actions: cutting of the plants and applying the herbicide solution. The last is applied to the cut surface by couplant equipment, then it is transferred into the plant root system and causes its death or significant decrease of life activity.

MATERIAL AND METHOD

The analysis of the machines constructions for weeding out, done by the authors, has shown the following drawbacks: significant herbicide loses, working tool deformation while contacts with very rough herb stems, impossibility to use the machines on the surfaces with large inclination.

The construction of the equipment of complex effect for eliminating the undesirable vegetation and simultaneous applying of herbicides was suggested in order to reduce the drawbacks (figure 1) [1].

This design solution is aimed to:
- effectively eliminate the top part of the herb;
- effectively eliminate the root system;
- avoid the transfer of chemicals on the crop plants;
- avoid the herbicide loses while windage and minimize loses for evaporation and dropping.

The equipment for elimination of undesired vegetation by complex method consists of three working tools: cutting mechanism, cut herb collector, couplant mechanism.

Efficiency of the process of elimination of undesired vegetation depends on the conditions of interaction of the working tool with the plant matter [6], geometrical and kinematical characteristics of the equipment, physical and mechanical characteristics of the plant and the position of the equipment in comparison with the plant.

In order to study the influence of the respective positioning of the plants and equipment on the efficiency

Резюме: *У даній роботі викладено результати теоретичних досліджень процесу взаємодії робочого обладнання пристрою для контактного мащення із рослинами. Обґрунтовано вирази для визначення висоти встановлення ріжучого апарату. Обґрунтовано розміщення барабану відносно зрізу рослин.*

Key words: *барабан, внесення гербіцидів, стебло рослини, контактний спосіб*

ПЕРЕДМОВА

Одним із екологічно перспективних видів машин для зведення небажаної рослинності на сільськогосподарських угіддях та пасовищах є машини для нанесення гербіцидів контактним способом [6,9,10]. Їх застосування дозволяє практично уникнути непродуктивних втрат гербіциду, які, наприклад, при обприскуванні, досягають 40-60% [1,7]. Суть контактного способу полягає у нанесенні розчину гербіциду шляхом безпосереднього контакту робочого органу з наземною частиною рослини. Ефект впливу гербіциду на рослини підвищується за рахунок поєднання операцій зрізання рослин і їхнього мащення. Розчин гербіциду подається на поверхню зрізу контактним способом, далі потрапляє у кореневу систему рослини і спричиняє її загибель або значне пригнічення процесів життєдіяльності.

МАТЕРІАЛ І МЕТОДИКА

Аналіз конструкцій машин для зведення бур'янів, виконаний авторами, виявив наступні недоліки: значні втрати гербіциду; деформація робочого органу під час зустрічі зі стеблами рослин значної жорсткості; неможливість використання обладнання на площах із значним ухилом.

З метою усунення недоліків була запропонована конструкція начіпного обладнання комбінованої дії для зведення небажаної високорослої рослинності (рис.1) [4]. Запропоноване конструктивне рішення спрямоване на:

- ефективне знищення наземної частини рослинності;
- ефективне знищення кореневої системи;
- відсутність потрапляння хімікатів на культурні рослини;
- відсутність втрати гербіциду при знесенні вітром та мінімізацію втрат на скапування випаровування.

Обладнання для зведення небажаної рослинності комбінованим способом включає в себе три робочі органи: ріжучий апарат, підбирач зрізаної рослинності та пристрій контактного мащення.

Ефективність процесу зведення небажаної рослинності залежить від умов взаємодії робочого обладнання з рослинним матеріалом [3], геометричних і кінематичних параметрів обладнання; фізико-механічних характеристик рослин, а також взаємного розташування обладнання та рослин.

of the process we will look at the computational model in the drawing 2.

З метою дослідження впливу взаємного розташування рослин і обладнання на ефективність процесу розглянемо розрахункову схему, подану на рис.2.

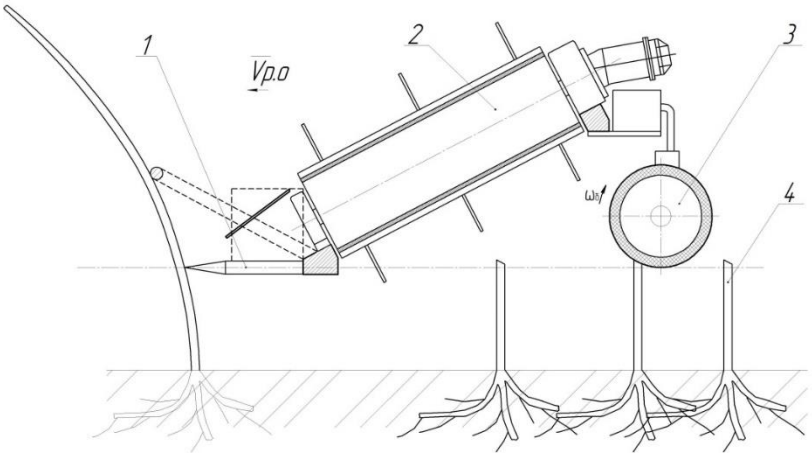

Fig. 1 - Scheme of equipment for elimination of undesired vegetation and weeds:
1 – cutting mechanism, 2 – collector, 3 – couplant apparatus, 4 – herb stem

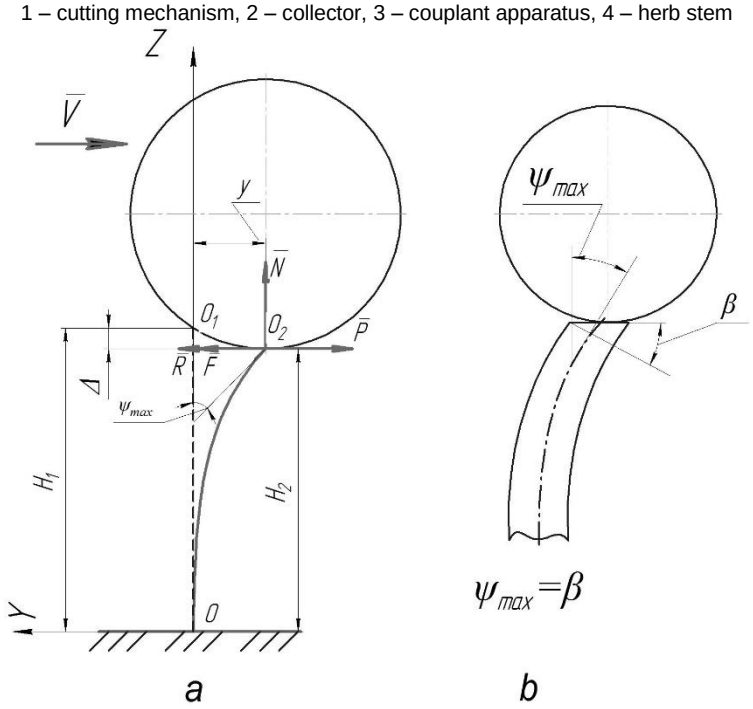

Fig. 2 - Computational model of interaction between the stem and the working tool:
a – power scheme in the contact zone;
b – interaction between the stem and drum on condition that ψmax=β.

We take into consideration that the height of the stem after the cut is H_1, in the moment when the drum touches the stem fluctuates from the original position at the angle ψ.

The authors study the change of the angle ψ of the stem fluctuation from initial vertical position in dependence to the physical and mechanical characteristics of the plant and the influence of its degree on the integral quality index of the couplant process. According to the results of the studies, we take that $\psi_{max}=\beta$ (drawing 2), where β is the angle of the plant cut, i.e further theoretical studies will be done for the most favourable conditions of the process. As we can see from the drawing, the drum should move with the height H_2 above the field surface in order to provide the plant and outer drum surface contact; in these

Припустимо, що після зрізання стебло має висоту H_1 і в момент дотику до нього барабану відхиляється від початкового положення на кут ψ.

Зміна кута ψ відхилення осі стебла від початкового вертикального положення залежно від фізико-механічних властивостей рослин і вплив його величини на інтегральний показник якості процесу контактного мащення досліджувалась авторами. Базуючись на результатах виконаних досліджень, приймаємо, що $\psi_{max}=\beta$ (рис.2), де β кут зрізання рослин, тобто подальші теоретичні дослідження будемо проводити для найбільш сприятливих умов протікання процесу. Зі схеми бачимо, що з метою забезпечення контакту рослини із зовнішньою поверхнею барабану, останній повинен рухатись над поверхнею поля на висоті H_2; причому $H_2 < H_1$. Барабан

circumstances $H_2 < H_1$. The drum moves in linear velocity vector direction *V*. In the moment, when the drum touches the cut stem, it fluctuates under the fluctuating power *P*. The reaction *R* is directed opposite the force *P* and tries to return the stem into initial position. There is friction in the contact zone $F=f \cdot N$, where *f* is friction index of the plant stem on the drum surface; *N* is normal force.

Let's examine the stem of the plant as overhung circular beam, then we will have beam equation [7]:

переміщується у напрямку вектора лінійної швидкості *V*. В момент дотику барабана зі зрізаним стеблом, останнє відхиляється під дією згинаючої сили *P*. Реакція *R* направлена протилежно силі *P* і прагне повернути стебло у початкове положення. У зоні контакту діє сила тертя $F=f \cdot N$, де *f* – коефіцієнт тертя стебла по поверхні барабану; *N* – нормальна сила.

Розглянемо стебло як консольно закріплену балку круглого перерізу, тоді рівняння лінії прогинів стебла запишеться [5]:

$$y = -\frac{P}{EI}\left(\frac{H_2 z^2}{2} - \frac{z^3}{6}\right) \quad (1)$$

where *EI is* roughness of the plant stem,

P is drum movement resistance force,

z is distance from the soil to the section, which is determined deflection,

Considering that $P = N(\cos\psi + f\sin\psi)$ [5], and $N = \frac{2EI}{H_2^2} tg\psi$, we get:

де EI – жорсткість стебла рослини,

P – сила опору переміщенню барабану,

z – відстань від поверхні грунту до перерізу, де визначається прогин.

Враховуючи, що $P = N(\cos\psi + f\sin\psi)$ [2], а $N = \frac{2EI}{H_2^2} tg\psi$, отримаємо:

$$P = \frac{2EI}{H_2^2}\sin\psi(1 + f tg\psi) \quad (2)$$

Having substituted equation (2) into equation (1), we get:

Підставивши вираз (2) у вираз (1), отримаємо:

$$y = -\frac{2\sin\psi(1 + f tg\psi)}{H_2^2}\left(\frac{H_2 z^2}{2} - \frac{z^3}{6}\right) \quad (3)$$

We are going to find stem deflection, which corresponds the maximal angle of rotation ψ_{max}. With this purpose we will substitute *z* for H_2 in the equation (3):

Знайдемо прогин стебла, що відповідає максимальному куту повороту ψ_{max}. Для цього у вираз (3) замість *z* підставимо H_2:

$$y_{z=H_2} = -\frac{2\sin\psi_{max}(1 + f tg\psi_{max})H_2}{3} \quad (4)$$

In order to find out the dependence between H_1 and H_2 when the stem fluctuates for the angle ψ_{max} by the power P_{max} we find the length of the line [2] in the interval $z = 0 \ldots H_2$:

Для визначення залежності між H_1 і H_2 при відхиленні стебла на кут ψ_{max} силою P_{max} визначимо довжину кривої [8] на проміжку $z = 0 \ldots H_2$:

$$H_1 = \int_0^{H_2} \sqrt{1 + y'^2}\, dz \quad (5)$$

where $y' = \frac{dy}{dz} = -\frac{P_{max}}{EI}\left(\frac{2H_2 z}{2} - \frac{3z^2}{6}\right) = -\frac{P_{max}}{EI}\left(H_2 z - \frac{z^2}{2}\right)$ (6)

where P_{max} is the power on the stem fluctuation on the angle ψ_{max} ,

де P_{max} - значення сили *P* при відхиленні стебла на кут ψ_{max} ,

$$P_{max} = \frac{2EI}{H_2^2}\sin\psi_{max}(1 + f tg\psi_{max}) \quad (7)$$

Taking into account (6), (7) the equation (5) looks like this:

З врахуванням (6), (7) вираз (5) набуде вигляду:

$$H_1 = \int_0^{H_2} \sqrt{1 + \frac{4\sin^2\psi_{max}\left(1 + ftg^2\psi_{max}\right)}{H_2^4}\left(H_2 z - \frac{z^2}{2}\right)^2}\, dz \quad (8)$$

Thus Δ, that determines the drum position respectively the plant stem cut, is equal:

Тоді величина Δ, що визначає положення барабану відносно зрізу стебла рослини, буде рівна:

$$\Delta = H_1 - H_2 = \int_0^{H_2} \sqrt{1 + \frac{4\sin^2\psi_{max}\left(1 + ftg^2\psi_{max}\right)}{H_2^4}\left(H_2 z - \frac{z^2}{2}\right)^2}\, dz - H_2 \quad (9)$$

RESULTS AND DISCUSSION

Practically, the maximal degree of the angle ψ_{max} is limited by the plant stem tenacity. The research with the field sow thistle stem has shown ψ_{max} =30º…45º. Having taken ψ_{max}=30^0, H_2=0…0.5 m, f=0.1, and having the integral equation (8) solved by the digital method in the Mathcad v.14, we build the graphs of interdependences $H_1=f(H_2)$, and $\Delta=f(H_2)$ (fig 3).

РЕЗУЛЬТАТИ

На практиці максимальне значення кута ψ_{max} обмежується міцністю стебла рослини. У ході виконаних досліджень для стебла осоту польового, встановлено, що ψ_{max} =30º…45º. Прийнявши ψ_{max}=30^0, H_2=0…0,5 м, f=0.1, і вирішивши інтеграл (8) чисельними методами у середовищі Mathcad v.14 побудуємо графіки залежності $H_1=f(H_2)$, та $\Delta=f(H_2)$ (рис.3).

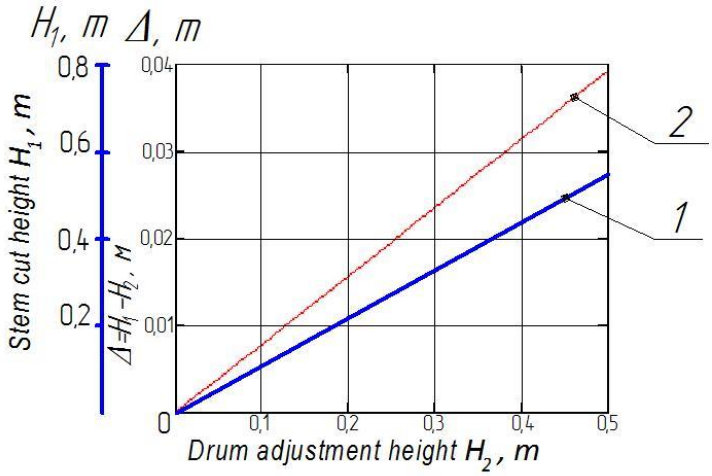

Fig 3 - The graphs of the functions: 1 - $H_1=f(H_2)$; 2 - $\Delta=f(H_2)$.

We will find out the dependence of the deflection y on the rotation angle ψ. With this purpose let us look at the equation that describes the geometrical sense of the derivative:

Визначимо, як залежить прогин y від кута повороту ψ. Для цього розглянемо вираз, що описує геометричний зміст похідної:

$$tg\,\psi = y' \quad (10)$$

From the other side:

З іншої сторони:

$$\frac{dy}{dz} = y' = tg(180^\circ - \psi) = -tg\psi \quad (11)$$

Thus:

Тоді:

$$tg\psi = \frac{P}{EI}\left(H_2 z - \frac{z^2}{2}\right) \quad (12)$$

Having substituted the equation (2) into the equation (12), we get:

Підставивши вираз (2) у вираз (12), отримаємо:

$$\frac{2EI\sin\psi(1+f tg\psi)}{H_2^2 EI}\left(H_2 z-\frac{z^2}{2}\right)=\frac{2\sin\psi(1+f tg\psi)}{H_2^2}\left(H_2 z-\frac{z^2}{2}\right)=tg\psi \quad (13)$$

Having divided the left and the right part of the equation (13) into *tgψ* we get:

Розділивши ліву і праву частини виразу (13) на *tgψ* отримаємо:

$$\frac{2\cos\psi(1+f tg\psi)}{H_2^2}\left(H_2 z-\frac{z^2}{2}\right)=1 \quad (14)$$

After the number of mathematical transformations the equation (14) looks like quadratic equation:

Після ряду математичних перетворень вираз (14) матиме вигляд квадратного рівняння:

$$z^2-2H_2 z+\frac{2{H_2}^2}{\cos\psi+f\sin\psi}=0 \quad (15)$$

Having solved it for *x,* we get the roots:

Розв'язавши його відносно *x,* отримаємо корені:

$$z_1=H_2-\sqrt{{H_2}^2-\frac{2{H_2}^2}{\cos\psi+f\sin\psi}} \quad (16)$$

$$z_2=H_2+\sqrt{{H_2}^2-\frac{2{H_2}^2}{\cos\psi+f\sin\psi}} \quad (17)$$

We substitute the equation (17) into the equation (3) and we get the dependence of the stem fluctuation on the bending angle:

Вираз (17) підставляємо у (3) і отримуємо залежність відхилення (прогину) стебла від кута його відгину:

$$y=-\frac{2tg\psi(\cos\psi+f\sin\psi)}{{H_2}^2}\left(\frac{H_2\left(H_2+\sqrt{{H_2}^2-\frac{2{H_2}^2}{\cos\psi+f\sin\psi}}\right)^2}{2}-\frac{\left(H_2+\sqrt{{H_2}^2-\frac{2{H_2}^2}{\cos\psi+f\sin\psi}}\right)^3}{6}\right) \quad (18)$$

Having taken H_2=0.3m, *f=0.1,* and *ψ =0…30°*, according to the equation we build the graph (fig 4) of the dependence of the stem fluctuation on the angle *ψ:*

Прийнявши H_2=0,3м, *f=0.1,* і *ψ =0…30°*, за отриманим виразом будуємо графік залежності (Рис.4) прогину стебла від кута *ψ*:

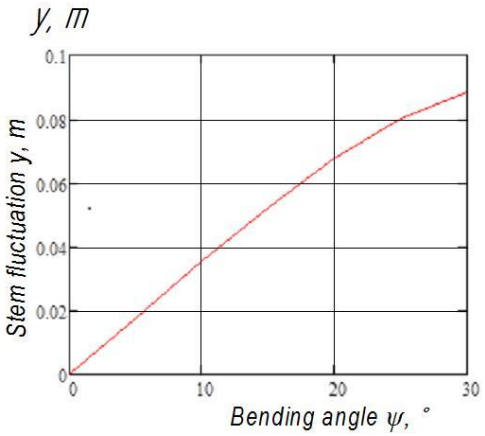

Fig 4 - The dependence on the bending angle

CONCLUSIONS

Theoretical researches done by the authors, together with the above mentioned laboratory and field experiments, allow to conclude:

- the use of the couplant method allows to avoid the nonproductive herbicide losses and to assure the effective abolishment of the top part of the herb and its root system;
- deflection of the stems under the influence of the working body of the couplant mechanism depends on the physical and mechanical characteristics of the plants, the cut angle and the height of the drum adjustment;
- according to the results of the field tests of the equipment, the top part of undesired vegetation is cut 0.25 … 0.35 m above the ground. Taking into account these results and the graph (fig 4) the best possible adjustment of the drum of the contact mechanism is by 0.02 … 0.028 m under the cut level of the herb;
- reasoning of the couplant mechanisms settings should be done according to the dependances resulting from this work.

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ВИСНОВОК

Теоретичні дослідження, виконані авторами, та результати лабораторних і польових досліджень, наведені у вище згаданих роботах авторів, дозволили зробити наступні висновки:

- застосування способу контактного мащення дозволяє уникнути непродуктивних втрат гербіциду та забезпечити знищення як наземної так і кореневої системи рослини;
- величина прогину стебел під впливом робочого обладнання пристрою для контактного мащення залежить від фізико-механічних властивостей рослин, кута їх зрізу та висоти встановлення барабану;
- як показали результати польових досліджень обладнання, наземну частину небажаної рослинності зрізують на висоті 0,25…0,35 м. З урахуванням цього та графіку (рис.4), оптимальною є установка барабану контактного пристрою на 0,02…0,028 м нижче висоти зрізання наземної частини рослини;
- обґрунтування параметрів пристрою контактного мащення доцільно здійснювати з урахуванням отриманих у роботі залежностей.

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RESEARCH RESULTS OF HARVESTING HAULM REMNANTS OF ROOT CROPS
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РЕЗУЛЬТАТИ ДОСЛІДЖЕННЯ ОБРІЗУВАННЯ ЗАЛИШКІВ ГИЧКИ КОРЕНЕПЛОДІВ

MSC Eng. Storozhuk I.M.[1)], MSC Eng. Pankiv V.R.[2)]
[1)]National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony 15, Kiev/ Ukraine
[2)] Ternopil Ivan Pul'uj National Technical University, Ruska str., 56, Ternopil / Ukraine
E-mail: 8455865@ukr.net

Abstract: *In this work it is presented the description of technological process of the improved machine for cutting haulm at root crops and the results of experimental research of beets haulm with three constructions of the cutter. The research it was made for three re-cutting constructions conducted on the principle of "passive knife - copier".*

Keywords: *fodder beet, haulm remnants, technological process, re-cutter of root crops heads, copier, sprung-loaded knife, polyfactorial experiment, empirical model, knocked out root crops.*

INTRODUCTION

Sustainable development of manufacturing is possible on the basis of further modern mechanization of all production processes. This can be achieved by ensuring the development and introduction of highly efficient crop harvesting technologies, including fodder beet roots [1].

The mechanized harvesting of fodder beet roots is one of the most labour intensive and of energy intensive operations in the overall context of the agricultural production not only in Ukraine but also in highly developed countries of the world community [2].

Haulm harvesting is one of the most intensive labor operations in the technological process of fodder beet production Modern directions for the development of single-phase propelled root crops machines provide block-modular principle of their construction. Two-stage method of haulm harvesting is the first stage of single-phase technology of harvesting root crops – cutting the main body of haulm by rotary haulm cutter followed by cutting the remnants of haulm by a «passive copier-passive knife» re-cutter [3].

The problem of improving of haulm-cleaning modules technical level, cutting haulm quality indicators are their assessment criteria, remains particularly relevant in terms of further development of root crops technique.

There are a lot of design and layout schemes for cutting and harvesting haulm and working bodies of beet harvesting machines: from haulm cutting rotors to fodder root re-cutters. This is related to both the harvesting technologies and agro-technical requirements for haulm cleaning and roots vegetables quality indicators [4, 5].

Since the first development and application of the technical devices and facilities for mechanical harvesting of root crops extensive experience in the establishment of relevant working bodies and machines has been gained in the world practice. The agrobiological and mechanical properties of root crops and haulm of fodder beets, their location relative to the surface of the soil largely influence the work conditions modules of harvesting haulm. These

Резюме. *У статті наведено опис технологічного процесу роботи удосконаленої гичкозбиральної машини та результати експериментальних досліджень обрізування головок буряків трьома конструкціями дообрізників, виконаних за принципом «пасивний копір–ніж».*

Ключові слова: *кормові буряки, залишки гички, технологічний процес, дообрізник головок коренеплодів, копір, підпружинений ніж, багатофакторний експеримент, емпірична модель, вибиті коренеплоди.*

ПЕРЕДМОВА

Сталий розвиток виробництва продукції агропромисловим комплексом України можливий на основі подальшої сучасної механізації всіх виробничих процесів шляхом забезпечення розробки та впровадження високоефективних технологій збирання сільськогосподарських культур, у тому числі і коренеплодів кормових буряків [7].

Механізоване збирання коренеплодів кормових буряків є однією з найбільш трудомістких і енергозатратних операцій в загальному контексті виробництва продукції сільськогосподарського виробництва не тільки в України, але й у високорозвинутих державах світової спільноти [2].

У технологічному процесі виробництва коренеплодів кормових буряків, однією з найбільш трудомістких операцій є збирання гички. Сучасні напрямки розвитку однофазних самохідних коренезбиральних машин передбачають блочно-модульний принцип їх побудови. Першим етапом однофазної технології збирання коренеплодів є збирання гички двостадійним способом – зрізування основного масиву гички роторним гичкорізом з наступним зрізуванням залишків гички дообрізником типу «пасивний копір–пасивний ніж» [8].

Проблема підвищення технічного рівня гичкозбиральних модулів, критеріями оцінки яких є показники якості зрізування гички, залишається особливо актуальною в плані подальшого розвитку коренезбиральної техніки.

Велика різноманітність конструктивних та компонувальних схем гичкозріувальних і гичковидаляючих пристроїв і робочих органів бурякозбиральних машин, від гичкозрізувальних роторів до дообрізників головок коренеплодів, пов'язана як з технологіями збирання, так і з агротехнічними вимогами до показників якості збирання гички та коренеплодів [14, 5].

З часу розробки та застосування перших технічних пристроїв і засобів для механізованого збирання коренеплодів у світовій практиці накопичено великий досвід з створення відповідних робочих органів і машин, у тому числі для збирання гички. Агробіологічні та механічні властивості коренеплодів і гички кормових

indicators accordingly regulate construction features of working bodies for harvesting the main array of haulm and cutting off its remnant from root crops heads [6, 7, 8].

Taking into account specific mechanical and technological properties of the root crops and haulm and the world tendency of single-phase haulm cleaning method, it can be concluded that the technological process of haulm cleaning is expediently carried out with a two-stage method. It includes cutting the main body of haulm followed by removal of haulm remnants on the heads of root crops by re-cutter «passive copier-passive knife» re-cutter [4, 9].

Therefore, the improvement of the structural and layout schemes and working bodies of the machines for haulm harvesting or haulm harvesting modules and substantiation parameters of their working bodies should be carried out taking into account the specific properties of this process. This is particularly important and actually in providing the necessary quality indicators of the work according to the agrotechnical requirements [5, 10].

The work objective is to increase technological process indicators of haulm harvesting of fodder beet root crops, through the development and substantiation of working parameters of haulm harvesting machines.

There are many ways of mechanical haulm removal of root crops such as cutting, beating down, tear off and etc. Cutting and beating down of haulm are the most common ones.

Based on the study of technological processes of cutting haulm and constructive-technological schemes of haulm harvesting modules and haulm harvesting machines of domestic and foreign production one can be stated the following. At present haulm-cutting devices typically cut haulm only on the principle "on the root". In such case, main body haulm harvesting occurs without copying the heads of root crops and haulm remnants cutting - with copying of root crops heads by different mechanisms [4, 11, 12, 13].

The devices that carry out haulm cutting on the root by the cutting method are divided into machines for single-phase haulm cleaning method and machines for the two-phase method of haulm harvesting, which in turn are divided according to the type of job.

The cutting, during which haulm cleaning is the result of knife blade cutting, is applied both for the bulk haulm harvesting and its remnants while cutting heads of the root crops. And the knives, which can be active or passive, carry out haulm cutting without anti-cutting elements or counter movement of the knives.

Primarily it is caused by root crops properties, fodder beet haulm and harvesting or using haulm technology – using haulm for fodder or as an organic fertilizer by spreading it on a harvested field [14, 15].

Reduction of the root crops yield during the harvesting is caused by their losses during digging up and haulm harvesting. This is due to the significant number of root crops knocked out from the soil (1.5...2.0%) and damaged root crops (15...20%) of these by chipping surface of heads cutting - up to 10%.

буряків, їх розміщення відносно поверхні грунту в значній мірі впливають на умови роботи гичкозбиральних модулів і, відповідно, регламентують особливості конструкції робочих органів для збирання основного масиву гички та дообрізування її залишків з головок коренеплодів [3, 16, 12].

Враховуючи специфічні механіко-технологічні властивості зв'язків гички з коренеплодами та світову тенденцію однофазного способу збирання коренеплодів, можна зробити висновок, що технологічний процес збирання гички доцільно здійснювати двостадійним способом, який включає в собі зрізування основного масиву гички з наступним видаленням залишків гички на головках коренеплодів дообрізником типу «пасивний копір–пасивний ніж» [14, 18].

Тому вдосконалення конструктивно-компонувальних схем та робочих органів машин для збирання гички, або гичкозбиральних модулів коренезбиральних машин і обгрунтування параметрів їх робочих органів необхідно проводити з урахуванням специфічних властивостей даного процесу, що є особливо важливим і актуальним у плані забезпечення необхідних показники якості роботи згідно з агротехнічними вимогами [5, 11].

Метою роботи є підвищення показників технологічного процесу збирання гички коренеплодів кормових буряків шляхом розробки та обґрунтування параметрів робочих органів гичкозбиральних машин.

При всій різноманітності способів механічного видалення гички коренеплодів (зрізування, збивання, відривання тощо) найбільш поширеними, є зрізування та збивання.

На основі дослідження технологічних процесів зрізування гички кормових буряків і конструктивно-технологічних схем гичкозбиральних модулів коренета гичкозбиральних машин вітчизняного і зарубіжного виробництва, можна констатувати, що на сучасному етапі гичкозрізувальні пристрої, як правило зрізують гичку тільки за принципом «на корені». При цьому збирання основного масиву гички відбувається без копіювання головок коренеплодів (безкопірний зріз), а дообрізування залишків гички – з копіюванням головок коренеплодів різноманітними механізмами [14, 9, 13, 20]. Пристрої, які здійснюють зрізування гички на корені, за способом виконання процесу зрізування поділяються на апарати для однофазного способу збирання гички та апарати для двофазного способу збирання гички, які у свою чергу поділяють за типом робочих органів.

Зрізування, під час якого видалення гички відбувається в результаті різання лезом ножа застосовується, як для збирання основної маси гички, так і її залишків під час обрізування головок коренеплодів. Причому ножі, які можуть бути активні чи пасивні, виконують різання гички без підпору, тобто без протирізальних елементів чи зустрічного руху ножів. Це зумовлено, в першу чергу властивостями коренеплодів і гички кормових буряків та технологією збирання або використання гички – використання гички на корм або у якості органічних добрив шляхом розкидання її на зібране поле [15, 6].

Зменшення урожаю коренеплодів під час збирання обумовлені їх втратами як під час викопування, так і під час збирання гички за рахунок значної кількості вибитих з грунту (1,5…2,0%) та пошкоджених (15…20%) коренеплодів, із них за рахунок сколів поверхні зрізування головки – до 10%. При цьому відходи маси

At the same time the wastes of cutted root crops heads with haulm to the total mass are within 5...8%, and the pollution of root crops thresh by remnants of haulm amounts to 3...5% [16, 17, 18, 19, 20].

The operating indicators obtained of machines for haulm cleaning or their harvesting modules are unsatisfactory. They do not correspond to the established parameters in accordance with the agrotechnical requirements on the basis of their imperfection constructive and technical decisions the main working bodies - rotary haulm cutters and of the haulm remnants re-cutters of the root crops heads.

MATERIAL AND METHOD

Development of modern perspective assembly schemes and new constructions of working bodies of machines for haulm harvesting and their modules must be based on world experience, taking into account the peculiarities of local agronomic, technical, economic, environmental and other requirements.

Based on the analysis of quality work indicators and technological parameters of haulm harvesting, we proposed an improved machine for haulm harvesting that is used according to the chosen haulm harvesting technology or method of haulm usage.

Constructive scheme of the improved machine for haulm harvesting is shown in Figure 1.The machine for haulm harvesting consists of frame 1, on which support wheel 2, horizontal rotor 3, auger 4, re-cutters of root crops heads 5 are consistently adjusted. Horizontal rotor 3 is designed as a drum 6. Knives for haulm cutting 7 are placed in drum of spiral. They are pivotally installed by means of supporting plates, are fixed on a drum rotor 3 and finger. Rotor 3 rotates the opposite direction of the machine for harvesting root crops haulm. Height of cutting of the main haulm array is regulated by moving of supporting wheels 2. Auger 4 is installed in horizontal gutter 8 and made in the form of drum 9 on which winds 10 are fixed. The top part of knives for haulm cutting 7 and auger 4 is closed by casing 11.

обрізаних головок коренеплодів із гичкою до їх загальної маси знаходяться в межах 5…8%, а забрудненість вороху коренеплодів залишками гички становить 3…5% [17, 19, 4, 10, 2].

Одержані незадовільні показники якості роботи гичкозбиральних машин, або їх збиральних модулів не відповідають встановленим показникам згідно з агротехнічними вимогами за ознаками недосконалості їх конструктивно-технічних рішень основних робочих органів – роторних гичкорізів і дообрізників залишків гички з головок коренеплодів.

МАТЕРІАЛ І МЕТОДИКА

Розробку сучасних перспективних компонувальних схем та нових конструкцій робочих органів гичкозбиральних машин і їх модулів, повинні базуватися на світовому досвіді, враховуючи при цьому особливості вітчизняних агротехнічних, техніко–економічних, екологічних та інших вимог.

На основі проведеного аналізу одержаних показників якості роботи та технологічних показників збирання гички, нами запропоновано удосконалені гичкозбиральні машини, які застосовують до вибраної технології збирання гички, або способу використання гички.

На рис. 1 наведено конструктивну схему удосконаленої гичкозбиральної машини. Гичкозбиральна машина складається з рами 1, на якій послідовно встановлено опорні колеса 2, горизонтальний ротор 3, шнек 4, дообрізники 5 головок коренеплодів. Горизонтальний ротор 3 виконано у вигляді барабана 6, на якому по гвинтовій лінії розміщено гичкозрізувальні ножі 7, які за допомогою опорних пластин, що закріплені на барабані 6 ротора 3 і пальця, встановлено шарнірно. Ротор 3 обертається зустрічно напрямку руху гичкозбиральної машини, а висоту зрізування основного масиву гички регулюють переміщенням опорних коліс 2. Шнек 4 встановлено у горизонтальному жолобі 8 та виконано у вигляді барабана 9 на якому закріплено витки 10. Верхня частина гичкозрізувальних ножів 7 і шнека 4 закрита кожухом 11.

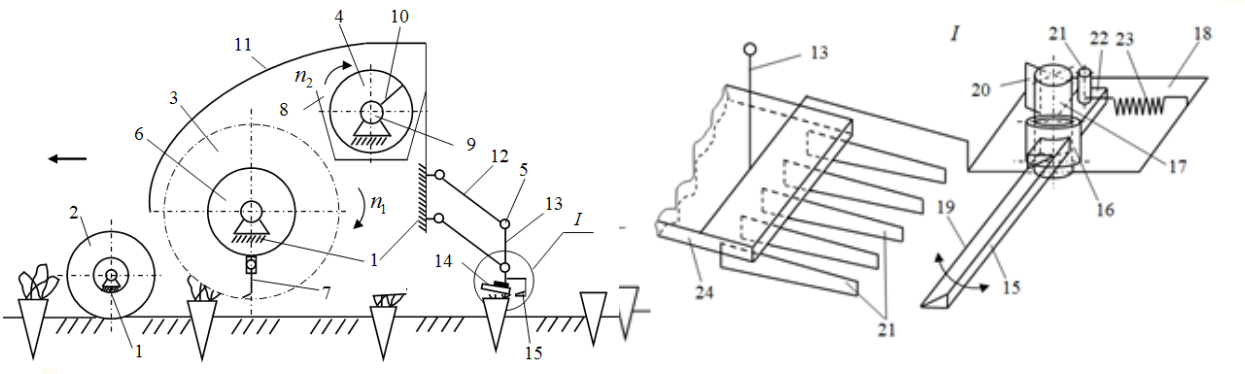

Fig. 1 - Constructive scheme of the improved machine for haulm cutting:
1 – chassis frame, 2 – support (reference) wheel, 3 – rotor, 4 – auger, 5 – cutter of heads root crops, 6, 9 – drum, 7 – knife, 8 – chute, 10 – spiral, 11 – casing, 12 - parallelogram hinged suspension; 13 – bracket, 14 – copier, 15 – knife, 16 - two-arm lever, 17 – finger, 18 – fixed support, 19 – knife blade, 20 - support, 21 – stop, 22 – arm of lever, 23 – spring, 24 - shock absorber blow

The cutter of root crops heads 5 is mounted behind the chute 8, each of them is designed as a parallelogram hinged suspension 12. Passive comb copier 14 and knife 15 are mounted sequentially on the bracket 13 of parallelogram hinged suspension 12.

Позаду жолоба 8 змонтовано дообрізники 5 головок коренеплодів, кожен з яких виконано у вигляді паралелограмної шарнірної підвіски 12, на кронштейні 13 якої послідовно змонтовано пасивний гребінчастий копір 14 і ніж 15.

Each knife 15 is designed as two-arm lever 16. The lever is installed at its finger 17 pivotally. The finger rigidly is fixed on a support 18, which is connected to the bracket 13 rigidly. Working stroke of the blade 19 of the cutting edge of the knife 15, in the horizontal plane is limited to support 20 which is mounted on the vertical finger 17 and support 21. The knife 15 is spring-loaded through a spring 23, one end of which is fixed on a two-arm lever 16, and the second - on the fixed support 18. Shock absorber blow is made in the form of gasket 24 of elastic material, or, for example, compression spring. It is installed between the bracket 13 parallelogram suspension 12 and copier 14.

RESULTS

When the machine for haulm harvesting is moving along the root crops rows knives 7 cut off the main bulk of haulm and move it so that it put l in the chute 8 or auger 4. The spiral 10 of auger 4 transports the haulm along the axis of rotation of auger 4, in the direction of its output part. The copier 14 of cutter 5 collides with the head of root crop and then knife 15 cuts off the head of root crop by blade cutting edge 19 at given height of cut. In the process of cutting of root crop head knife 15 and support 20 reclaim from vertical fingers 17 to 21 stops, thus carrying out the cutting by method of sliding.

Moreover, during a meeting of the copier 21 with the of root crops head there is a blow interaction of working surface of copier and the head of root crops. It results to the beating out from the soil or damage of root crops. Due to the shock absorber blow that is made in the form of gasket 24 impact force of copier is significantly reduced. A part of the impact energy is spent on the deformation of the shock absorber, or compensated for deformation gaskets and it reduces beating out from the soil or damage of root crops.

To determine use efficiency of improved re-cutter construction mounted on the machine field comparative experimental studies of the number knocked out root crops from the soil of three types re-cutters: a standard re-cutter of root crops heads (firms «Kleine», «Moreau», «Tim» etc.), re-cutter of root crops heads which has a spring-loaded knife and a cutter of root crops heads which has a spring-loaded knife and copier is installed on shock absorber in the form of an elastic plate.

The variable factors of two-factor experiment implemented in three levels of factors variation (lower (-1), zero (0), top (1)) were accepted: machine speed; root crops height relative to the surface of the soil level. The results of coding and numerical values of levels of factors variation are shown in the table 1 below.

Кожен ніж 15 виконано у вигляді двоплечевого важеля 16, встановленого шарнірно на своєму пальці 17, який жорстко закріплений на опорі 18, жорстко зв'язаною з кронштейном 13. Робочий хід леза 19 ріжучої кромки ножа 15 в горизонтальній площині обмежено упором 20, який закріплено на вертикальному пальці 17 і упором 21, закріпленим на плечі 22 двоплечевого важеля 16. Ніж 15 виконано підпружиненим завдяки пружині 23, один кінець якої закріплено на плечі 22 двоплечевого важеля 16, а другий – на опорі 18. Між кронштейном 13 паралелограмної підвіски 12 і копіром 14 встановлено амортизатор удару, який виконано у вигляді прокладки 24 з пружного матеріалу, або, наприклад, пружини стиску.

РЕЗУЛЬТАТИ

Під час переміщення гичкозбиральної машини вздовж рядків коренеплодів ножі 7 зрізують основний масив гички та подають її по траєкторії направлення кожуха 18 так, щоб вона попадала в жолоб 14, або на шнек 4. Витки 16 шнека 4 транспортують гичку вздовж осі обертання шнека 4 в сторону його вихідної частини 17. Гребінчастий копір 21 обрізувача 5 наїжджає на головку коренеплодів, а ніж 22 лезом 23 ріжучої кромки обрізує головку коренеплодів на заданій висоті зрізу. У процесі зрізування головки коренеплодів ніж 22 і упор 28 відхиляється на вертикальному пальці 25 до упора 27, виконуючи різання методом ковзання.

Крім того, під час зустрічі копіра 21 з головкою коренеплодів відбувається ударна взаємодія робочої поверхні копіра 21 та головки коренеплодів, що призводить до їх вивалювання з грунту, або пошкодження. Завдяки виконанню копіра пружним, або наявності амортизатора удару, виконаного у вигляді прокладки 31, сила удару копіра значно зменшується за рахунок того, що частина енергії удару витрачається на деформацію амортизатора, або компенсується на деформацію прокладки 31. Це знижує вивалювання коренеплодів з ґрунту та їх пошкодження.

Для визначення ефективності використання вдосконаленої конструкції дообрізника, який встановлено на машину, були проведено польові порівняльні експериментальні дослідження кількості вибитих коренеплодів з грунту для трьох типів дообрізників - серійного дообрізника (фірми «Kleine», «Moreau», «Tim» та ін.), дообрізника, ніж якого виконаний підпружиненим і дообрізника, у якого ніж виконаний підпружиненим, а копір встановлений на амортизаторі, виконаним у вигляді пружної пластини.

Змінними факторами двофакторного експерименту, реалізованого на трьох рівнях (нижній (-1), нульовий (0), верхній (+1)) варіювання факторами, приймали: швидкість руху дообрізника (машини) V_M; висоту розташування коренеплодів відносно поверхні рівня ґрунту h_k. Результати кодування та числові значення рівні варіювання факторами наведено у табл. 1.

Table 1

Results of the coding of factors and their variation levels

Factors	Designation of factors		The interval of variation	Levels of factors variation, Natural / Coding		
	Coding	Natural				
Machine speed, m/s	x_1	V_M	0,3	1,4/-1	1,8/0	2,2/+1
The height of placement of root crops in relation to soil level, cm	x_2	h_k	3	3/-1	6/0	9/+1

The average numeric values of general sample handling the experiments (the sample size was 100 units) number knocked out root crops from the soil were inscribed in the corresponding boxes of plan-matrix conducting two-factor experiments (Tab.2). The regression equations which were received after processing of numeric values Tab.2.

Середні числові значення обробки генеральної вибірки проведених експериментів (обсяг генеральної вибірки становив 100 шт.) кількості вибитих коренеплодів з грунту заносили у відповідні графи план-матриці проведення двофакторних експериментів (табл. 2).

Table 2

Plan Matrix and medium numeric values of two-factor experiments

№ п/п	Factors		Of the number of root crops			Of the root crops total mass		
	Machine speed, V_M, m/s	The height of placement of root crops in relation to soil level, h_k, cm	B_{1k}, %	B_{2k}, %	B_{3k}, %	B_{1m}, %	B_{2m}, %	B_{3m}, %
1	1.4	3	2	1	0	0,3	0,2	0
2	1.8	3	6	4	0	0,7	0,5	0
3	2.2	3	9	6	2	1,1	0,9	0,3
4	1.4	6	7	3	0	0,9	0,4	0
5	1.8	6	17	11	3	2,1	1,3	0,5
6	2.2	6	21	14	7	2,5	1,7	0,9
7	1.4	9	29	17	15	3,3	2,0	1,7
8	1.8	9	43	29	23	5,1	3,5	2,6
9	2.2	9	54	42	35	6,7	5,1	4,0

They describe the dependence of change of the number of partially root crops knocked out from the soil for three types performing of cutter heads of haulm remnants on the heads of fodder beet root crops:

– as a percentage of the number of root crops:

Після обробки числових значень табл. 2 отримані рівняння регресії, які характеризують залежність зміни кількості вибитих коренеплодів з ґрунту для трьох типів виконання дообрізника залишків гички на головках коренеплодів кормових буряків:

- в процентах від кількості коренеплодів

$$B_{1k} = -12.64 + 34.17V_M - 12.47h_k + 3.75V_M h_k - 10.42V_M^2 + 0.98h_k^2 \quad (1)$$

$$B_{2k} = 10.26 + 10.83V_M - 12.78h_k + 4.17V_M h_k - 5.21V_M^2 + 0.8h_k^2 \quad (2)$$

$$B_{3k} = 57.93 - 36.7V_M - 15.03h_k + 3.75V_M h_k + 7.29V_M^2 + 1.2h_k^2 \quad (3)$$

where B_{1k} – number knocked out root crops from the soil by a standard re-cutter of root crops heads,%;

B_{2k} – number knocked out root crops from the soil by re-cutter of root crops heads which has a spring-loaded knife,%;

B_{3k} – number knocked out root crops from the soil by cutter of root crops heads which has a spring-loaded knife and copier is installed on shock absorber in the form of an elastic plate,%;

V_M – machine speed, m/s;

h_k – the height of placement of root crops in relation to surface of the soil, cm.

де B_{1k} – кількість вибитих коренеплодів з грунту серійним дообрізником, %;

B_{2k} – кількість вибитих коренеплодів з грунту дообрізником, ніж якого виконано підпружиненим, %;

B_{3k} – кількість вибитих коренеплодів з грунту дообрізником, ніж якого виконано підпружиненим, а копір встановлено на амортизаторі, %;

V_M – швидкість руху машини, м/с.

h_k – висота розміщення головок коренеплодів відносно рівня поверхні грунту, см

– as a percentage of the root crops total mass

- в процентах від загальної маси коренеплодів:

$$B_{1m} = -0.13 + 2.92V_M - 1.63h_k + 0.54V_M h_k - 1.04V_M^2 + 0.12h_k^2 \quad (4)$$

$$B_{2m} = 2.33 + 0.25V_M - 1.6h_k + 0.5V_M h_k - 0.31V_M^2 + 0.1h_k^2 \quad (5)$$

$$B_{3m} = 5.83 - 3.67V_M - 1.6h_k + 0.42V_M h_k + 0.73V_M^2 + 0.11h_k^2 \quad (6)$$

where B_{1m} – number knocked out root crops from the soil by a standard re-cutter of root crops heads,%;

B_{2m} – number knocked out root crops from the soil by re-cutter of root crops heads which has a spring-loaded knife,%;

B_{3m} – number knocked out root crops from the soil by cutter of root crops heads which has a spring-loaded knife and copier is installed on shock absorber in the form of an elastic plate,%;

Based on the analysis of regression equations (1)-(6) and the response surfaces (Fig. 2-3), it was established that the character change of the number, B_{ik}, B_{im}, of the

де B_{1k} – кількість вибитих коренеплодів з грунту серійним дообрізником, %;

B_{2k} – кількість вибитих коренеплодів з грунту дообрізником, ніж якого виконано підпружиненим, %;

B_{3k} – кількість вибитих коренеплодів з грунту дообрізником, ніж якого виконано підпружиненим, а копір встановлено на амортизаторі, %.

На основі проведеного аналізу рівнянь регресії (1)-(6) та поверхонь відгуку (рис. 2-3) встановлено, що характер зміни кількості вибитих коренеплодів з ґрунту B_{ik}, B_{im} для трьох типів виконання дообрізника однаковий - зі збільшенням швидкості руху машини V_k

knocked out root crops from the soil for the three types re-cutters constructions is the same. With increasing the machine speed, V_k, and the root crops height h_k relatively to the soil level, the values of B_{ik}, B_{im} increase as a percentage of root crops (B_{1k}, B_{2k}, B_{3k}, Fig. 2) and as a percentage of root crops total mass (B_{1m} ,$B_{2m,}$ B_{3m}, Fig. 3). Moreover the largest number of knocked out root crops from the soil, as a percentage of root crops B_{ik}, and as a percentage of root crops total mass B_{im} it is observed at the standard re-cutter, whose values are in the range of B_{1k} =5…53%, B_{1m} =1,0…6,5%. Accordingly, the minimum values of number of knocked out root crops from the soil B_{3k} =4…34%, B_{3m}=0,5…3,9% are inherent for the re-cutter, in which the knife is made spring-loaded and copier rigidly is fixed on the shock absorber which is designed as an elastic plate.

і висоти розташування коренеплодів щодо рівня грунту h_k, значення B_{ik}, B_{im} збільшуються, як у відсотках від кількості коренеплодів (B_{1k}, B_{2k}, B_{3k}, рис. 2), так і у відсотках від загальної маси коренеплодів (B_{1m} ,$B_{2m,}$ B_{3m}, рис. 3). При цьому найбільша кількість вибитих коренеплодів з ґрунту B_{ik}, як у відсотках від кількості коренеплодів, так і у відсотках від загальної маси коренеплодів B_{im} спостерігається у серійного дообрізника, значення яких знаходяться у діапазоні B_{1k} = 5…53%, B_{1m} = 1,0…6,5%. Відповідно, мінімальні значення кількості вибитих коренеплодів з ґрунту B_{3k} = 4…34%, B_{3m} = 0,5…3,9% притаманні дообрізнику, у якого ніж виконаний підпружиненим, а копір жорстко встановлено на амортизаторі, виконаного у вигляді пружної пластини.

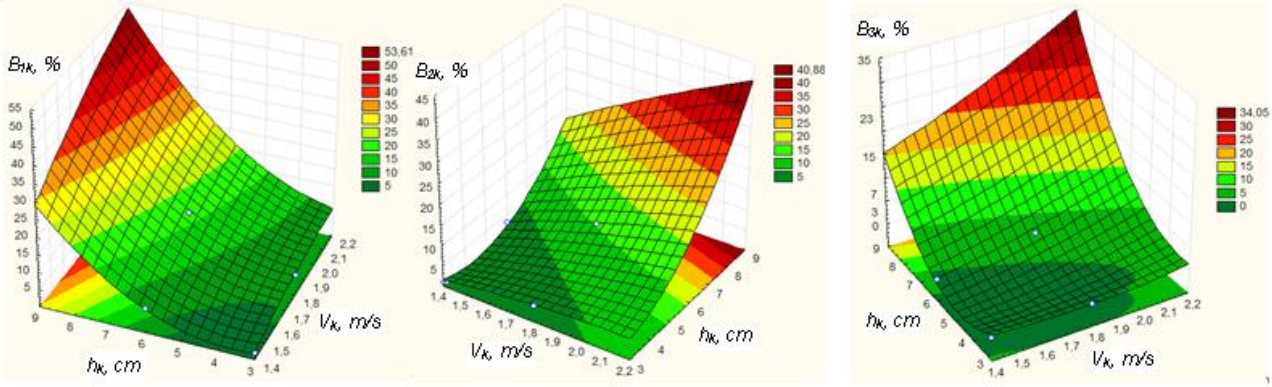

Fig. 2 - The response surface as a functional of $B_{ik} = f(V_k, h_k)$

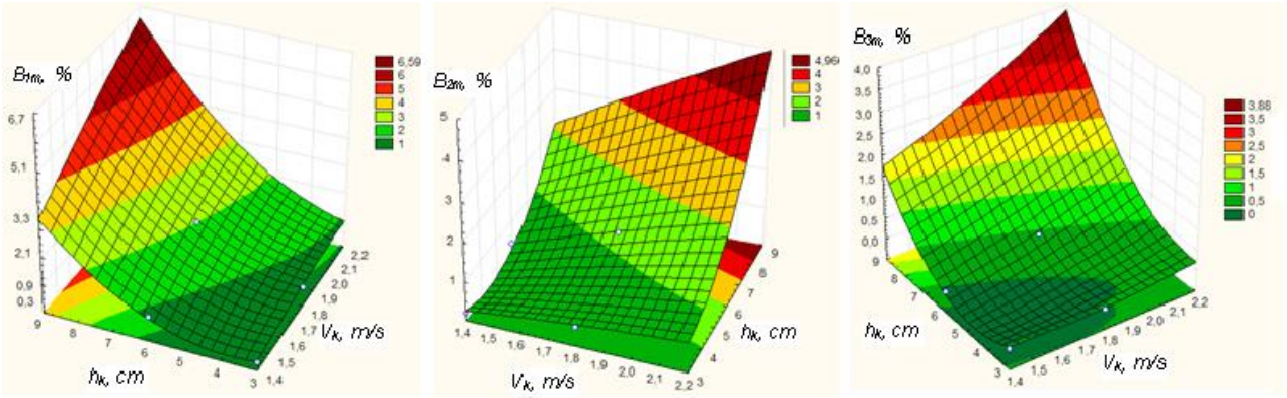

Fig. 3 - The response surface as a functional of $B_{im} = f(V_k, h_k)$

The significant decrease of the number of root crops knocked out from the soil, B_{3k} (B_{3m}) relatively B_{1k} (B_{1m}), it is reached by replacing rigid processes of the haulm cutting at the process of cutting by method of sliding the blade cutting edge of the spring-loaded knife and partial compensation of the horizontal component of knocked out root crops through shock absorber.

The placement height of the root crops heads in relation with the soil level is the dominant factor, which influence the parameter optimization indicators or the number of knocked out roots h_k from the soil (Fig. 4).

Within the limits of increasing of this factors from 3 to 9 cm, the number of root crops knocked out from the soil of the working organs of all types re-cutter are increasing: B_{ik} -on average in 6 times, B_{im} - on average in 4 times

Значне зменшення кількості вибитих коренеплодів з ґрунту B_{3k} (B_{3m}) відносно B_{1k} (B_{1m}) досягається за рахунок заміни жорсткого процесу «зрубування» черешків гички на процес різання методом ковзання леза ріжучої кромки підпружиненого ножа дообрізника та частковою компенсацією амортизатором горизонтальної складової сили вивалювання коренеплодів.

Домінуючим фактором, який впливає на показник параметра оптимізації або кількості вибитих коренеплодів з ґрунту являється висота розташування головок коренеплодів відносно рівня ґрунту h_k (рис. 4).

В межах збільшення даного фактору від 3 до 9 см кількість вибитих коренеплодів з ґрунту робочими органами всіх типів виконання дообрізника збільшуються: B_{ik} – у середньому в 6 раз; B_{im} – у середньому в 4 рази.

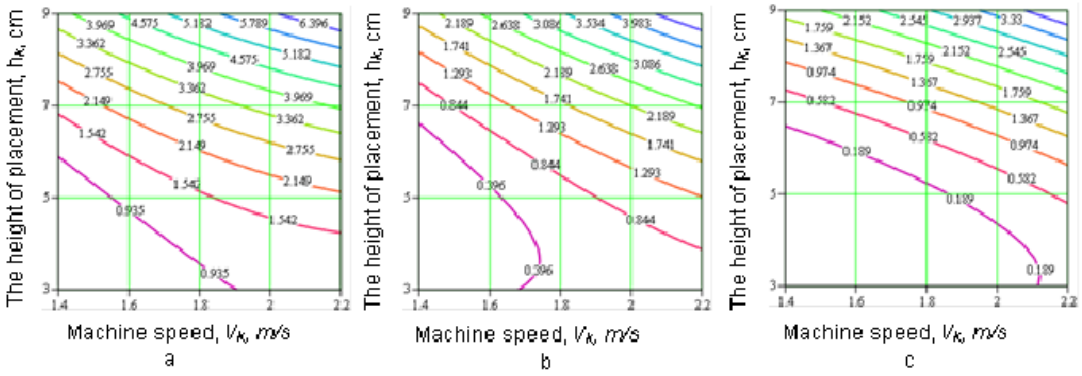

Fig. 4 - The change dependence of the number of knocked out root crops from V_k and h_k:
a – B_{1k} =f(V_k,h_k); b – B_{2k} =f(V_k,h_k); c – B_{3k} =f(V_k,h_k).

CONCLUSIONS

The empirical mathematical models (1)-(6) by the results of comparable experimental researches were obtained. They describe the number of knocked out root crops by working bodies by three types re-cutter of root crops haulm remnants. The use of mathematical models can empirically determine the number root crops knocked out from the soil within the established limits change of factors.

Thus, the improved design of machine for haulm remnants re-cutter of root crops of fodder beet consists in the re-cutter, which is designed as a passive copier and it is mounted on shock absorbers and with spring-loaded knife. Using this design is allowed to intensify the process of removing haulm remnants, while the number of root crops knocked out from the soil is reduced by about 1.5 ... 2.0 times.

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ВИСНОВОК

За результатами проведених експериментальних порівняльних досліджень одержано емпіричні математичні моделі (1)-(6), які характеризують кількість вибитих коренеплодів робочими органами трьома типами дообрізників залишків гички. Використання математичних моделей дозволяє на емпіричному рівні визначати кількість вибитих коренеплодів з грунту в встановлених межах зміни факторів.

Таким чином, використання удосконаленої конструкції дообрізника залишків гички з головок коренеплодів кормових буряків, який виконаний у вигляді пасивного копіра, встановленого на амортизаторі, а ніж - підпружиненим, дозволяє інтенсифікувати процес видаленні залишків гички, при цьому кількість вибитих коренеплодів з ґрунту зменшується приблизно в 1, 5 ... 2,0 рази.

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RESEARCHES ON QUALITY OF LAVENDER SCREENING PROCESS
/
CERCETĂRI PRIVIND CALITATEA PROCESULUI DE SORTARE LA LEVĂNŢICĂ (Lavandula angustifolia L)

Ph.D. Stud. Biol. Pruteanu. A.[1)], Prof. Ph.D. Eng. David L.[2)], Ph.D. Eng. Vladut V. [1)], Ph.D. Stud. Eng. Matache M.[1)], Ph.D. Stud. Eng. Muscalu A.[1)], Ph.D. Eng. Danciu A.[1)]
[1)] National Institute of Research - Development for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest/Romania
[2)]Polytechnic University of Bucharest, Faculty of Biotechnical Systems Engineering / Romania
Tel: 0740690268; E-mail: pruteanu_augustina@yahoo.com

Abstract: *Medicinal plants contain biologically active substances with therapeutic value. Medicinal plants cultivation and capitalization by different processing operations are important for assuring an enhanced quantity of raw material and preserving or increasing their valuable constituents. Furthermore, obtaining available high quality phyto-therapeutic products is possible only by using state-of-the art technical equipment adapted to each plant requirements. The paper presents experimental researches on lavender herb, related to sorting the fragments of dry and chopped plant. The screening evaluation taking into account the screening degree by means of power and polynomial functions, obtained by experimental data processing, is presented. The results represent an important asset for medicinal plant processors in Romania, as well as for manufacturing specialized equipment of high performance.*

Keywords: *screening process, plane sifters, lavender, high quality products, essential oil.*

Rezumat: *Plantele medicinale conţin substanţe biologic active cu valoare terapeutică. Cultivarea şi valorificarea acestor plante prin diferite operaţii de prelucrare sunt importante pentru asigurarea unei cantităţi sporite de materie primă şi pentru păstrarea sau creşterea constituenţilor valoroşi conţinuţi de aceste plante. În plus, obţinerea unor produse fitoterapeutice de calitate şi accesibile este posibilă numai prin folosirea unor echipamente tehnice perfecţionate continuu şi adaptate la cerinţele specifice fiecărei plante. Lucrarea prezintă cercetări experimentale la herba de levănţică cu privire la sortarea fragmentelor de plantă uscată şi tocată. Se prezintă evaluarea procesului de sortare, prin aprecierea gradului de sortare, cu ajutorul funcţiilor putere şi polinom, obţinute prin prelucrarea datelor experimentale. Rezultatele constituie o importantă premisă pentru procesatorii de plante medicinale din România, precum şi pentru realizarea unor utilaje specializate performante.*

Cuvinte cheie: *proces de sortare, site plane, levănţică , produse de calitate, ulei volatil*

INTRODUCTION

Medicinal plants are a vegetal species which accumulates in certain parts of the plant different active substances useful in different affections treatment. [10]. In order to cultivate medicinal plants, establishing of ecological or even biological crops is very important [1,8].
Lavender *(Lavandula angustifolia L)* - fig.1 is one of the most important aromatic species. Its origins are Mediterranean, being cultivated for its inflorescences with pleasant characteristic and fresh odour. Essential oil obtained by fresh inflorescences represents the main product of this species and is widely used in perfume industry, cosmetics, pharmaceutical products, aromatherapy etc [5]. Lavender is also a good melliferous plant [8].

INTRODUCERE

Plantele medicinale sunt o categorie de specii vegetale care acumulează în anumite părţi ale plantei diverse substanţe active utile în tratarea diferitelor afecţiuni [10]. Pentru cultivarea plantelor medicinale este importantă înfiinţarea de culturi ecologice sau chiar biologice [1,8].
Levănţica *(Lavandula angustifolia L)* - fig.1 este una din cele mai valoroase specii aromatice. De origine mediteraneană, se cultivă pentru inflorescenţele ei cu miros plăcut, caracteristic, cu note de prospeţime.Uleiul volatil obţinut prin distilarea inflorescenţelor proaspete reprezintă produsul principal al acestei specii şi are largi utilizări în industria parfumurilor, produselor cosmetice, produselor farmaceutice, aromoterapiei,etc [5]. Lavanda este şi o foarte bună plantă meliferă [8].

Fig. 1 – Lavender *(Lavandula angustifolia L)* [8]

There are 48 species of lavender of hundred different genotypes differentiating by growing till chemical composition of essential oil: camphor, propylene, linalool, linalyl acetate, ocimene etc. [12]. In our country, especially in Moldavia centre conditions, ,,Codreanca"[5] lavender variety, homologated in 1992, and on smaller surfaces-lavandin (*Lavandula hybrida*) represented by local population as ,,De Brăneşti", have been cultivated. Appropriate area for extending lavender and lavandin crops are the southern and south-eastern areas of Romania [11].

At national level, studies of multiplying lavender genotypes with high biosynthetic potential [3] and also studies related to high capitalization of essential oil extraction from medicinal plants [4], have been achieved.

Obtaining high quality products with phyto-therapeutic value is possible only by a correct processing suitable to each species of plant [9]. In terms of structure, the technological process comprises all the interconnected operations and stages necessary for preparing, respectively passing the vegetal matter harvested, or purchased, to a production unit [6], the matter being in a state appropriate to storage, packaging and subsequent processing [6].

Primary and advanced processing of different medicinal plant parts can be used for obtaining essential oils, tea (as sachets or bags), macerates, vegetal extracts, tinctures, syrups, tablets, food dyes, cosmetics, natural fertilizers, bio-insecticides, etc. [2].

Given the importance of suitable processing for medicinal plants use as raw material in obtaining phyto-therapeutic products of high quality, this paper presents the results of some experimental researches of lavender sorting as well as the processing of experimental data obtained on a dimensional sorter, in order to identify an optimum working regime.

MATERIAL AND METHOD

Lavender used in experimental determinations was purchased as chopped plant from SC Hofigal SA and afterwards processed within INMA. Four varieties of vegetal fragments were experimentally determined with sorter by varying 3 feeding rates: 90 kg/h, 60 kg/h and 30 kg/h by means of an inclined conveyer with band and four electric current frequencies: 50Hz, 45Hz, 40Hz and 35Hz with a frequency converter.

In fig.2 are presented aspects during the experimental researches.

Există 48 de specii de lavandă cu sute de diverse genotipuri diferenţiate de forma de creştere şi până la compoziţia chimică a uleiului esenţial: camfor, cariopropilen, linalool, acetat de linalil, ocimen, pinen, etc. [12]. În ţara noastră, în special în condiţiile din centrul Moldovei se cultivă soiul de lavandă ,,Codreanca"[5], omologat în anul 1992 şi, pe suprafeţe mai mici, lavandinul (*Lavandula hybrida*) reprezentat de populaţia locală ,,De Brăneşti". Propice pentru extinderea culturii lavandei şi lavandinului trebuie să se facă în partea de sud şi sud-est a ţării noastre [11].

Pe plan national s-au realizat studii pentru multiplicarea genotipurilor de lavandă cu potenţial biosintetic crescut [3] dar şi studii referitoare la valorificarea superioară prin extragerea uleiurilor volatile la plantele medicinale [4].

Obţinerea unor produse de calitate cu valoare fitoterapeutică este posibilă numai printr-o prelucrare corectă şi adecvată fiecărei specii de plantă [9]. Din punct de vedere al structurii, procesul tehnologic de prelucrare cuprinde totalitatea operaţiilor şi fazelor intercorelate necesare pentru pregătirea, respectiv trecerea materialului vegetal recoltat sau achiziţionat, într-o stare corespunzătoare depozitării, ambalării sau prelucrării ulterioare, în cadrul unei unităţi de producţie [6].

Prelucrarea primară şi avansată a diferitelor părţi din plantele medicinale se poate utiliza pentru obţinerea de uleiuri volatile, ceaiuri (pliculete, pungi), macerate, extracte vegetale, tincturi, siropuri, comprimate, coloranţi alimentari, produse cosmetice, fertilizanţi naturali, bioinsecticide etc. [2].

Dată fiind importanţa prelucrarii adecvate în vederea utilizării plantelor medicinale ca materie primă pentru obţinerea de produse fitoterapeutice şi nu numai, de calitate superioară, în această lucrare se prezintă rezultatele unor cercetări experimentale ale procesului de sortare a lavandei, precum şi prelucrarea datelor experimentale obţinute pe un sortator dimensional, în vederea identificării unui optim de lucru.

MATERIAL ŞI METODĂ

Levănţică utilizata la determinările experimentale a fost achizitionată în stadiul de tocătură de la SC Hofigal SA şi prelucrată pe sortatorul de plante tocate din cadrul INMA. Au fost determinate experimental patru sorturi de fragmente vegetale pe echipamentul de sortat variindu-se 3 debite de alimentare: 90 kg/h, 60 kg/h si 30 kg/h cu ajutorul unui transportor înclinat cu bandă şi patru frecvenţe ale curentului electric: 50 Hz, 45 Hz, 40 Hz şi 35 Hz cu ajutorul unui convertizor de frecvenţă.

În fig. 2 se prezintă aspecte din timpul desfăşurării cercetărilor experimentale.

Fig. 2 – Aspects during experimental researches

Sorter of cut plants is a mechanical equipment used for screening the vegetal products through refusal method, driven by 2 electric vibrating engines, by which means the frequency and amplitude of sifters oscillations can be varied and three slope angles of sifters, that may vary between 12-15^0 depending on the crop type. Equipment is endowed with 9 frames with sifters, used in sets of three different size square meshes, made of braided wire.

In order to separate the lavender chopped, sifters with holes of 5 mm, 8 mm and 10 mm were used. Slope angle of sifter frame was of 13.33^0, angle of slope of electro-vibrating engines in comparison with sieve plan-was of 45^0, and running time of an experiment took 30 seconds.

The interpretation of results obtained has been achieved for the four varieties by means of power function, using the percentages calculated from masses obtained. Variety 1, aimed to be obtained, was calculated with II degree polynomial function with two unknowns, with its general form shown in relation (1) [7]:

Sortatorul de plante tăiate este un echipament mecanic folosit pentru separarea produselor vegetale prin metoda refuzurilor, acționat de 2 motoare electrice vibratoare, cu ajutorul cărora se poate regla frecventa si amplitudinea oscilațiilor sitelor si trei unghiuri de inclinare ale sitelor ce pot varia între 12-15^0 funcție de tipul de cultura. Echipamentul este prevăzut cu 9 rame cu site, utilizate în seturi de câte trei cu ochiuri de dimensiuni diferite, confecționate din împletitura de sarma având forma orificiilor pătrata.

Pentru separarea tocăturii de levănțică s-au folosit sitele cu dimensiunile orificiilor de 5 mm, 8 mm şi 10 mm. Unghiul de înclinare al batiului cu site a fost de 13,33^0, unghiul de înclinare al motoarelor electrovibratoare faţă de planul sitei 45^0, iar timpul de desfășurare al unui experiment a fost de 30 secunde.

Interpretarea rezultatelor obținute s-a făcut pentru toate cele patru sorturi cu ajutorul funcției putere folosind procentele calculate din masele obținute. Sortul 1, cel dorit, s-a calculat cu ajutorul funcției polinom de grad II cu două necunoscute, având forma generală prezentată în relația (1) [7]:

$$y_{(x_1,x_2)} = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_1^2 + a_4 \cdot x_1 \cdot x_2 + a_5 \cdot x_2^2 \quad (1)$$

where:
a_0, a_1, a_2, a_3, a_4, a_5 are the coefficients of function resulted from Mathcad program;
x_1 is the flow rate Q; x_2 is the frequency f.

unde:
a_0, a_1, a_2, a_3, a_4, a_5 sunt coeficienţii funcţiei rezultaţi din programul Mathcad; x_1 este debitul Q; x_2 - frecvenţa f.

RESULTS

Experimental data characterizing the sorting process with dimensional sorter of 4 varieties, are shown in table 2.

REZULTATE

Datele experimentale ce caracterizează procesul de sortare cu ajutorul sortatorului dimensional pe 4 sorturi, sunt prezentate în tabelul 2.

Table 1

Experimental results regarding the screening of lavander fragments

Frequency [Hz]	Mass Variety 1 [kg]	Mass Variety 2 [kg]	Mass Variety 3 [kg]	Mass Variety 4 [kg]	Total mass [kg]	Experimental flow [kg/s]
50	0.478	0.038	0.021	0.012	0.549	0.0183
45	0.592	0.070	0.039	0.006	0.707	0.0236
40	0.412	0.023	0.008	0.003	0.445	0.0148
35	0.252	0.014	0.005	0.002	0.273	0.0091
50	0.408	0.028	0.016	0.006	0.458	0.0153
45	0.426	0.035	0.020	0.008	0.489	0.0163
40	0.376	0.019	0.011	0.004	0.410	0.0137
35	0.202	0.009	0.003	0.001	0.215	0.0072
50	0.198	0.010	0.007	0.003	0.218	0.0073
45	0.218	0.013	0.009	0.005	0.245	0.0082
40	0.144	0.006	0.003	0.002	0.155	0.0052
35	0.090	0.003	0.001	0.001	0.095	0.0032

Significance and dimensions of varieties masses shown in table 1 are the following:
- variety 1 mass represents the sorter lower sifter sieving, which dimensions are between 0.1...5 mm;
- variety 2 mass comprises the middle sifter sieving and lower sifter refusal and is made of vegetal waste of 5.1...8 mm;
- variety 3 mass comprises the big sifter sieving and middle sifter refusal, the vegetal fragments dimensions being of 8.1...10 mm;
- variety mass 4 represents the big sifter refusal, the vegetal fragments dimensions being over 10 mm.

Based on results obtained, the variation of screening degree for the 4 varieties was shown in graphic at different frequencies and flows (fig. 3).

Semnificația şi dimensiunile masei sorturilor prezentate în tabelul 1 sunt următoarele:
- masa sortului 1 reprezintă cernutul sitei inferioare a sortatorului cu dimensiunile cuprinse între 0,1...5 mm;
- masa sortului 2 este formată din cernutul sitei mijlocii şi refuzul sitei inferioare şi cuprinde fragmente vegetale cuprinse între 5,1...8 mm;
- masa sortului 3 este formată din cernutul sitei mari şi refuzul sitei mijlocii, cu dimensiunile fragmentelor vegetale cuprinse între 8,1...10 mm;
- masa sortului 4 reprezintă refuzul sitei mari cu dimensiunile fragmentelor vegetale mai mari de 10 mm.

Pe baza rezultatelor obținute s-a reprezentat grafic variația gradului de sortare pentru cele patru sorturi la frecvențe şi debite diferite (fig. 3).

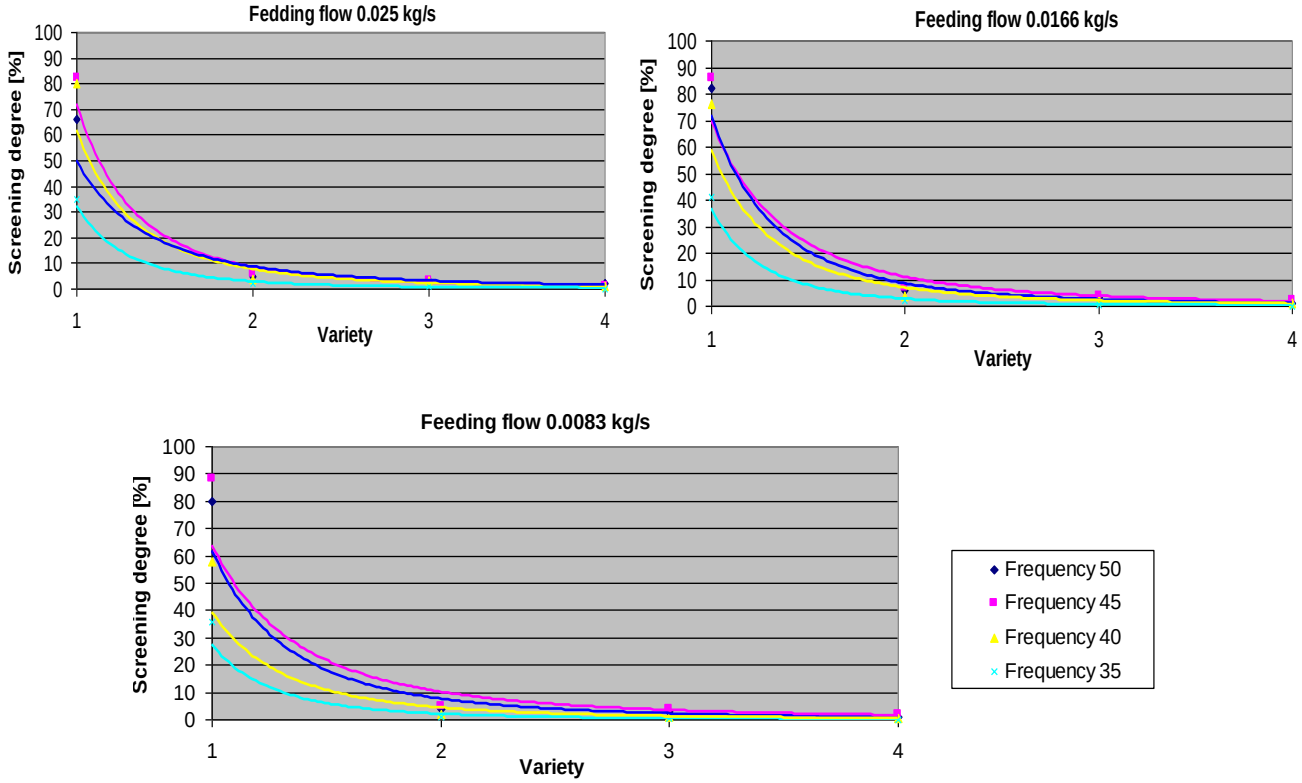

Fig. 3 – Screening degree of four dimensional varieties of lavander fragments at different frequencies and flow rates

Equations corresponding to curves shown in figure 3, expressed by power function, are:

Ecuaţiile corespunzătoare curbelor prezentate în figura 3, exprimate cu funcţia putere, sunt:

- **For Q = 0.025 kg/s**:

f 50 Hz=f(n)=49,95·n$^{-2,58}$; R^2=0,937
f 45 Hz=f(n)=72,11·n$^{-3,08}$; R^2=0,982
f 40 Hz=f(n)=61,94·n$^{-3,03}$; R^2=0,945
f 35 Hz=f(n)=32,43·n$^{-3,54}$; R^2=0,977

- **For Q = 0.0166 kg/s**:

f 50 Hz =f(n)=72,11·n$^{-3,08}$; R^2=0,982
f 45 Hz =f(n)=69,99·n$^{-2,67}$; R^2=0,966
f 40 Hz =f(n)=58,70·n$^{-3,10}$; R^2=0,962

For Q = 0.0083 kg/s:

f 50 Hz =f(n)=61,94·n$^{-3,03}$; R^2=0,945
f 45 Hz =f(n)=63,96·n$^{-2,66}$; R^2=0,919
f 40 Hz =f(n)=39,24·n$^{-3,18}$; R^2=0,924
f 35 Hz =f(n)=27,44·n$^{-3,77}$; R^2=0,972

Using the experimental data for sorting lavender chopped, for a constant value of variety 1 (desired variety) was determined the variation of sorting degree, depending on experimental flow ($Q=x_1$) and frequency ($f = x_2$). Calculation has been made by Mathcad program, using the II-nd degree polynomial function with two unknowns (relation 1).

After defining the normal equation system was calculated the correlation coefficient $R^2=0.959$, resulting in function and function coefficients replaced, as (2):

Folosind datele experimentale de la sortarea fragmentelor de levănţică, pentru valoarea constantă a sortului 1 (sortul dorit) s-a determinat variaţia gradului de sortare, în funcţie de debitul experimental ($Q=x_1$) si frecvenţă ($f = x_2$). Calculul s-a realizat în programul Mathcad folosind funcţia polinom de grad II cu două necunoscute (relaţia 1).

După definirea sistemului de ecuaţii normale s-a calculat coeficientul de corelaţie $R^2=0.959$, rezultând funcţia şi coeficienţii funcţiei înlocuiţi, de forma (2):

$$y_{(f,Q)} = -0.36 + 10.49 \cdot Q - 1.878 \cdot f + 0.063 \cdot Q^2 - 0.262 \cdot Q \cdot f + 0.08 \cdot f^2 \quad (2)$$

From figure 4, the variation of sorting degree of variety 1 can be determined based on frequency and experimental flow of sifters.

Din figura 4 se poate determina variaţia gradului de sortare pentru sortul 1, funcţie de frecvenţa şi debitul experimental al sitelor.

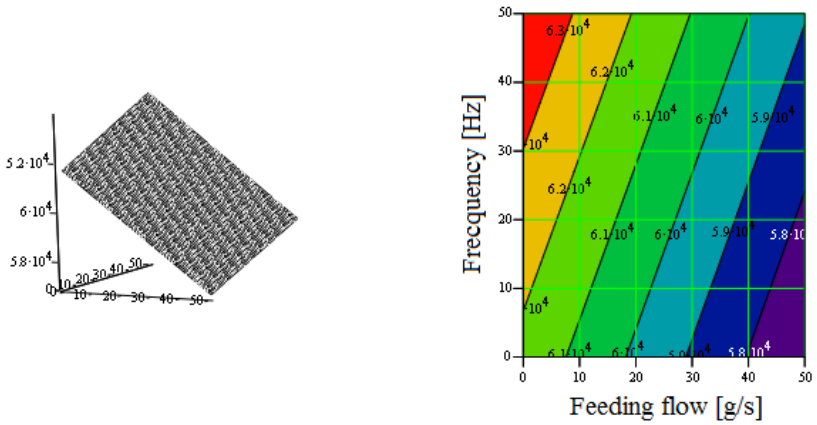

Fig. 4 – Variation of sorting degree for lavender 1 variety

In figure 5 is comparatively presented the sorting degree obtained during the 12 experiments, for experimental, respectively theoretical values.

În figura 5 se prezintă comparativ gradul de sortare obținut în cele 12 experimente, pentru valorile experimentale respectiv cele teoretice.

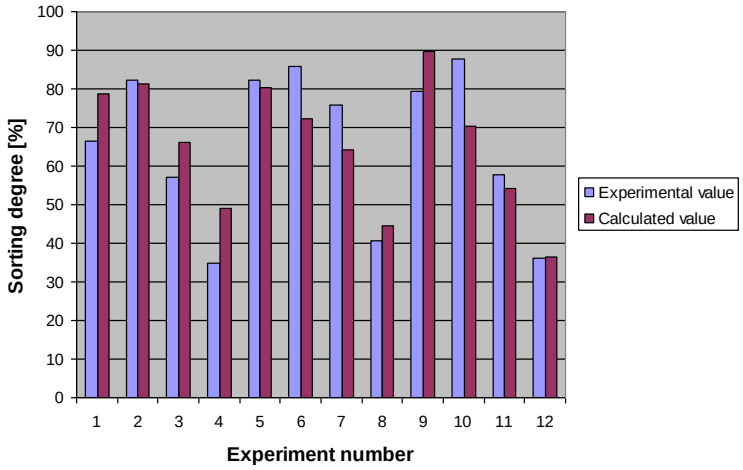

Fig. 5 – Sorting degree for variety 1 depending on frequency and experimental flow

CONCLUSIONS

In order to assure an appropriate processing, dry or fresh lavender inflorescences are mostly used for obtaining essential oils, through the method of distillation in water and/or vapour, as infusions, tinctures, oils, inhalations, baths, but they also may be contained by granules, tablets, alcoholic extracts, in perfume industry, but also as spices.

Following the analysis and interpretation of data obtained for the 4 varieties, the following have found out:

- variety 1 contains only inflorescences and is designed mainly to extraction of essential oils with maximum percentage obtained after screening; variety 2 contains inflorescences and stems and can be used at packaging in paper bags for tea; varieties 3 and 4 contain only lavender stems and are considered waste;
- parameters (frequency and flow) low values do not achieve the separation and determine fragments stratification, thus, reducing productivity and precision of screening process;
- parameters higher values increase the quantity of separated fragments and diminish sorting precision;
- optimum frequency is the small one for fragments which size is suitable for sifter holes dimensions and the big one for the smallest fragments;

CONCLUZII

În vederea prelucrarii corespunzătoare, de la levănţică se folosesc inflorescenţele uscate sau proaspete, de cele mai multe ori, pentru obţinerea de uleiuri volatile, prin metoda distilării în apă şi/sau abur; sub formă de infuzii, tincturi, uleiuri, inhalaţii, băi, dar ele pot intra şi în compoziţia granulelor, tabletelor, comprimatelor, extractelor alcoolice; în industria parfumurilor dar şi ca condiment.

Din analiza şi interpretarea datelor obţinute pentru cele 4 sorturi, se constată următoarele:

- sortul 1, conţine numai inflorescenţe şi este destinat, în principal, extracţiei de uleiuri volatile cu procentul maxim obţinut în urma sortării; sortul 2, conţine inflorescenţe şi tulpini, poate fi folosit la ambalarea în pungi de hârtie pentru ceaiuri, sorturile 3 şi 4, conţin numai tulpini, sunt considerate deşeu;
- valorile scăzute ale parametrilor (frecvenţă şi debit) nu realizeazş separarea şi determină stratificarea fragmentelor vegetale implicit reducerea productivităţii şi preciziei procesului de sortare;
- valorile mari ale parametrilor determină creşterea cantităţii de fragmente separate şi scade precizia sortării;
- frecvenţa optimă este cea mică pentru fragmentele cu dimensiuni apropiate de dimensiunile orificiilor sitei şi cea mare pentru alte fragmente, în general cele mai mici;

- optimum flow is when material stratification and sifter holes clogging are avoided; thus, at a high flow and small frequency, the fragments remain blocked on the sieves;
- following the analysis of experimental and calculated values for variety 1 of lavender, choosing the frequency of 45 Hz and an experimental flow of 0.0163 kg/s is considered to be optimum;
- from the analysis of results obtained, it has found that the dimensional sorter with oscillating plane sifters can be successfully used for sorting chopped medicinal plants, if working parameters are appropriately chosen for capitalizing the respective vegetal matter.

Data presented may be important for all the specialists and workers in the field of medicinal plants processing, especially referring to sorting operation in technological process.

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- debitul optim este cel în care nu are loc stratificarea materialului şi înfundarea orificiilor sitei; aşadar, la debit mare şi frecvenţă mică fragmentele rămân blocate pe site;
- din analiza valorilor experimentale şi calculate pentru sortul 1 la levănţică se consideră optim alegerea frecvenţei de 45 Hz şi a unui debit experimental de 0,0163 kg/s;
- din analiza rezultatelor obţinute se constată că sortatorul dimensional cu site plane oscilante poate fi utilizat cu succes pentru sortarea plantelor medicinale tocate dacă parametrii regimului de lucru sunt aleşi corespunzător pentru scopul urmărit în valorificarea materialului vegetal.

Datele prezentate pot fi importante pentru toţi specialiştii şi lucrătorii în domeniul procesării plantelor medicinale, cu referire, în primul rând, la operaţia de sortare a procesului tehnologic.

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ANALYSIS OF A CONVECTIVE DRYING PROCESS OF PLUMS
/
ANALIZA PROCESULUI DE DESHIDRATARE CONVECTIVĂ A PRUNELOR

PhD. Stud. Eng. Ingeaua M.[1)], Prof. PhD. Eng. Prisecaru T.[1)], Prof. PhD. Eng. Pirna I.[2)], PhD. Eng. Sorică C.[2)]
[1)] University Politehnica of Bucharest / Romania; [2)] INMA Bucharest / Romania
E-mail: marius_imv@yahoo.com

Abstract: *Fruits and vegetables play an important role in human nutrition providing vitamins, minerals, fibers and essential nutrients. In order to prolong the marketing of these products and ensure nutrients throughout the year, preservation by different methods of fruit and vegetables is necessary. Dehydration is one of the oldest forms of conservation of fruits and vegetables and is used in order to reduce both the water content of the product and thus the activity of microorganisms and their multiplication, and the mass and volume of products, the costs of packaging, storage and transport. This paper aims analyze a convective drying process of plums, in order to identify opportunities for the energy consumption optimization process through monitoring and controlling essential parameters like: temperature, relative humidity and air velocity, as well as automatic control algorithms of the dehydration process.*

Keywords: *convective dehydration, plum dehydration analisys, dehydration curve*

INTRODUCTION

Fruits and vegetables play an important role in human nutrition. Besides vitamins and minerals fruits and vegetables are good sources of fiber and essential nutrients that have a number of beneficial effects on health such as antioxidants, anti-inflammatory, decreasing fats and have beneficial effects on blood pressure and endocrine functions [2]. To provide these elements thought the entire year, it is necessary to preserve of fruit and vegetables by different methods. Preservation using high temperatures or exposure to oxygen leads to the loss of a significant portion of nutrients, especially vitamins, some of which are destroyed at temperatures above 40 ºC [8]. Dehydration is one of the oldest forms of conservation of fruits and vegetables [7]. The dehydration process reduces both water content of products in order to preserve them, as well as mass and volume reducing the cost of packaging, storage and transport [9]. It also reduces the activity of microorganisms and prevents their growth, which leads to the preservation of fresh edible products for a long time. After dehydration products must retain as many of their baseline characteristics such as flavor, color, nutritional value, vitamins etc.

Horticultural products contain large amounts of water, in most cases a percentage between 70% and 96%. By dehydration the content of water is reduced to percentages usually between 6% and 25%, depending on their final destination. In Table 1 presents data on fruit dehydration process [3, 4, 5, 10].

Rezumat: *Fructele și legumele joacă un rol deosebit de important în alimentația omului prin aportul de vitamine, minerale, fibre și nutrienți esențiali. În vederea prelungirii perioadei de comercializare a acestor produse în extrasezon și asigurării elementelor nutritive pe tot parcursul anului, este necesară conservarea fructelor și legumelor proaspete prin diferite metode. Deshidratarea este una dintre cele mai vechi forme de conservare a fructelor și legumelor, fiind folosită în scopul reducerii atât a conținutului de apă al produselor și implicit a activității microorganismelor și înmulțirii acestora, cât și al masei și volumului produselor, a costurilor cu ambalarea, stocarea și transportul. Lucrarea își propune să realizeze o analiză a procesului de deshidratare convectivă a prunelor, în scopul identificării posibilităților de optimizare energetică a procesului prin monitorizarea și controlul parametrilor esențiali: temperatura, umiditatea relativă și viteza aerului, precum și a algoritmilor de conducere automată a procesului de deshidratare.*

Cuvinte cheie: *deshidratare convectivă, analiza deshidratării prunelor, curbă deshidratare*

INTRODUCERE

Fructele și legumele joacă un rol deosebit de important în alimentația oamenilor. Pe lângă aportul de vitamine și minerale fructele și legumele reprezintă o sursă de fibre și nutrienți esențiali care au o serie de efecte benefice privind sănătatea cum ar fi antioxidanți, anti-inflamatorii, duc la scăderea grăsimilor și au efecte benefice asupra presiunii sângelui și a funcțiilor endocrine [2]. Pentru asigurarea acestor elemente pe întreaga perioadă a anului, este necesară conservarea fructelor și legumelor proaspete prin diferite metode. Conservarea produselor prin utilizarea temperaturilor înalte sau expunerea la oxigen duce la pierderea unei părți importante din nutrienți, în mod special de vitamine, unele dintre acestea fiind distruse la temperaturi de peste 40 ºC [8]. Deshidratarea este una dintre cele mai vechi forme de conservare a fructelor și legumelor [7]. Prin deshidratare se reduce atât conținutul de apă al produselor, în scopul conservării acestora, cât și masa și volumul lor, a costurilor cu ambalarea, stocarea și transportul [9]. De asemenea, acest proces reduce activitatea microorganismelor și împiedică înmulțirea acestora, lucru care duce la păstrarea în stare comestibilă un timp mai îndelungat al produselor. În urma deshidratării produsele trebuie să își păstreze cât mai multe dintre caracteristicile inițiale cum ar fi: gustul, culoarea, valoarea nutritivă, vitaminele etc.

Produsele horticole conțin mari cantități de apă, în majoritatea cazurilor un procent cuprins între 70 % și 96%. Prin deshidratare procentul de apă se reduce de regulă până la procente cuprinse între 6 % și 25 %, în funcție de destinația finală a acestora. În Tabelul 1 sunt prezentate date privind procesul de deshidratare a fructelor [3, 4, 5, 10].

Table 1

Fruit dehydration process parameters

Nr.	Fruit	Duration [h]	Temperature [°C]	Final Humidity content [%]	Density [kg/m^2]
1	Apricots	18…24	45…50 / 55…65	15	4…5 (halves)
2	Cherries and sour cherries	6…10	45…55 / 65…72	6…12	6…8 and 8…10
3	Peaches	6…12	55…60	16	5…6
4	Plums	24…30	50…55 / 70…75	22…24	10
5	Grapes	12…20	50…55 / max. 70	13…20	8…10
6	Apples (slices)	6…10	50…60 / 70…72	5-12	6
7	Pears (slices)	5…9	45…50 / 65…70	10…12	13
8	Quince (slices)	6…8	65…70	22	10
9	Bananas (slices)	6…8	70	5-15	4…6
10	Strawberries (slices)	5…8	50…60	9-12	7…8

In case of fruits and vegetables, the dehydration can be done immediately after harvest to reduce their weight and size. Thus by applying dehydration early in the process chain can reduce the weight and volume of products thereby reducing transportation and storage costs.

Before dehydrating, fruits and vegetables are prepared by blanching or steaming to increase cell membrane permeability. Products prepared this way can be dehydrated more easily than uncooked products. Products may be sulfured or dipped in lemon juice to prevent color change during dehydration.

Depending on the subsequent use of products and their characteristics, fruits and vegetables can be dehydrated to a water content percentage that will not harm their characteristics. To keep the vegetables in optimal conditions, dehydration should be stopped at percentages ranging between 6 and 10%. In the case of fruit this percentage may be higher than in vegetables and can be between 12 and 25%.

Dehydration process leads to some changes in the products:

- decrease the volume;
- migration of soluble constituents;
- thermal browning;
- warp;
- reversibility of tissue;
- loss of volatile substances;

MATERIAL AND METHOD

For the analysed process we used convective dehydration, the most common method of dehydration of fruits and vegetables (Fig. 1), which uses a heat source and an agent for removing water vapor from the surface of the body subject to dehydration.

În cazul unor fructe și legume deshidratarea se poate realiza imediat după cules pentru reducerea masei și volumului ocupat de acestea. Astfel prin aplicarea deshidratării cât mai devreme în lanțul tehnologic se poate reduce greutatea și volumul produselor reducând astfel costurile cu transportul și depozitarea.

Înainte de deshidratare fructele și legumele sunt preparate prin opărire sau aburire pentru mărirea permeabilității membranelor celulare (blanșare). Produsele astfel preparate pot fi deshidratate mai ușor decât produsele nepreparate. Produsele se pot sulfata sau imersa în zeamă de lămâie pentru evitarea schimbării culorii în timpul deshidratării.

În funcție de utilizarea ulterioară a produselor cât și a caracteristicilor acestora, fructele și legumele pot fi deshidratate până la procente de umiditate care nu deteriorează caracteristicile acestora. Pentru păstrarea legumelor în condiții optime, deshidratarea trebuie facută până la procente cuprinse între 6 și 10 %. În cazul fructelor acest procent poate fi mai ridicat decât în cazul legumelor și poate fi cuprins între 12 și 25 %.

Procesul de deshidratare duce la unele schimbări ale produselor:

- micșorarea volumului;
- migrarea componentelor solubile;
- brunificarea termică;
- scorojirea;
- reversibilitatea țesuturilor;
- pierderea substanțelor volatile.

MATERIAL ŞI METODĂ

Pentru procesul analizat am folosit deshidratarea convectivă, cea mai răspândită metodă de deshidratare a fructelor și legumelor (fig. 1), în care se folosește o sursă de căldură și un agent pentru îndepărtarea vaporilor de apă de pe suprafața corpului supus deshidratării.

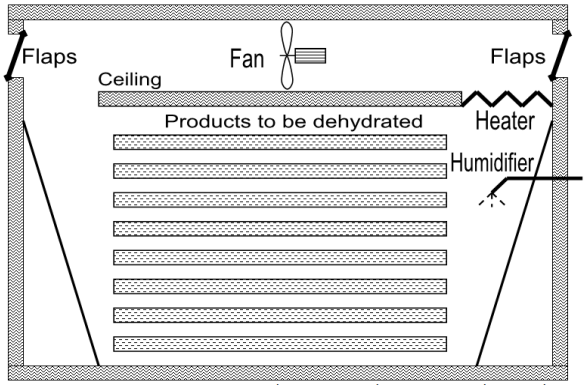

Fig. 1 - Chamber for convection dehydration - schematic drawing

To achieve a higher drying speed, the fruits have been cut in halves. [6]

In order to study the convective drying process of plums, we used a dehydration plant equipped with an automation system and a system for recording air parameters and mass of the products placed on one of its trays (Fig. 2).

Pentru a obține o viteză de deshidratare mai bună, au fost rupte în jumătăți. [6]

În vederea studierii procesului de deshidratare convectivă a prunelor, s-a utilizat o instalație de deshidratare dotată cu un sistem de automatizare și un sistem pentru înregistrarea parametrilor aerului cât și a masei produselor așezate pe una dintre tăvile acestuia (fig.2).

Fig. 2 - Dehydration plant equipped with automation and monitoring system

Our dehydration process (Fig. 3) was divided into several main phases: heating, drying and cooling.

Procesul de deshidratare analizat (fig. 3) a fost împărțit în câteva faze principale: încălzirea, uscarea propriu-zisă și răcirea.

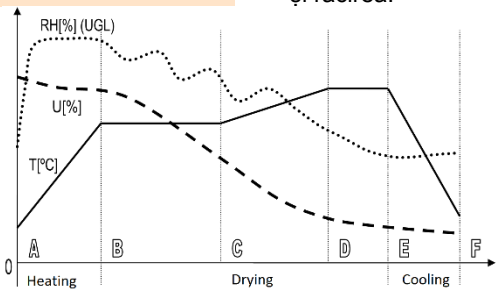

Fig. 3 - Dehydration stages

Heating (AB) was done in a saturated atmosphere to heat the products in a controlled manner. In a saturated atmosphere, the heat input is transferred to the products because the evaporation is stopped. The heating gradient was set to 20 ºC/h. From the moisture chart we can see that drying curve falls very little in this phase, only as necessary to carry out air saturation. In most cases, heating is done in an atmosphere in which the partial pressure of the vapor on the surface of the products and the air's are equal (RH <100%).

Drying itself (BE) was realized by rising the temperature from 50 to 68ºC in a 12 hour interval, at the same time venting out the moisture. For moisture exhaust, the flaps C1 and C2 were commanded in phase, while C3 was in antiphase to reduce air recirculation. The dehydration was stopped after 12 hours because we gathered all the necessary data for our analysis, dehydrating further being unnecessary for our purpose.

Cooling (EF) was done for 1 hour by venting in fresh air with 0% recirculation.

The plant has an enclosure made of polystyrene insulated panels and walls of stainless steel sheet, 24 perforated trays with dimensions of 0.62 x 0.62 m and a total drying area of 9.2 m².

As actuators, the installation presents: a fan of 0.75 kW / 1450 rpm for circulating hot air through the enclosure; a hot water heater for heating the air with the water inlet temperature of 70-90 ° C provided by a boiler that runs on wood chips or sawdust, with a maximum power of 75 kW; two flaps for venting out moisture and a flap for air recirculation obstruction. The dehydration plant's layout is shown in Fig. 4.

Încălzirea camerei (AB) a fost făcută în atmosferă saturată pentru a încălzi cât mai controlat produsele. În atmosferă saturată toată căldura introdusă în incintă este cedată produselor deoarece evaporarea este oprită. Gradientul de încalzire a fost de 20 ºC/h. Din graficul curbei de uscare se observă că umiditatea produselor scade foarte puțin în această fază, numai cât este necesar pentru a duce aerul la saturare. În majoritatea cazurilor încalzirea se face în atmosferă în care presiunea parțială a vaporilor de pe suprafața produselor și cea a vaporilor din aer sunt egale (RH < 100%).

Uscarea propriu-zisa (BE) a constat în ridicarea temperaturii de la 50 la 68 ºC într-un interval de 12 ore concomitent cu evacuarea umidității. Pentru evacuarea umidității și admisia de aer proaspăt erau acționate clapetele C1 și C2 în fază, iar C3 era acționată în antifază pentru obturarea recircularii aerului. Procesul de deshidratare a fost oprit dupa 12 ore deoarece am obtinut datele relevante necesare analizei, ne mai fiind necesară deshidratarea până la final.

Răcirea (EF) s-a efectuat pe durata a 1 oră prin aport de aer proaspăt și cu 0% recirculare.

Instalația are o incintă construită din panouri cu izolație din polistiren și pereți din inox, 24 tavi din tablă de inox perforat cu dimensiunile de 0.62 x 0.62 m și o suprafață totală de uscare de 9.2 m².

Ca elemente de execuție, instalația prezintă: un ventilator de 0.75 kW/1450 rpm pentru vehicularea aerului cald prin incintă; un radiator pentru încălzire alimentat cu apă caldă la temperatura de 70-90 ºC furnizată de o centrală termică care funcționează cu tocătură sau rumeguș, cu o putere maximă de 75 kW; două clapete pentru evacuarea aerului umed și o clapetă pentru obturarea recirculării aerului. Schema instalației de deshidratare este prezentată în Fig. 4.

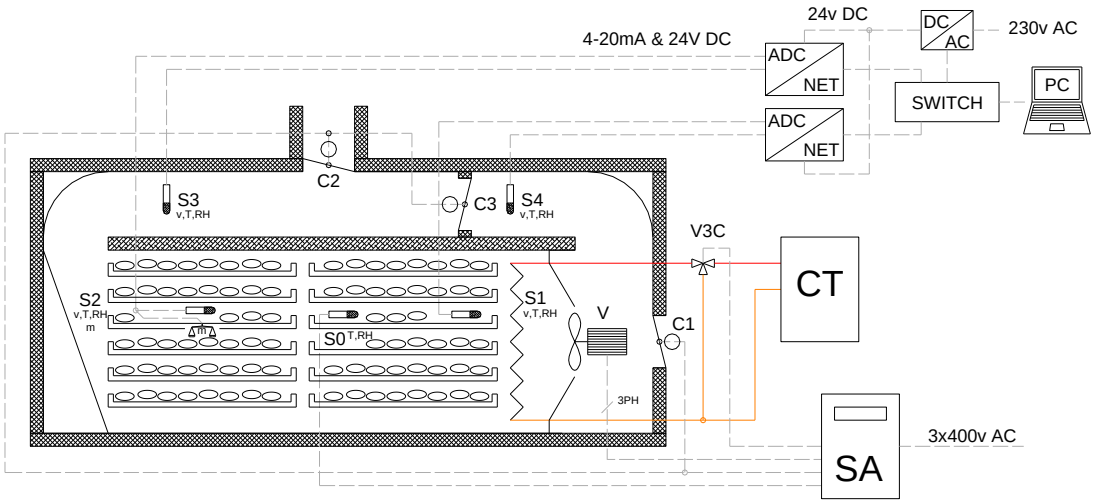

Fig. 4 - Dehydration plant layout

The significance of the elements in Figure 4 is as follows: S0 - T + RH probe for the automation system; S1 - v + T + RH probe placed immediately after the radiator; S2 - v + T + RH probe located between product trays; m - the load cell located under the middle tray; S3 - v + T + RH probe located prior to air discharge; S4 – v + T + RH probe placed after air recirculation obstruction flap; C1 - fresh air intake flap; C2 - moist air exhaust flap; C3 - recirculation obstruction flap.

Measuring accuracy in the working ranges are as follows: for temperature the accuracy is ± 0.4 °C, for relative humidity the accuracy is ± 2.5% RH, for specific humidity the accuracy is ± 2 g/kg, and for air velocity the accuracy is ± (0.10 m/s + 1% of reading). The values are written in the database at a configurable interval, in this case being set at 10 seconds. The program generates an Access 2003 database, and the data can be exported in various formats used for further processing. The experiment consisted in 60 kg of plum dehydration. Plums were washed, sectioned in half and pits removed. Following these operations the remaining mass was 50 kg of products.

RESULTS

Pitted fruit's initial mass was 50 kg and the final mass after completion of the drying process was 15.2 kg, resulting for a product with 85% water content such as plums, i.e. 42.5 kg of water in fruits submitted dehydration, remained 7.7 kg water after dehydration, i.e. 50.6% moisture in the product dehydrated. The drying lasted about 12 hours. Products and dehydration chart are shown in Figures 5 and 6.

Semnificația elementelor din figura 4 este următoarea: S0 – sondă T+RH destinată sistemului de automatizare; S1 – sondă T+RH+v amplasată imediat dupa radiator; S2 – sondă T+RH+v amplasată între tăvile cu produse; m – doză tensometrică amplasată pe tava din mijloc; S3 – sondă T+RH+v amplasată înainte de evacuare; S4 – sondă T+RH+v amplasată după clapeta de oprire a recirculării; C1 – clapetă de admisie aer proaspăt; C2 – clapetă de evacuare aer umed; C3 – clapetă pentru oprirea recirculării.

Precizia de măsurare în gamele de lucru se prezintă astfel: pentru temperatură, precizia este de ± 0.4 °C, pentru umiditatea relativă de ± 2.5 % RH, pentru umiditatea specifică de ±2 g/kg, iar pentru viteza aerului de ± (0.10 m/s + 1 % din valoarea masurată). Înregistrarea valorilor în baza de date se face la un interval configurabil, în cazul de față acesta fiind de 10 secunde. Programul generează o bază de date de tip Access 2003, datele din acesta putând fi exportate în diverse formate utilizate pentru prelucrări ulterioare. Experimentul a constat în deshidratarea a 60 kg de prune. Prunele au fost spălate, secționate în jumătați și sâmburii au fost înlăturați. În urma acestor operații masa acestora a fost de 50 kg de produse.

REZULTATE

Masa inițială a fructelor fără sâmburi a fost de 50 kg, iar masa finală după încheierea procesului de uscare a fost 15.2 kg, rezultând ca pentru un produs cu conținut de apă de 85%, cum ar fi prunele, 42.5 kg este apă în fructele proaspete, iar la final a rămas 7.7 kg apă, adică 50.6% umiditate în produsul deshidratat. Uscarea a durat aproximativ 12 ore. Produsele și graficul de deshidratare sunt prezentate în figurile 5 si 6.

Fig. 5 - Aspect products before, during and after dehydration

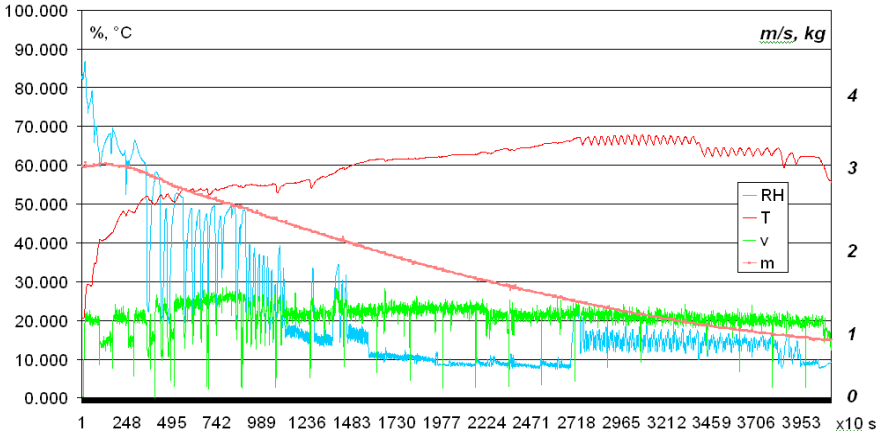

Fig. 6 - Plum drying chart

Air parameters variation during the drying process of plums for a period of 400 seconds is shown in Figure 7. We analyzed various parameters over several successive periods inside the air exhaust, a period being the time elapsed between the closing of the flaps, e.g. sample 1 and the next time the flaps are closing, sample 14 in this case.

Variația parametrilor aerului în timpul procesului de deshidratare a prunelor pe o perioadă de 400 de secunde, este prezentată în Figura 7. S-a analizat variația parametrilor de-a lungul mai multor perioade succesive de evacuare a aerului din incintă, o perioadă reprezentand timpul scurs între momentul închiderii clapetelor, de exemplu eșantionul 1 și următorul moment de închidere al acestora eșantionul 14 în cazul de față.

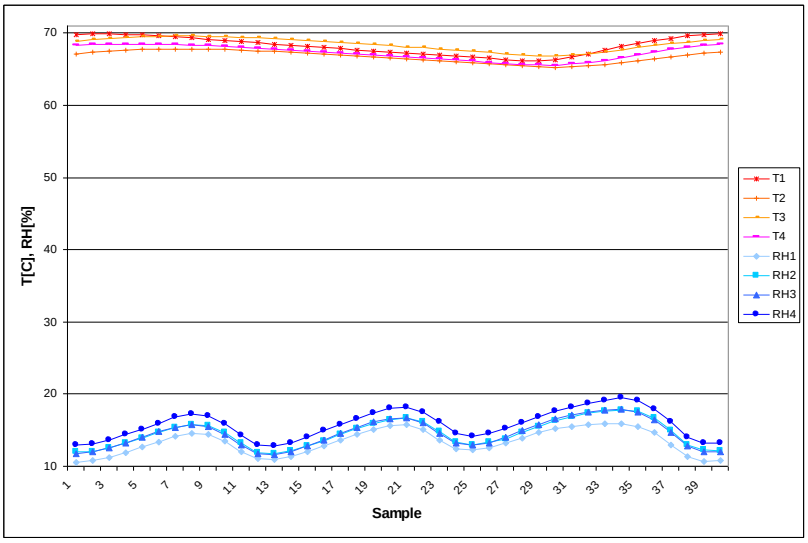

Fig. 7 - Air's parameter values in an interval of 400 seconds during the drying process studied (10 second samples)

The trial was set for total recirculation and air inside exhausted upon reaching a relative humidity threshold high enough to provide meaningful data for the analysis. Samples were extracted during the slow dehydration period because it has the longest time of all phases and improving its effectiveness, the efficiency of the entire process will be influenced. To analyze the process the flaps closing moments were chosen (samples 1 and 14) and flaps opening moments (samples 9 and 22). After closing the flaps, inside relative humidity increases between samples 1 and 9, and falls between samples 10-13 after flaps closing. The process is repeated in the subsequent intervals. For a quantitative analysis of the process we analyzed the amount of moisture in the air, because relative humidity cannot provide relevant information. Thus, the amounts of moisture values were calculated and the graph plotted in Figure 8.

Procesul a fost configurat pentru recircularea totală a aerului din incinta și evacuarea acestuia în momentul atingerii unui prag al umidității relative suficient de mare pentru a furniza date relevante analizei. Eșantioanele au fost extrase din perioada de deshidratare lentă deoarece aceasta are cel mai lung timp dintre toate fazele și prin îmbunătățirea eficienței acesteia, eficiența întregului proces va fi influențată. Pentru analiza procesului s-au ales momentele închiderii clapetelor (eșantioanele 1 și 14) și deschiderii clapetelor (eșantioanele 9 și 22). După închiderea clapetelor, umiditatea relativă din incintă crește în intervalul 1-9, iar din momentul deschiderii clapetelor aceasta scade în intervalul 10-13. Procesul se repetă similar în continuare în intervalele următoare. Pentru o analiză cantitativă a procesului am analizat cantitatea de umiditate din aer, deoarece umiditatea relativă nu poate oferi informații relevante. Astfel s-au calculat valorile cantității de umiditate și s-a trasat graficul din Figura 8.

$$x_n = 0.622 \cdot \frac{\varphi_n \cdot p_{As}}{p_B - \varphi_n \cdot p_{As}}, \text{ [kg/kg]} \quad (1)$$

where:

x_n is the water vapor content [kg/kg];

φ – is the relative humidity [RH % / 100];

p_{As} - water vapor saturation pressure at the temperature at which the calculation is made [bar];

p_B – Atmospheric pressure [bar].

With these values we can analyze various parameters such as the amount of moisture vaporized from the surface of the products, the amount of moisture discharged from the system and the rate of vaporization.

The amount of moisture vaporized from the product's surface reported per kg of air is represented by the difference between the amount of moisture measured by the sensor S1 placed before the products and its value measured by the sensor S3 placed after the products. The variation of this parameter is shown in Figure 9.

unde:

x_n este cantitatea de vapori de apă în aer [kg/kg];

φ – umiditatea relativă [RH % / 100];

p_{As} - presiunea de saturație a vaporilor de apă la temperatura la care se face calculul [bar];

p_B – presiunea atmosferică [bar].

Cu ajutorul acestor valori se pot analiza mai mulți parametri cum ar fi: cantitatea de umiditate vaporizată de pe suprafața produselor, cantitatea de umiditate evacuată din instalație și viteza de vaporizare.

Cantitatea de umiditate vaporizată de pe suprafața produselor raportată la un kg de aer este reprezentată de diferența dintre cantitatea de umiditate măsurată de senzorul S1 amplasat înaintea produselor și valoarea acesteia măsurată de către senzorul S3 amplasat după produse. Variația acestui parametru este prezentată în Figura 9.

$$dx_{3-1t}(n) = x_3(n) - x_1(n), \quad (2)$$

where *n* is the sample number.

unde *n* reprezintă indicele eșantionului.

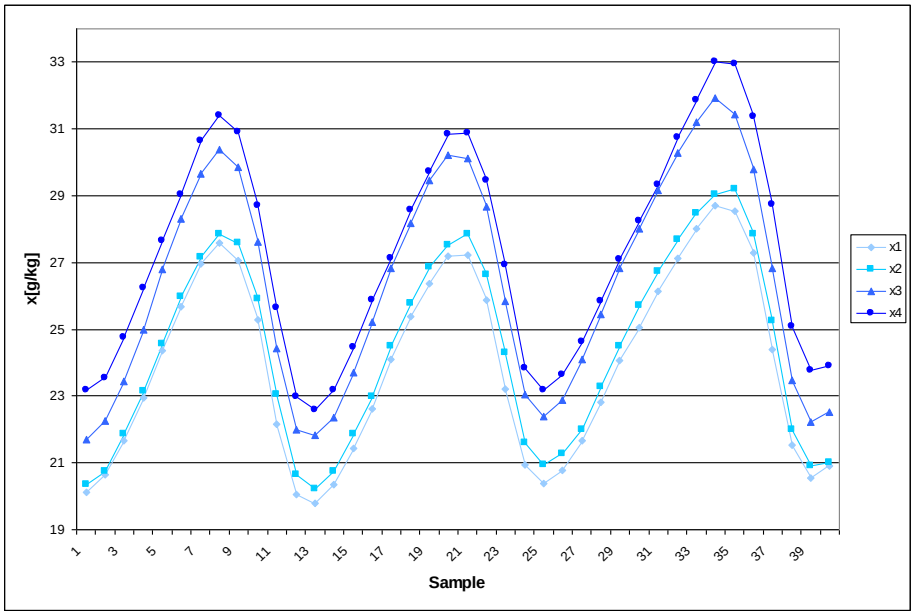

Fig. 8 - The values of the amount of moisture in the air

Since sensor calibration showed a measuring error for dx_{3-1}, the corrected real value becomes:

Deoarece calibrarea senzorilor a indicat o eroare de măsurare pentru dx_{3-1}, valoarea reală corectată a acesteia devine:

$$dx_{3-1r}(n) = x_3(n) - x_1(n) - \dot{\varepsilon}_{dx_{3-1}}; \qquad \dot{\varepsilon}_{dx_{3-1}} = 1.923 \text{ g/kg} \quad (3)$$

By integrating the curve we can calculate the total amount of vaporized moisture that can provide important data on process speed, remaining time, etc.

For the analyzed system, the difference between the previous values indicated by the S3 sensor and the current values of the S1 sensor will indicate the amount of moisture discharged from the system.

Prin integrarea curbei se poate calcula cantitatea totală de umiditate vaporizată, valoare care ne furnizează date importante privind viteza procesului, timpul ramas, etc.

În cazul instalației analizate, diferența dintre valorile anterioare indicate de către senzorul S3 și cele actuale ale senzorului S1 ne va indica cantitatea de umiditate evacuată din instalație.

$$dx_{3'-1t}(n) = x_3(n-1) - x_1(n) \quad (4)$$

where *n* is the sample number, and the real value corrected with the measuring error is:

unde *n* reprezintă indicele eșantionului, iar valoarea reală corectată cu eroarea de măsurare este:

$$dx_{3'-1r}(n) = x_3(n-1) - x_1(n) - \dot{\varepsilon}_{dx_{3-1}} \quad (5)$$

Figure 10 shows the trend of this parameter.

If a process that takes place in optimal conditions, the integrals of these curves will be equal to the amount of moisture vaporized or amount of moisture discharged from the system.

În Figura 10 este trasată variația acestui parametru.

În cazul unui proces care se desfășoară în condiții optime, integralele acestor curbe vor fi egale cu cantitatea de umiditate vaporizată, respectiv cantitatea de umiditate evacuată din instalație.

$$m_{vap} = \int dx_{3-1}\delta t \ ; \ m_{ev} = \int dx_{3'-1}\delta t \quad (6)$$

Because we have discrete values we summarize these values and we get the amount of moisture vaporised per unit of mass of fluid that is circulated:

Deoarece dispunem de valori discrete vom însuma aceste valori și vom obține cantitatea de umiditate vaporizată raportată la unitatea de masă a fluidului în care se face difuzia:

$$m_{vap} = \sum_1^{40} dx_{3-1}(n) = 21.463 \text{ g/kg} \quad (7)$$

and the amount of moisture discharged from the system compared to the same unit mass is:

și cantitatea de umiditate evacuată din instalație raportată la aceeași unitate de masă ca fiind:

$$m_{ev} = \sum_1^{40} dx_{3'-1}(n) = 21.398 \text{ g/kg} \quad (8)$$

The difference between the two values is the amount of moisture exhausted out of the enclosure:

Diferenta dintre cele două valori reprezintă cantitatea de umiditate neevacuată din incintă, avand valoarea de:

$$\Delta x = m_{vap} - m_{ev} = 0.0648 \text{ g/kg} \quad (9)$$

Note that the two values are very close, indicating that not all of the moisture has been evacuated from the system.

Observăm că cele două valori sunt foarte apropiate, ceea ce indică faptul ca nu toată cantitatea de umiditate a fost evacuată.

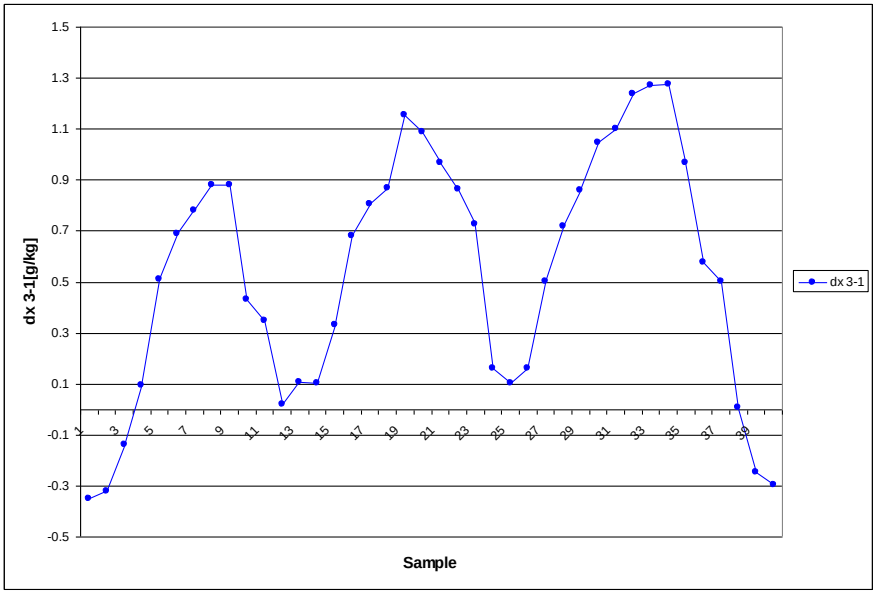

Fig. 9 - The amount of moisture vaporized from the surface of the products dx_{3-1} [g/kg]

To quantify the real value of the amount of moisture in the air the values must be reported for the mass of the air being circulated. Because in the experiment we used sensors to measure air velocity, we can calculate the mass flow rate of air circulated so the mean air velocity in the examined time being:

Pentru a putea cuantifica valoarea reală a cantității de umiditate valorile trebuiesc raportate la masa aerului supus măsuratorilor. Datorită faptului ca în experiment am utilizat și senzori pentru măsurarea vitezei aerului, vom calcula debitul masic de aer vehiculat, astfel viteza medie a aerului în intervalul de timp analizat fiind de:

$$\bar{v}_3 = \frac{\sum_1^{40} v_3(n)}{40} = 4.93 \text{ m/s} \quad (10)$$

for the sensor S3, in a flow section of $0.69m \times 0.4m$, meaning a flow surface S of $0.276m^2$. This being said, the air mass flow is:

în dreptul senzorului S3, într-o secțiune de curgere cu dimensiunile de $0.69m \times 0.4m$, adică o suprafață S de $0.276m^2$. Astfel debitul masic de aer este:

$$\dot{m}_3 = \rho_{aer} \cdot \bar{v}_3 \cdot S = 1.03\frac{kg}{m^3} \cdot 4.93\frac{m}{s} \cdot 0.276m^2 = 1.401 \text{ kg/s} \quad (11)$$

where ρ_{aer} is the air density at an average temperature of 68 ºC. The same mass air flow is at sensor S1 and also on the product's surface, but the velocity is less because the flow section is larger. The average flow velocity in this area is:

unde ρ_{aer} este densitatea aerului la temperatura medie de 68 ºC. Același debit de aer este și în dreptul senzorului S1 și pe suprafața produselor, dar viteza de curgere este mai mică deoarece secțiunea de curgere este mai mare. Viteza medie măsurată de curgere a aerului în această zonă este:

$$\bar{v}_1 = \frac{\sum_1^{40} v_1(n)}{40} = 1.0549 \text{ m/s} \quad (12)$$

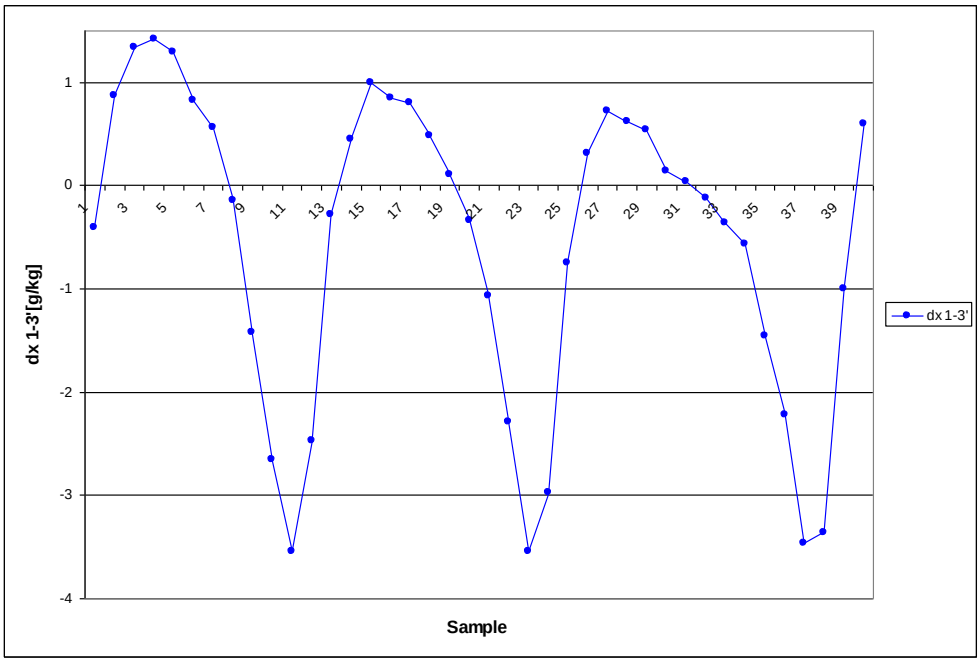

Fig. 10 - The amount of moisture discharged from the system $dx_{1-3'}$ [g/kg]

If we multiply the value of $dx_{3-1}(n)$ with the air flow mass $\dot{m}_3$, we will get the speed of moisture vaporization from the product's surface in respect to the unit of time $\dot{m}_{3-1}$:

Daca înmulțim valoarea lui $dx_{3-1}(n)$ cu debitul masic de aer $\dot{m}_3$, vom obține viteza de vaporizare a umidității de pe suprafața produselor raportată la unitatea de timp $\dot{m}_{3-1}$:

$$\dot{m}_{3-1} = dx_{3-1} \cdot \dot{m}_3 \text{, [g/s]} \quad (13)$$

where $\Delta t = 10s$ is the time interval between two consecutive samples.

In the period considered, the mass of vaporized moisture from the surface of products is:

unde $\Delta t = 10s$ este intervalul de timp între două eșantioane succesive.

În intervalul de timp analizat, masa umidității vaporizate de pe suprafața produselor este:

$$m_{total} = \sum_1^{40} (\dot{m}_{3-1}) \cdot \Delta t = 300.7 \text{ g} \quad (14)$$

For the period considered, the average surface speed of vaporization is:

Pentru intervalul de timp analizat, viteza de vaporizare medie pe suprafața produselor este:

$$\overline{\dot{m}}_{1-40} = \frac{\dot{m}_{total}}{t_{total}} = \frac{300.7g}{400s} = 0.752 \text{ g/s} \quad (15)$$

To plot the specific moisture content based on dry material, versus time, the Henderson-Pabis model can be used [1]:

Pentru trasarea graficului conținutului de umiditate specific raportat la materialul uscat, în funcție de timp, poate fi folosit modelul Henderson-Pabis cu ecuația [1]:

$$m_c = \frac{m_a}{m_s} = a \cdot e^{-k \cdot t}, \text{ [kg/kg]} \quad (16)$$

where: m_a is the moisture content;
m_s = is the mass of the solid content;
$a = 5.906$ and $k = 0.000369$ are calculated coefficients.
So, for the studied process, the equation is:

unde: m_a este conținutul de umiditate;
m_s = masa substanței solide;
$a = 5.906$ si $k = 0.000369$ - coeficienții calculați.
Astfel, pentru procesul studiat ecuația devine:

$$m_c = 5.906 \cdot e^{-0.000369 \cdot t}, \; R^2 = 0.9985 \quad (17)$$

where *t* is the time, measured in tens of seconds.
For an accurate calculation of coefficients the time period between the beginning and the end of the dehydration was examined, ignoring irrelevant information during heating.

unde *t* reprezintă timpul în zeci de secunde.
Pentru calcularea cât mai exactă a coeficienților, s-a analizat perioada de timp între începutul deshidratării și sfârșitul acesteia, ignorând datele nerelevante din timpul încălzirii.

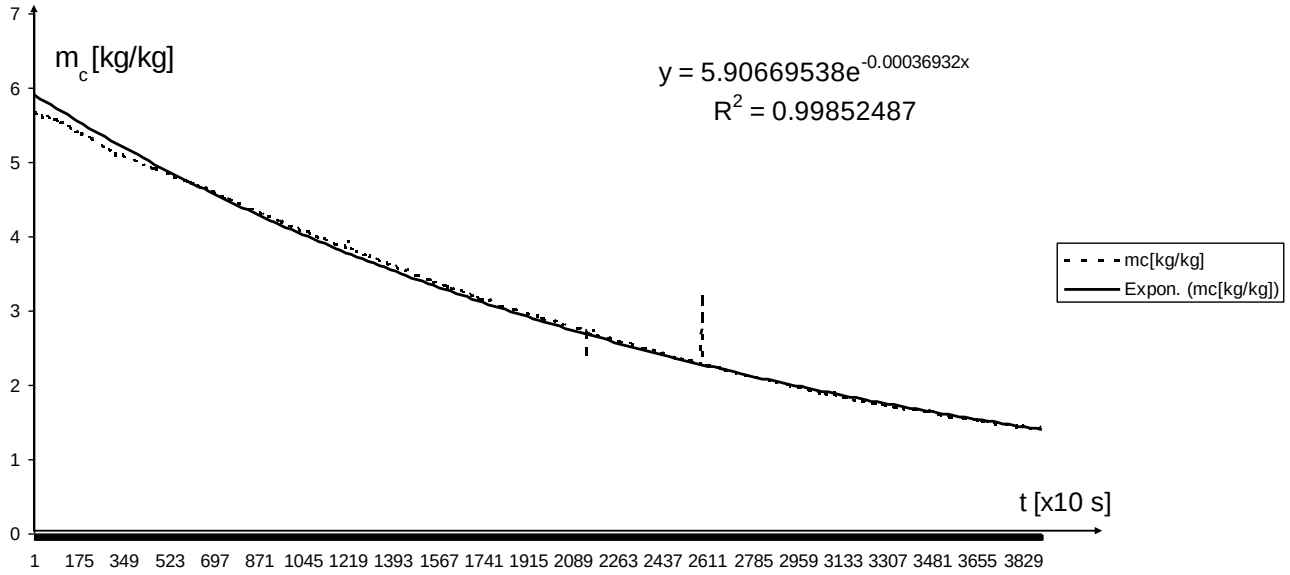

Fig. 11 - The amount of moisture depending on time

CONCLUSIONS

For effective control of dehydration equipment we need at least two sets of sensors placed before and after the products subjected to the process. Through this site we obtain vital information for increasing the process efficiency.

Using the calculated values we can get some important information regarding the development of the process even during dehydration, such as: the time until the end of the process, energy consumption, internal and external temperature of the products etc. The process time is a useful parameter that can be estimated after the passing of a certain time from the process because we need some data on the speed of dehydration to use a mathematical model such as Newton, Page, logarithm etc.

CONCLUZII

Pentru controlul eficient al unei instalații de deshidratare avem nevoie de cel puțin două seturi de senzori amplasate înainte și după produsele supuse procesului. Prin acest amplasament obținem informații vitale în eficientizarea acestuia.

Cu ajutorul valorilor calculate se pot afla informații importante privind desfășurarea procesului de deshidratare chiar în timpul acestuia, cum ar fi: durata până la sfârșitul procesului, consumul energetic, temperatura interioară și exterioară a produselor etc. Durata procesului este un parametru folositor care poate fi estimat după scurgerea unui anumit timp din proces deoarece avem nevoie de date privind viteza de deshidratare pentru a o introduce într-un model matematic cum ar fi Newton, Page, Logaritmic etc.

The temperature of the inner and outer surfaces of the products can be calculated using the wet bulb temperature, since we know that the products have this surface temperature, so their inside must be at a lower or equal temperature of the wet bulb.

Due to the large measurement error of the sensors for this analysis, a calibration is required before starting the process. This eliminates the need for absolute calibration of each sensor which leads to savings in time and money. It is well known that a relative humidity sensor regardless of the method of transforming the physical size to electrical quantities can provide at best modest measurement accuracy. Because the environment in which they are used, these sensors would require a calibration pretty quick, but by implementing a relative calibration we can increase this interval as accurate absolute values we would provide more relevant information than obtained by a precision close to that provided by the manufacturer. After the relative calibration of the sensors can we choose to assign an offset value to one of the RH sensors so its value can be used in calculations and process control.

The Henderson-Pabis model, offers a good precision for the plum's dehydration process analysis with a square root error of: $R^2 = 0.9985$.

The data obtained from experimentation will allow optimization of automatic control algorithms and the entire dehydration process in order to improve its overall efficiency.

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Temperatura interioara și cea exterioară a produselor pot fi calculate cu ajutorul temperaturii termometrului umed, deoarece știm că suprafața produselor se află la acea temperatură, deci interiorul acestora se va afla la o temperatură cel mult egală cu temperatura termometrului umed.

Datorită erorii de măsurare a senzorilor, este necesară o calibrare relativă a acestora înainte de pornirea efectivă a procesului. Acest proces elimină necesitatea calibrării absolute a fiecarui senzor ceea ce conduce la economii de timp și financiare. Este bine cunoscut că un senzor pentru umiditate relativă în funcție de metoda de transformare a mărimii fizice în marime electrică poate oferi precizii de măsurare cel mult modice. Datorită mediului în care sunt utilizați, acești senzori ar necesita o calibrare destul de deasă, dar prin implementarea unei calibrări relative putem mări acest interval de calibrare deoarece valorile absolute exacte nu ne-ar oferi informații mai relevante decât obținem printr-o precizie apropiată de cea oferită de producator. După calibrarea relativă vom alege unul dintre senzori de RH pentru a i se atribui o valoare de offset pentru ca valoarea să poată fi utilizată în calcule și controlul procesului.

Modelul Henderson-Pabis oferă o precizie bună pentru analiza procesului de deshidratare al prunelor cu un coeficient de corelație $R^2 = 0.9985$.

Datele obținute în urma experimentării vor permite optimizarea algoritmilor de conducere automată a procesului de deshidratare în vederea eficientizării acestui proces.

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EXPERIMENTAL ASPECTS REGARDING SEED SEPARATION WITH MECHANICAL SEPARATING MACHINES WITH DRUMS
/
ASPECTE EXPERIMENTALE PRIVIND SEPARAREA SEMINŢELOR LA MAŞINILE DE SEPARARE MAGNETICĂ PE TAMBURI

[1, 2)]Ph.D. Stud. Eng. Ciobanu V., [2)] Prof. Ph.D. Eng. Căsăndroiu T., [1, 2)]Ph.D. Stud. Eng. Persu C., [1)] Ph.D. Eng.Păun A., [1)] Ph.D. Eng. Muraru V.
[1)]INMA Bucharest / Romania
[2)] Politehnica University of Bucharest, Faculty of Biotechnical Systems Engineering / Romania
Tel: 0768656306; E-mail: dns.gabriela@yahoo.com

Abstract: *In the paper is presented a method for the mechanical separation of seeds using cleaning and sorting machines with drums in order to obtain a seed material destined for sowing that corresponds to the legal quality demands. Experimental researches were conducted in which the influence of the main parameters on the behavior of seeds in the process of separation on the surface of magnetic drums was followed.*

Keywords: *magnetic separation, seeds, magnetic drum, speed of revolution, dodder*

INTRODUCTION

One of the most dangerous groups of parasite weeds that affect both the quality of agricultural productions and the animal health is dodder [5, 11, 15, 16, 17].

Preventing the spreading of dodder is a compulsory work for all plant growers and for all units in charge of ensuring high agricultural yields, because if measures of combat are not taken early, dodder multiplies very rapidly and, as it expands, plants dry out and perish, the yield of cultivated plants being reduced to up to 90% or even to 100%. [5, 16, 17]

Damages caused by dodder to the agricultural crops are significant, the percentage of its presence in the cultivated plants being of: 50-75% in tomatoes, 70-90% in carrots, 50% in beans, 50% in sugar beet, 87% in lentil, 60% in lupine beans, 58% in pea, 80% in blueberries, 86% in chickpea, 60-85% in alfalfa, 80-100 % in clover [1, 5, 8, 9, 10, 12, 13, 18, 20].

Obtaining rich and quality crops is ensured by using for sowing a seed material "free" of dodder weed, corresponding to the legal quality demands [5, 6, 7, 17].

The seeds of parasite weeds, quarantine plants, especially dodder seeds are very hard to separate from the mass of seeds of the base crop, because the shape, size and aerodynamic properties of these seeds are almost identical to the ones of the plants grown. [4, 5, 6, 11].

In this case, for a total separation was elaborated the method of separating by magnetic means, which requires cleaning and sorting equipment based on the principle of separating using magnetic drums, [2, 5, 7], similar to the method of separating metal powders from the metal industry encountered as early as the XVIII – XIX centuries, receiving a significant development in the beginning of the XX century, in Sweden [3, 19].

Numerous theoretical and experimental studies were dedicated to the phenomenon of separating by magnetic means in the field of mine industry and ceramic

Rezumat: *În lucrare se prezintă o metodă de separare pe cale magnetică a seminţelor care utilizează maşini de curăţire şi sortare cu tamburi în vederea obţinerii unui material semincer destinat însămânţării care să corespundă cerinţelor legale de calitate. Au fost efectuate cercetări experimentale în care s-a urmărit influenţa principalilor parametrilor asupra comportamentului seminţelor în procesul de separare pe suprafaţa tamburilor magnetici.*

Cuvinte cheie: *separare magnetică, seminţe, tambur magnetic, turaţie, cuscută*

INTRODUCERE

Una dintre cele mai periculoase grupe de buruieni parazite care afectează atât calitatea producţiilor agricole, cât şi sănătatea animalelor este cuscuta. [5,11,15,16,17].

Împiedicarea răspândirii cuscutei este o lucrare obligatorie pentru toţi cultivatorii şi pentru toate unităţile care răspund de asigurarea unor producţii agricole ridicate, deoarece dacă nu se iau măsuri de combatere din timp, cuscuta se înmulţeşte foarte repede şi pe măsura extinderii ei, plantele se usucă şi pier, producţia plantelor cultivate fiind redusă până la 90% sau chiar 100%. [5,16,17]

Pagubele aduse de cuscută asupra culturilor agricole sunt semnificative, procentul prezenţei acesteia în plantele cultivate fiind de : 50 - 75 % în roşii, 70 – 90 % în morcov, 50 % în fasole, 50 % în sfecla de zahăr, 87 % linte, 60% în lupin, 58 % mazăre de câmp, 80 % în afine, 86 % în năut, 60 – 85 % lucernă, 80 - 100 % în trifoi [1, 5, 8, 9, 10, 12, 13, 18, 20].

Obţinerea unor recolte bogate şi de calitate este asigurată de folosirea la însămânţare a unui material semincer „lipsit" de buruieni de cuscută, care să corespundă cerinţelor legale de calitate [5, 6, 7, 17].

Semintele buruienilor parazite, plantelor de carantină, în special seminţele de cuscută sunt foarte greu de separat din masa de seminţe ale culturilor de bază, deoarece forma, dimensiunile şi proprietăţile aerodinamice ale acestora sunt aproape identice cu ale seminţelor plantelor cultivate. [4, 5, 6, 11]

În acest caz pentru o separare totală s-a elaborat metoda de separare pe cale magnetică, care necesită echipamente de curăţire şi sortare bazate pe principiul separării cu ajutorul tamburilor magnetici, [2, 5, 7], similar metodei separării pulberilor metalice din industria metalurgică întâlnite încă din sec. XVIII – XIX , căpătând o dezvoltare semnificativă la începutul sec. XX, în Suedia [3, 19].

Numeroase studii teoretice şi experimentale i-au fost consacrate fenomenului de separare pe cale magnetică în domeniul industriei minereurilor şi de prelucrare a

processing, but also in the field of technologies for processing agricultural products [2, 3, 4, 19]

Separation by magnetic means applied in the process of cleaning the seeds of the base crop of dodder seeds, is usually conducted on the surface of a horizontal cylindrical drum driven in a rotation movement. Dodder seeds (fig.1a,b), having a rough, wrinkled tegument, are filled with iron filings, acquiring the properties of ferromagnetic bodies, are retained on the surface of the drum and are detached later, while the seeds of the base crop (fig.2a,b), having a smooth external surface (without iron filings) are not retained on the surface of the drum and leave it earlier, moving in a free fall movement into separate areas [2, 3, 4, 5, 6].

For a successful application of the separating method, complex equipment is used, that have included in their components some systems for prior preparation of the seed mixture before the actual separation. Preparation consists in mixing the seeds with iron filings that adhere to the surface of dodder seeds but do not adhere to the smooth surface of alfalfa seeds. The mixture this way prepared is brought on the surface of the separating magnetic drum, which performs the separation [2, 5, 6, 11].

ceramicii, cât şi în domeniul tehnologiilor de prelucrare a produselor agricole [2, 3, 4, 19]

Separarea pe cale magnetică aplicată în procesul de curăţire a seminţelor plantelor culturii de bază de seminţele de cuscută, se realizează de regulă pe suprafaţa unui tambur cilindric orizontal acţionat în mişcare de rotaţie. Seminţele de cuscută (fig.1a,b) având tegumentul rugos, zbârcit sunt umplute cu pilitura de fier, căpătand proprietăţile corpurilor feromagnetice sunt reţinute pe suprafaţa tamburului şi se desprind mai târziu, în timp ce seminţele culturii de bază, (fig. 2a,b) având suprafaţa exterioară netedă (fără pilitură de fier) nu sunt reţinute pe suprafaţa tamburului şi o părăsesc mai devreme, deplasându-se într-o mişcare de cădere liberă în zone separate.[2, 3, 4, 5, 6]

La aplicarea cu succes a metodei de separare se utilizează utilaje complexe în componenţa cărora sunt incluse şi sisteme de pregătire prealabilă a amestecului de seminţe înainte de separarea propriu zisă. Pregătirea constă în amestecarea acestora cu pilitură de fier care aderă la suprafaţa seminţelor de cuscută şi nu aderă la suprafaţa netedă a seminţelor de lucernă. Amestecul astfel pregătit este adus pe suprafaţa tamburului magnetic separator care realizează separarea [2, 5, 6, 11].

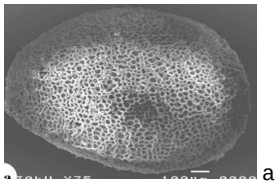

Fig. 1a – Dodder seed [9]

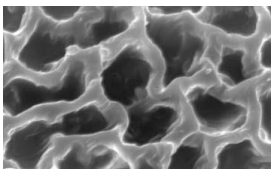

Fig. 1b - Surface detail for dodder seed

Fig. 2a – Alfalfa seed

Fig. 2b - Surface detail for alfalfa seed

MATERIAL AND METHOD

Figure 3 shows the technological diagram for the machine for magnetic separation of dodder seeds from the mass of alfalfa seeds, used for conducting experimental researches.

The separated seed material must correspond to the legal quality demands, namely the numerical content of dodder seeds (fig.4 a,b) to be 0, and in the case of finding seeds of *dodder spp. fragile* (fig.5 a,b) or gray (fig. 6 a,b) up to white-cream colored seeds in the analysis sample, these are considered inert matters. [21, 22, 23]

MATERIAL ŞI METODĂ

În fig. 3 este prezentată schema tehnologică a maşinii de separare pe cale magnetică a seminţelor de cuscută din masa de seminţe de lucernă utilizată la efectuarea cercetărilor experimentale.

Materialul semincer separat trebuie să corespundă cerinţelor legale de calitate şi anume conţinutul numeric de seminţe de Cuscuta (fig. 4 a,b) să fie 0, iar în cazul în care se găsesc seminţe de *cuscuta spp. fragile* (fig.5 a,b) sau de culoare gri-cenusie (fig. 6 a,b) până la alb-crem în proba de analiză, acestea sunt considerate materii inerte [21, 22, 23].

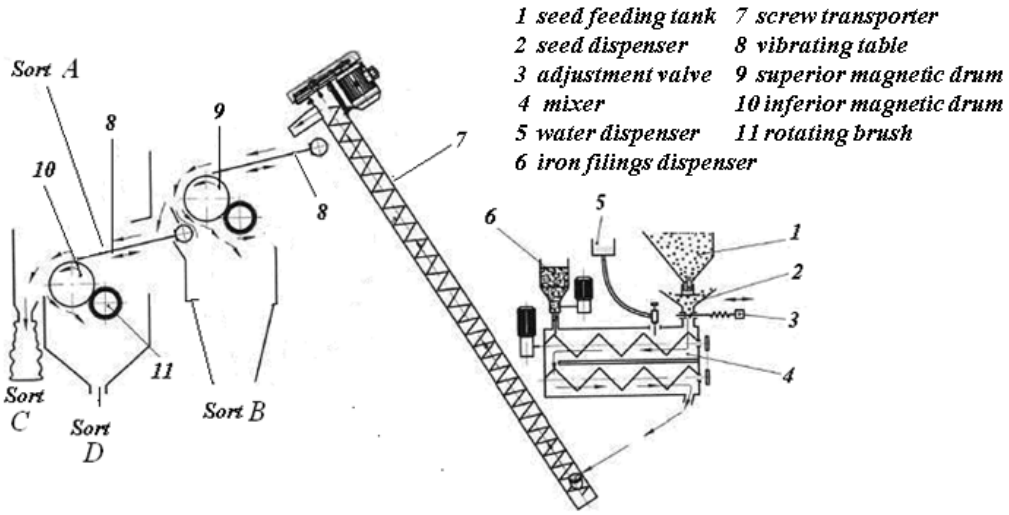

Fig. 3 – Technological diagram for the machine, corresponding to the collected sorts [5]

Fig. 4a – Dodder seeds

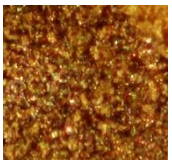

Fig. 4b – Detail for dodder seeds

Fig. 5a– Fragile dodder seeds

Fig. 5b – Detail for fragile dodder seeds

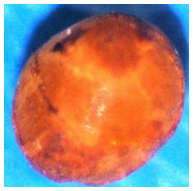

Fig. 6a – Gray dodder seeds

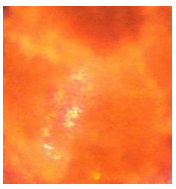

Fig. 6b – Detail for gray dodder seeds

The main objective of experiments has aimed to obtain a material with the qualification „free" of dodder.

Ensuring the quality of the process of separating dodder seeds from the mass of alfalfa seeds requires primarily a correct choice of drum speed, because it represents the active working body and on its surface takes place the separation.

The behavior of the seed in the process of separation was followed, starting from values of the magnetic drums within the domain of usual values used for separating machines according to the status of their surface existing in work, namely $\omega = 40{,}48{,}54$ rot/min. [2, 3, 4, 7, 11]

The manner of assessing the degree of purity is represented by the numerical content of seeds in the sample for analysis, which has to be 0.

For each experiment were taken samples from the collected sorts A and C, in order to subsequently determine the quality of the seed material obtained and the manner of operating of the machine with one drum (sort A) and with two drums (sort C).

Sort B and D – impurities.

In order to determine the numerical content of dodder seeds in the samples for analysis, a mass of 50 (g) was used, by weighing using the scales with 0.01 (g) precision.

RESULTS

When conducting the experimental researches, first was established the value of the speed of revolution at which the behavior of seeds is carried out normally on the surface of the separating drum with a 205 mm radius.

For the three values of the drum's speed of revolution, was noticed that at a speed of 54 rot/min (fig.7), seeds begin to move in jumps on the drum, for the value of 48 rot/min they start to decrease their speed of movement on its surface (fig.8), but at speed of 40 rot/min they have a normal behavior, reason for which the speed of revolution was set to the value of 40 rot/min (fig.9), in order to conduct the tests.

Obiectivul principal al experimentărilor a avut în vedere obţinerea unui material cu calificativul "liber" de cuscută.

Asigurarea calităţii procesului de separare a seminţelor de cuscută din masa de seminţe de lucernă, necesită în primul rând alegerea corectă a turaţiei tamburului, deoarece acesta reprezintă organul activ de lucru şi pe suprafaţa căruia are loc separarea.

S-a urmărit comportamentul seminţelor în procesul de separare pornind de la valori ale turaţiilor tamburilor magnetici din domeniul valorilor uzuale folosite la maşinile de separare după starea suprafeţei lor existente în lucru, şi anume $\omega = 40{,}48{,}54$ rot/min. [2, 3, 4, 7, 11]

Modul de apreciere al gradului de puritate îl reprezintă conţinutul numeric de seminţe din proba de analiză, care trebuie să fie 0.

La fiecare experiment au fost prelevate monstre din sorturile de colectare A şi C, ca ulterior să se determinate calitatea materialului semincer obţinut şi modul de lucru al maşinii cu un tambur (sort A) şi cu doi tamburi (sort C).

Sort B şi D – impurităţi.

Pentru determinarea conţinutului numeric de seminţe de cuscută din probele de analiză, a fost utilizată o masă de 50 (g), prin cântărire cu balanţa de precizie 0.01 (g).

REZULTATE

La efectuarea cercetărilor experimentale s-a stabilit în primul rând valoarea turaţiei la care comportamentul seminţelor se desfăşoară normal pe suprafaţa tamburului separator de rază 205 mm.

Pentru cele trei valori ale turaţiei tamburului, s-a constatat că la turaţia de 54 rot/min, (fig.7)., seminţele încep să se deplaseze cu salturi pe tambur, la valoarea de 48 rot/min acestea încep a îsi micşora viteza de deplasare pe suprafaţa lui, (fig.8)., însă la turaţia 40 rot/min acestea au o comportare normală, motiv pentru care turaţia a fost stabilită la valoarea 40 rot/min, (fig.9), în vederea efectuării probelor.

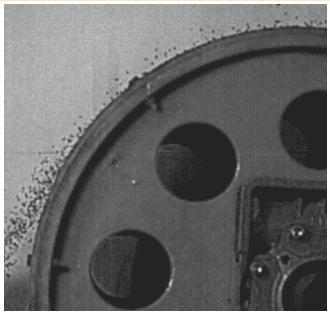

Fig. 7 – Seed behavior at a 54 rot/min speed

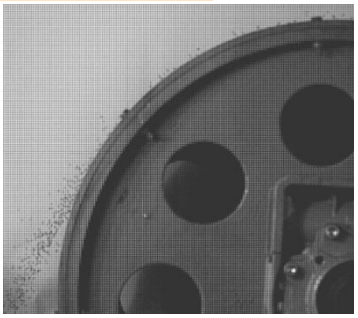

Fig. 8 - Seed behavior at a 48 rot/min speed

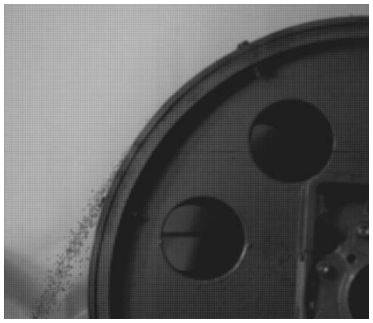

Fig. 9 - Seed behavior at a 40 rot/min speed

Alfalfa samples of numerical content of dodder seeds of 11494/100 g alfalfa seeds was built.

From the experiments have resulted that the content of dodder seeds expressed as a percentage by mass (weight ratio) is inconclusive, that why we agreed that this

S-au alcătuit probe de seminţe de lucernă conţinutul numeric de seminţe de cuscută 11494/100 g seminţe lucernă. Din experimentările noastre a rezultat că, conţinutul de seminţe de cuscută exprimat procentual masic (raport de mase) este neconcludent, din acest motiv am convenit ca acest parametru (conţinut numeric de

parameter (numeric dodder seed content in alfalfa seed) to be expressed in number dodder seed to 100 g of alfalfa seeds. În this purpose, the samples for analysis are separated and has been counted the number of dodder seeds and related to the mass of seeds of alfalfa weighed in the sample (number.of dodder seeds / mass of seeds of alfalfa in the sample taken * 100).

In order to establish the influence of the feeding flow and of the water quantity on the degree of separating the seed mixture, the speed of the drum (40 rpm) and the quantity of iron filings used (19 g/min) were kept constant, the values of the parameters that varied during experimental testing, being shown in table 1.

seminţe de cuscută în seminţele de lucernă) să-l exprimăm în număr de seminţe de cuscută la 100 g de seminţe de lucernă. În acest scop, din probele prelevate pentru analiză, s-au separat seminţele de cuscută care au fost numărate şi raportate la masa de seminţe de lucernă cântărite din proba prelevată (nr. de seminţe de cuscută din proba prelevată/ masa de seminţe de lucernă din proba prelevată *100).

Pentru stabilirea influenţei debitului de alimentare şi cantităţii de apă asupra gradului de separare al amestecului de seminţe, turaţia tamburului (40 rpm) şi cantitatea de pulbere de fier utilizată (19 g/min) s-au păstrat constante, valorile parametrilor variaţi în cadrul determinărilor experimentale fiind prezentate în tabelul 1.

Table 1

No.	**Drum speed - 40** [rot/min] **numerical content of dodder seeds - 11494 /100g alfalfa**			
	Feeding flow		Water quantity	
	(g/s)	Valve position (mm)	[g/min]	Water drops/min
1	16.36	5	3.28	38
2	25.39	8	4.78	55
3	65.56	12		

The results obtained for a 10 % concentration of dodder seeds are shown in table 2.

Rezultatele obţinute pentru concentraţia de seminţe de cuscută de 10 % sunt prezentate în tabelul 2.

Table 2

Concentration values and numerical dodder seed content in the samples for analysis

Drum speed $\omega = 40$ [rpm]						
$q_{water} = 3.28$ (g/min), $q_{powder} = 19$ g/min						
Valve position (mm)	C_A %	C_B %	C_c %	*Nb. of dodder seeds Sort C*	*Nb. of dodder seeds Sort D*	*Nb. of dodder seeds Sort B*
5	0.52	2.68	16.7	264	1384	8608
8	0.18	4.56	34.46	96	2296	17768
12	0.32	5.4	22.48	168	2784	11584
$q_{water} = 4.78$ (g/min), $q_{powder} = 19$ (g/min)						
Valve position (mm)	C_A %	C_B %	C_c %	*Nb. of dodder seeds Sort C*	*Nb. of dodder seeds Sort D*	*Nb. of dodder seeds Sort B*
5	0.54	4.94	28.6	280	2544	14744
8	0.46	4.98	31.32	232	2576	16144
12	0.38	4.6	29.56	200	2368	15240

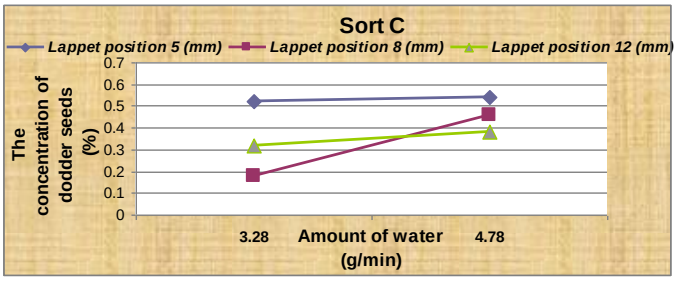

Fig. 10 – Dodder content variation depending on the feeding flow and quantity of water used

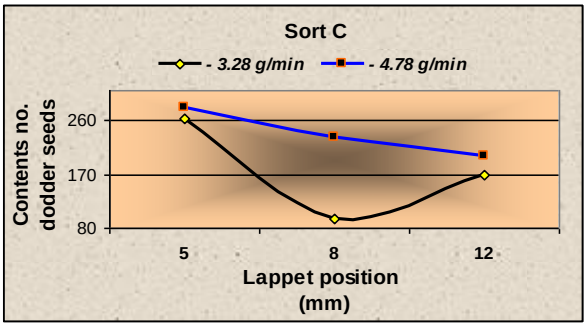

Fig. 11 – Numerical dodder content variation depending on the feeding flow

From the experimental data represented graphically in figures 10 and 11 it is noticed that:

- As the water quantity increases, the quality of the separation process decreases, the numerical content of dodder seeds increases.
- For a water quantity of 3.28 (g/min), the feeding flow corresponding to valve position 8 (mm) is efficient for obtaining a minimum concentration of dodder seeds, and for a water quantity of 4.78 (g/min), the valve position is 12 (mm), but in comparison, the minimum content of dodder seeds is obtained for the quantity of 3.28 g/min of water.

Further, tests were conducted starting from the optimal parameters established and namely from the speed of 40 rot/min, the feeding flow corresponding to valve position 8 (mm), water quantity of 38 drops/min, at which the numerical content of dodder seeds was minimal, by adding a smaller speed – 20 rpm and a minimum quantity of iron filings – 3.2 g/min, to observe what happens when reducing them.

Experiments were conducted for a concentration of dodder seeds of 380 seeds/ 100 (g) of alfalfa, aiming to obtain the qualification "free" of dodder and also following the manner of operating of the machine with one drum (sort A) and with two drums (sort C), according the legal quality demands for the seed material.

The results obtained for the two speeds when using a 3.2 g/min quantity of filings are shown in table 3.

Din datele experimentale reprezentate grafic în fig. 10 şi 11 se observă că:

- odată cu creşterea cantităţii de apă calitatea procesului de separare scade, conţinutul numeric de seminţe de cuscută creşte;
- pentru o cantitate de apă de 3.28 (g/min), debitul de alimentare corespunzător poziţiei clapetei 8 (mm) este eficient pentru obţinerea unei concentraţii minime de seminţe de cuscută, iar pentru cantitate de apă de 4.78 g/min poziţia clapeteii este 12 (mm), însă comparativ conţinutul minim de seminţe de cuscută este obţinut la cantitatea de 3.28 g/min apă.

În continuare au fost efectuate probe pornind de la parametrii optimi stabiliţi şi anume de la turaţia 40 rot/min, debitul de alimentare corespunzător poziţiei clapetei – 8(mm), cantitatea de apă de 38 picături/min, la care conţinutul numeric de seminţe de cuscută a fost minim, prin adăugarea unei turaţii mai mici - 20 rpm şi a unei cantităţi minime de pulbere de fier - 3,2g/min, pentru a observa ce se întâmplă în cazul micşorării acestora.

Experimentările au fost efectuate pentru o concentraţie de seminţe de cuscută de 380 seminţe cuscută / 100 (g) lucernă, urmărind obţinerea calificativului „liber" de cuscută şi de asemenea modul de lucru al masinii cu un tambur (sort A) si cu doi tamburi (Sort C), conform cerinţelor legale de calitate a materialului semincer.

Rezultatele obţinute pentru cele două turaţii la utilizarea cantităţii de pulbere de 3.2 g/min sunt prezentate în tabelul 3.

Table 3

Values of experimental data

No. machine passes	380 dodder seeds / 100 (g) alfalfa $q_{apa} = 3.28(g/\min)$ *(38 water drops /min)*					
	Drum speed at 20 rot/min					
	First drum Sort A			Second drum Sort C		
	Dodder seeds	*Dodder seeds inert matter*	Total	Dodder seeds	*Dodder seeds inert matter*	Total
T1	*70*	32	102	*51*	29	80
T2	*45*	40	85	*37*	27	64
T3	*27*	18	45	*18*	8	26
T4	*15*	16	31	*4*	10	14
T5	*2*	12	14	*0*	4	0+4
Drum speed at 40 rot/min						
T1	*112*	23	135	*92*	26	118
T2	*104*	18	122	*75*	21	96
T3	*68*	22	90	*56*	19	75
T4	*45*	17	62	*38*	14	52
T5	*27*	16	43	*19*	13	32
T6	*15*	10	25	*11*	8	19
T7	*6*	8	14	*3*	6	9
T8	*1*	7	8	*0*	5	0+5

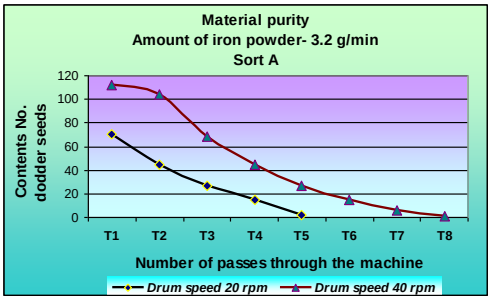

Fig. 12 – Variation of the dodder seeds number depending on the drum speed when separating on the first drum

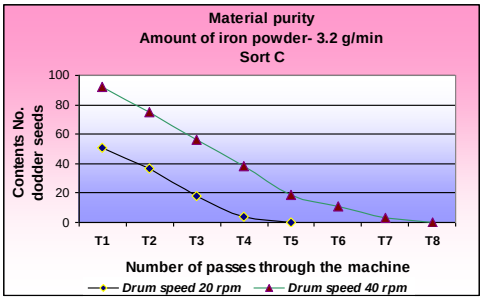

Fig. 13 – Number of material passes through the machine when separating on the second drum

From graphic representations, fig. 12-13, it is noticed that the number of passes of the material destined for separation through the machine increases with the increase of drum speed. Also, the numerical content of dodder seeds is minimal when the value of the drum speed is small.

In table 4 are presented the experimental data obtained when using a 19 g/min quantity of iron filings for the two values of the speed of the separating drum.

Din graficele fig.12,13, se observă că numărul trecerilor prin maşină a materialului destinat separării creşte odată cu creşterea turaţiei tamburului. De asemenea conţinutul numeric de seminţe de cuscută este minim, atunci când valoarea turaţiei tamburului este mică.

În tabelul 4 sunt prezentate datele experimentale obţinute la utilizarea cantităţii de pulbere de fier de 19 g/min pentru cele două valori ale turaţiei tamburului separator.

Table 4

Values of experimental data

No. machine passes	***380 dodder seeds / 100 (g) alfalfa seeds*** $q_{water} = 3.28(g/\min)$ ***(38 water drops/min)***					
	Drum speed at 20 rpm					
	First drum			**Second drum**		
	Dodder seeds	***Dodder seeds inert matter***	**Total**	**Dodder seeds**	***Dodder seeds inert matter***	**Total**
T1	*22*	16	38	*13*	14	27
T2	*9*	9	18	*3*	9	12
T3	*2*	4	6	*0*	4	0+4
Drum speed at 40 rpm						
T1	*51*	20	71	*35*	19	54
T2	*21*	15	36	*13*	18	31
T3	*4*	16	20	*2*	12	14
T4	*1*	7	7	*0*	10	0+10

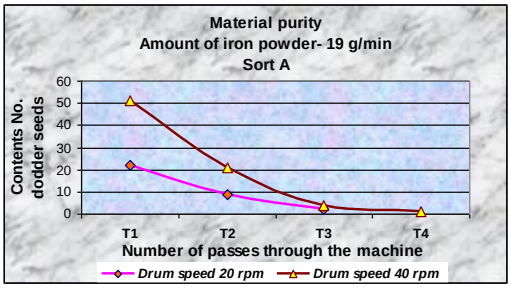

Fig. 14 – Seed material purity on the first drum

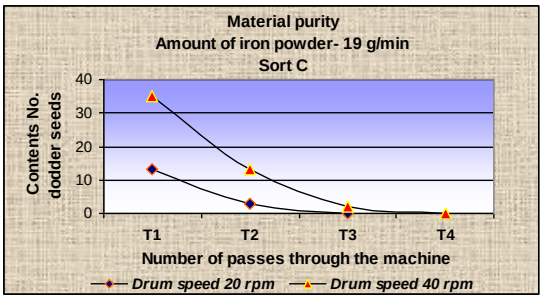

Fig. 15 - Seed material purity on the second drum

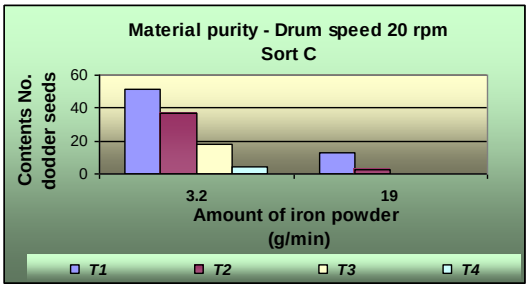

Fig. 16 – Variation of the numerical content of dodder seeds depending on the quantity of filings used

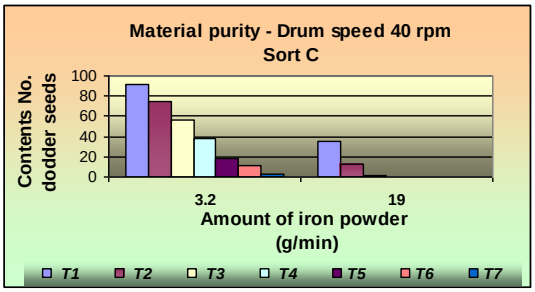

Fig. 17 - Variation of the numerical content of dodder seeds depending on the quantity of filings used

From the data obtained from experiments, represented graphically in fig.14-17, a significant difference is found, namely that at a smaller drum speed, the same quantity of water and iron filings and the same feeding flow, the degree of separation is superior, the content of dodder seeds is smaller, thus requiring fewer passes of the seed material through the machine.

Also, it is noticed that the degree of purity of the material subjected to separation is influenced by the quantity of iron filings used, thus along with increasing the quantity of iron filings used, the number of passes of the seed material through the machine decreases significantly, for the same speed.

Din datele obţinute experimental, reprezentate grafic în fig.14–17, se constată o diferenţă semnificativă, şi anume că la o turatie mai mica a tamburului, aceeaşi cantitate de apa si pulbere de fier, acelasi debit de alimentare, gradul de separare este superior, continutul de seminte de cuscuta este mai mic, necesitand astfel mai putine treceri prin masina a materialului destinat însămânţării.

De asemenea se observă, că gradul de puritate al materialului supus separării este influenţat de cantitatea de pulbere de fier utilizată, astfel odată cu creşterea cantităţii de pulbere de fier utilizată se reduce semnificativ numărul de treceri prin maşină a materialului semincer, pentru aceeaşi turaţie.

In comparison, the numerical content of dodder seeds obtained at a large speed using a maximum quantity of iron filing is almost identical to the one obtained at a low speed and using minimum quantities of iron filings.

CONCLUSIONS

The efficiency of the process of separating the seed mixture is ensured firstly by the correct choice of the speed of the separating drum.

Following experimental researches conducted, the following aspects were noticed:

- the quantity of filings used should increase along with increasing the speed, in order to have a minimal numerical content of dodder seeds;
- the number of passes through the machine of the material subjected to separation is influenced by the drum speed and by the quantity of iron filings used;
- along with speed increasing the quantity of filings used decreases the number of material passes through the machine, regardless of the drum speed;
- the qualification "free" of dodder is ensured by the use of adequate parameters: drum speed, water quantity, iron filings quantity, seed feeding flow.

The data presented can be useful for assessing the working process of separating equipment fitted with magnetic drums for obtaining a seed material of superior quality and are useful, in the same time, for designers and for enterprises that manufacture machinery and for economic agents specialized in the field.

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Comparativ, conţinutul numeric de seminţe de cuscută obţinut la o turaţie mare folosind o cantitate de pulbere de fier maximă, este aproape identic cu cel obţinut la o turaţie mică şi la utilizarea unei cantităţi minime de pulbere de fier.

CONCLUZII

Eficienţa procesului de separare a amestecului de seminţe este asigurată în primul rând de alegerea corectă a turaţiei tamburului separator.

In urma cercetărilor experimentale efectuate s-au constatat următoarele:

- cantitatea de pulbere de fier utilizată trebuie sa crească odată cu creşterea turaţiei pentru a avea un conţinut numeric de seminţe de cuscută minim;
- numărul de treceri a materialului supus separării prin maşină este influenţat de turaţia tamburului şi de cantitatea de pulbere de fier utilizată;
- odată cu creşterea cantităţii de pulbere utilizată scade numărul de treceri a materialului prin maşină, indiferent de turaţia tamburului;
- calificativul "liber" de cuscută este asigurat de utilizarea parametrilor adecvaţi: turaţia tamburului, cantitatea de apă, cantitatea de pulbere de fier, debitul de alimentare al seminţelor.

Datele prezentate pot fi utile în evaluarea procesului de lucru al echipamentelor de separare prevăzute cu tamburi magnetici pentru obţinerea unui material semincer de calitate superioară şi sunt folositoare, în acelaşi timp, proiectanţilor şi unităţilor constructoare de maşini şi agenţilor economici specializaţi în domeniu.

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DEVELOPMENT AND INVESTIGATION OF RECIPROCATING SCREW WITH FLEXIBLE HELICAL SURFACE
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РОЗРОБКА ТА ДОСЛІДЖЕННЯ ШНЕКА З ЕЛАСТИЧНОЮ ГВИНТОВОЮ ПОВЕРХНЕЮ

Prof. Ph.D. Eng. Hevko R.B., Eng. Zalutskyi S.Z., Prof. Ph.D. Eng. Tkachenko I.G., Ph.D. Eng. Klendiy O.M.
Ternopil National Economical University, Lvivska Str., 11, Ternopil / Ukraine
E-mail: faem_tneu@ukr.net

Abstract: The analysis of known reciprocating screw working parts with flexible helical surfaces and screw conveyer operation has been carried out. A new structure of reciprocating screw with flexible helical surface and its manufacturing method have been proposed. The bench has been developed and manufactured for conduction of experimental researches. Experimental findings have been provided considering the definition of influence on the value of flexible sheet deformation, its width and cantilevered cog size as well as comparative results of grain material destruction degree with rigid and flexible reciprocating screw working surfaces.

Key words: *reciprocating screw, flexible helical surface, unit of flexible sheet, bench, deformation, sheet width, cantilevered cog size.*

INTRODUCTION

Screw conveyors are widely used for transportation of grain, seed materials, granular mineral fertilizers, that can be seriously damaged during the relocation, which is inadmissible.

The main reasons of bulk solids damages are falling of particles into the gap between rotate reciprocating screw and stationary internal surface of conductor pipe. As a result complete or partial material damages take place and wedging of working part is also possible, which leads to malfunction and causes increased energy consumption.

Changes of gaps between circumference of reciprocating screw and pipe surface, application of different external edging shape of helical surfaces considering geometrical and rheological characteristics of bulk solids cannot solve the problem completely.

The following papers [1, 2, 3, 4, 6, 7, 8, 10] are dedicated to solving such problems as development of original design for helical working parts and their rational characteristics and operational modes. However, such developments do not solve the problem completely, because existing reciprocating screw designs and production methods are labour-intensive and working parts are specified as those having low reliability and maintainability.

MATERIAL AND METHOD

The objective of this research is to create new reciprocating screw design with changeable flexible helical surface, develop its production methods and experimental benches for investigation purposes. The design of reciprocating screw with flexible helical surface and design styles of flexible units in the form of sheets are shown in fig. 1. It contains central shaft 1, where bearing tape helix 2 with operating flexible spiral on its edge 3 is mounted. Operating flexible spiral 3 is fixed on the bearing tape helix by means of sectional screw sheets 4, and bolt connection with semicircular heads 5 and nuts 6 with spring washers.

Резюме: Проведено аналіз відомих конструкцій робочих органів шнеків з еластичними поверхнями та процесів роботи гвинтових конвеєрів. Запропоновано нову конструкцію шнека з еластичною гвинтовою поверхнею та спосіб його виготовлення. Розроблено та виготовлено стенд для проведення експериментальних досліджень. Наведено результати експериментальних досліджень з визначення впливу на величину деформації секції еластичної пластини її ширини та величини консольного виступу, а також порівняльні результати ступеня пошкодження зернового матеріалу шнеком із жорсткою та еластичною робочими поверхнями.

Ключові слова*: шнек, еластична гвинтова поверхня, секція еластичної пластини, стенд, деформація, ширина пластини, величина консольного виступу.*

ПЕРЕДУМОВА

Шнекові конвеєри знайшли широке застосування для транспортування зернових, насіннєвих матеріалів, гранульованих мінеральних добрив, які при переміщенні зазнають значних пошкоджень, що є недопустимим.

Основними причинами травмування сипких матеріалів є попадання їх частинок у зазор між обертовим шнеком і нерухомою внутрішньою поверхнею направляючої труби. Внаслідок цього відбувається повне або часткове пошкодження матеріалів, а також можливе заклинювання робочого органу, що призводить до його поломок та підвищення енерговитрат.

Зміна зазорів між периферією шнека та поверхнею труби, застосування різних профілів зовнішніх кромок гвинтових поверхонь в залежності від геометричних та реологічних параметрів сипкого матеріалу не в повній мірі може вирішити дану проблему.

Вирішенню даних питань, а саме розробці оригінальних конструкцій гвинтових робочих органів та вибору їх раціональних параметрів і режимів функціонування присвячені праці [1, 2, 3, 4, 5, 7, 8, 10]. Однак, такі розробки не в повній мірі вирішують дану проблему, оскільки відомі конструкції шнеків і методи їх виготовлення є трудомісткими, а робочі органи характеризуються низькою надійністю та ремонтоздатністю.

МАТЕРІАЛ І МЕТОДИКА

Метою даного дослідження є створення нової конструкції шнека зі змінною еластичною гвинтовою поверхнею, розробка способу його виготовлення та експериментальних стендів для проведення досліджень. Конструкція шнека з еластичною гвинтовою поверхнею, а також варіанти виконання еластичних секцій у вигляді пластин зображено на рис. 1. Він містить центральний вал 1, на якому встановлена несуча смугова гвинтова спіраль 2, по периферії якої закріплена робоча еластична спіраль 3. На несучій смуговій спіралі за допомогою секційних гвинтових пластин 4, а також болтових з'єднань з напівкруглими головками 5 та гайок 6 з пружинними шайбами закріплена робоча еластична спіраль 3.

Working flexible spiral can be integrated (fig. 1 a, b, c), or consist of separate units (fig. 1 e, f, g). The units of working flexible spiral are fixed onto bearing screw spiral through two gaps at least, and circumferential surface of working flexible spiral can come in the form of cut sheets with different width (fig. 1 e, f, g) according to geometrical and rheological characteristics of material transported.

Робоча еластична спіраль може бути виконана як суцільною (рис. 1 a, b, c), так із окремих секцій (рис. 1 e, f, g). Секції робочої еластичної спіралі кріпляться до несучої гвинтової спіралі щонайменше через два отвори, а периферійна поверхня робочої еластичної спіралі може бути виконана у вигляді розрізних пластин різної ширини (рис. 1 e, f, g) в залежності від геометричних та реологічних параметрів транспортованого матеріалу.

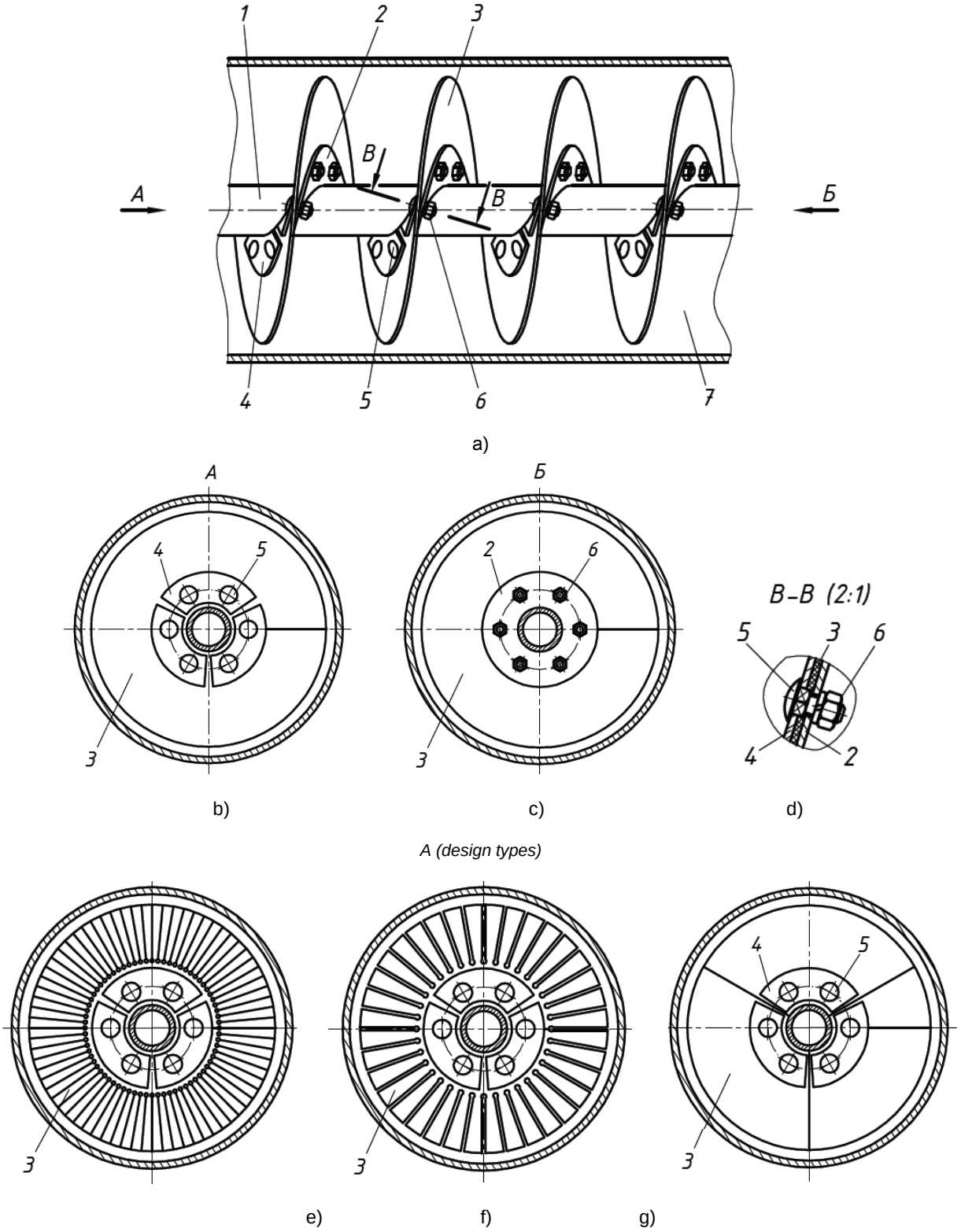


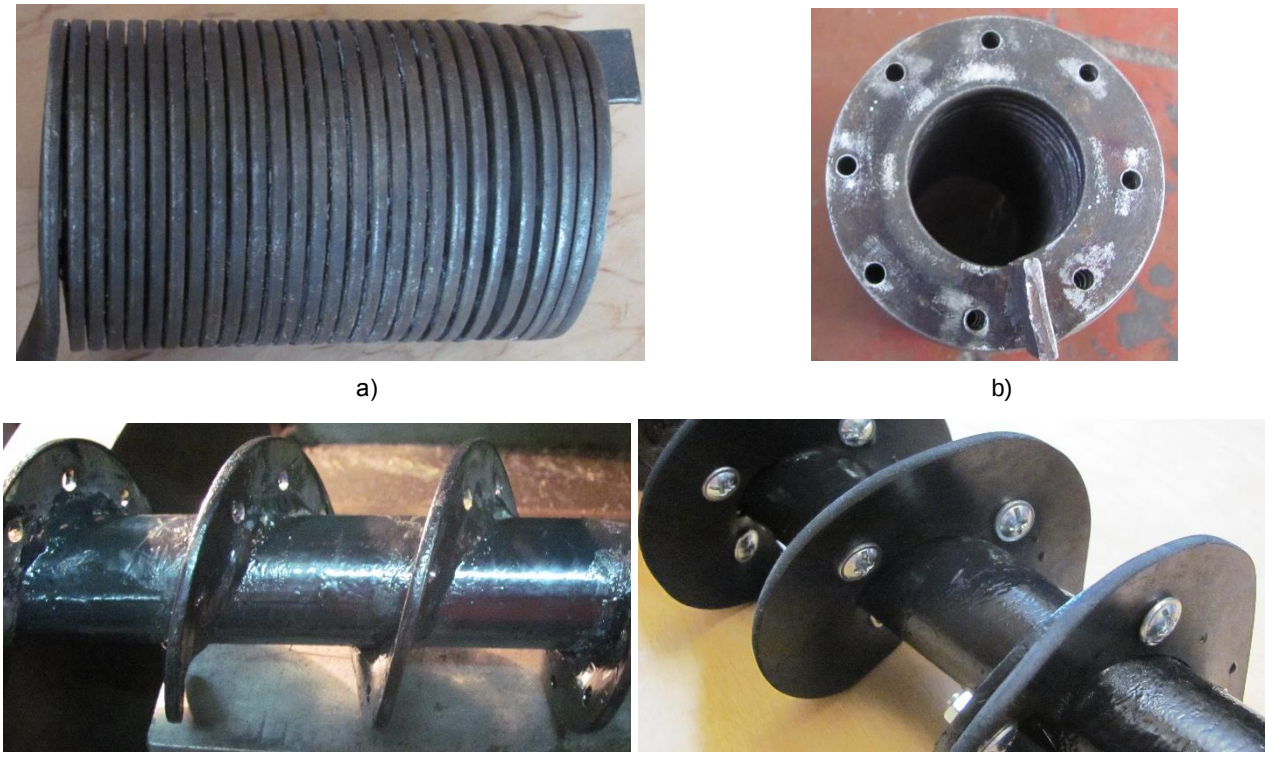
Fig. 1 – Reciprocating screw with flexible helical surface

During the transportation of agricultural bulk solids in guide pipe 7 they interact with working flexible helical surface. In case of jamming, for instance, grains between surface of the pipe and working flexible helical surface cut sheets are sagged, thus preventing grain damage. The width and rigidity of working flexible helical surface are chosen according to physical and chemical properties of the transported material.

The production method of this working part [5] is shown in fig. 2. The stripe of rectanglular crossing is previously coiled on arbor on rib in faggot (fig. 2 a). Then the faggot is pressed on the arbor and according to diameter at the edges of the faggot gaps (fig. 2 b). After that the faggot is mounted on shaft and stretches spiral to the back step untill the complete contact of internal spiral with the shaft, then it is welded onto the latter. On the next stage working spiral or its units are fixed to gaps of bearing spiral (fig.1d).

В процесі транспортування сипких матеріалів сільськогосподарського виробництва в направляючій трубі 7 вони взаємодіють з робочою еластичною гвинтовою поверхнею. У випадку защемлення, наприклад, зернини між поверхнею направляючої труби та робочою еластичною гвинтовою поверхнею розрізні пластини прогинаються, що виключає пошкодження зернини. Ширина та жорсткість пластин робочої еластичної гвинтової поверхні вибирають в залежності від фізико-механічних властивостей транспортованого матеріалу.

Спосіб виготовлення даного робочого органу [5] зображено на рис. 2. Попередньо смуга прямокутного перетину навивається на оправку на ребро в пакет (рис. 2 а). Далі пакет стискається на оправці та рівномірно по діаметру по периферії пакету виконують отвори (рис.2 b). Після цього пакет встановлюють на вал і розтягують спіраль на заданий крок до повного контакту внутрішньої спіралі з валом, після чого її приварюють до останнього. В подальшому до отворів даної несучої спіралі кріплять робочу еластичну спіраль або її секції (рис. 1 d).



a) b)

c) d)

Fig. 2 – Producion technique of reciprocating screw design with flexible helical surface:
a – metal stripe is coiled on the rib in faggot; b – evenly made gaps of the diameter of the edges of coiled metal stripe on the rib in faggot; c – gauged spiral is set on the shaft; d - reciprocating screw is fixed with flexible spiral

For definition of deformation value “Δ” of free edge of flexible sheet unit (fig. 1 e, f, g) and its width “B” and value of cantilevered cog “*h*” experimental bench has been developed and manufactured. During the loading process of flexible sheet unit its free edge was deflected and the deformation value was noticed according to the bulk of measuring loads. Experimental studies have been conducted for the material of flexible sheet “polyurethane PU-60” with thickness of 2,5 mm. The value of cantilevered cog of flexible sheet was discretely set with distance of h = 25; 20; 15; 10 mm, with discrete values of these sheet widths of B = 25; 20; 15; 10; 5 mm.

Для встановлення впливу на величину деформації “Δ” вільного кінця секції еластичної пластини (рис. 1 e, f, g) її ширини “*B*” та величини консольного виступу “*h*” розроблено та виготовлено експериментальний стенд. В процесі навантаження секції еластичної пластини її вільний кінець прогинався, а величина даної деформації фіксувалась в залежності від маси мірних вантажів. Експериментальні дослідження проводились для матеріалу еластичної пластини “поліуретан PU-60” з товщиною 2,5 мм. Величину консольного виступу еластичної пластини дискретно встановлювали з відстанню: h = 25; 20; 15; 10 мм, при дискретних величинах ширини таких пластин: B = 25; 20; 15; 10; 5 мм.

RESULTS AND DISCUSSION

Fig.3 illustrates the findings of experimental research for cantilevered fixed flexible sheet deformation respectively to its loading value.

РЕЗУЛЬТАТИ

На рис. 3 представлено результати експериментальних досліджень деформації консольно закріпленої еластичної пластини від величини її навантаження.

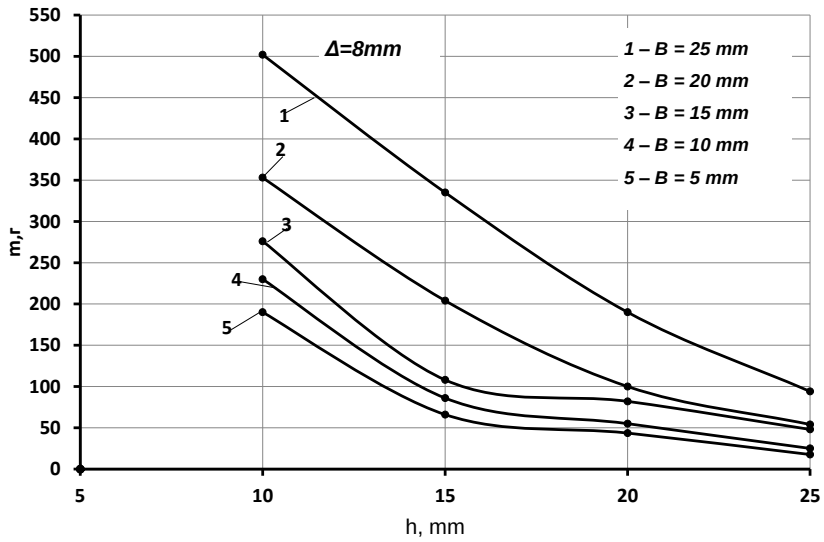


Fig. 3 – Characteristic curve for influence of measuring loads mass m_g, the value of cantilevered cog of flexible blade *h* respectively to the deformation of sheet's free edge in Δ = 8 mm under *B* variables

The experimental research for evaluation of the seed material damage degree the bench [5] has been developed, as shown in fig. 4.

It consists of cradle, featuring angular position regulator, and the screw conveyor mounted on it. Reciprocating screw working part with flexible helical surface is placed in the guiding pipe. The hopper is mounted on the loading side with the opening in its off-load zone for conveying the material into the container. The working part gear is driven by the electric motor. Frequency converter (Altivar 71) with Power Suite v.2.5.0. software were employed to start the engine and control its rotational speed. Altivar 71 system was wired to the network and computer.

Для проведення експериментальних досліджень з визначення ступеня пошкодження насіннєвого матеріалу розроблено стенд [6], загальний вигляд якого зображено на рис. 4.

Він складається із рами, на якій, з можливістю зміни кутового положення, розміщений шнековий транспортер. В направляючій трубі транспортера розташований шнековий робочий орган з еластичною гвинтовою поверхнею. Зі сторони завантаження матеріалу встановлений бункер, а в зоні його вивантаження – вікно, з якого транспортований матеріал переводився в тару. Привід робочого органу здійснюється від електродвигуна. Для пуску двигуна та регулювання частоти його обертання використовували перетворювач частоти (Altivar 71) з програмним забезпеченням Power Suite v.2.5.0. Система Altivar 71 приєднана до мережі та до комп'ютера.

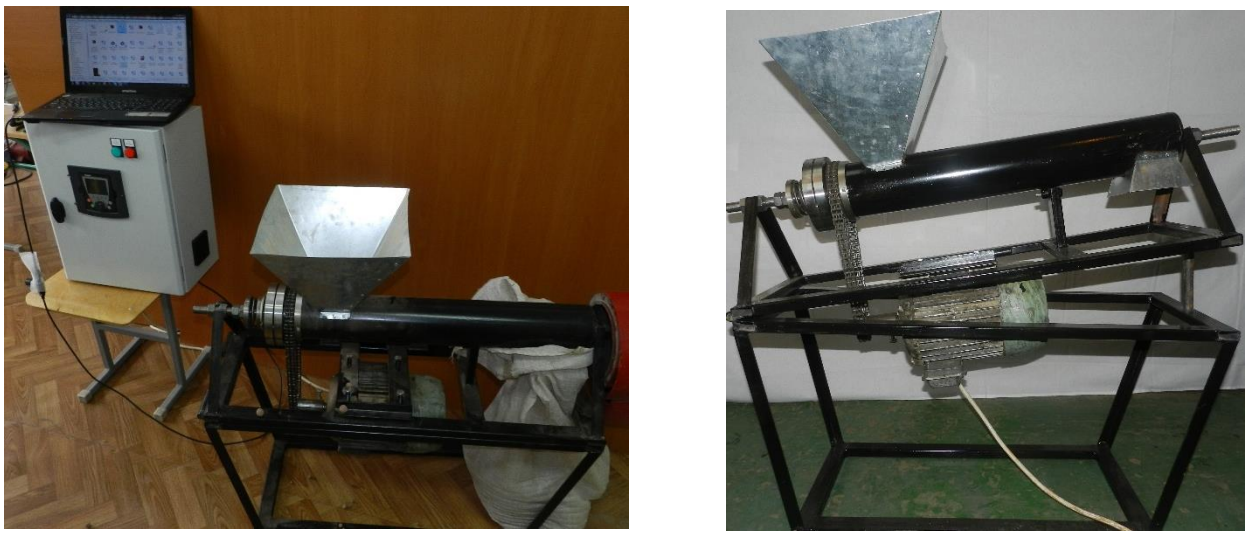


Fig. 4 – Bench for research of reciprocating screw conveyer with flexible working part

The percentage of damage has been evaluated prior to the experimental research [2]. Then grain was transported in the conveyer for several times at set angular position and rotational rate. After that the percentage of material damage was evaluated in the same manner. The difference in percentage determined the degree of material damage directly during its transportation at set parameters of working parts for specific distance, which equals the reciprocating screw length multiplied by the number of material passings on the conveyer.

The findings of experimental research during the transportation of grain material with rigid reciprocating screw (solid line) and with flexible surface reciprocating screw (dashed line) at different gaps between reciprocating screw and guide pipe (δ = 2; 6 mm), angles of obliquity of reciprocating screw β and rotational rate n are illustrated in fig. 5.

Перед експериментальними дослідженнями попередньо визначався наявний відсоток його пошкодження [3]. Далі зерно кілька разів транспортували в конвеєрі при встановленому куті його нахилу та частоті обертання. Після цього аналогічним способом визначали відсоток пошкодження матеріалу. Різниця у відсотковому вимірі характеризувала ступінь пошкодження матеріалу безпосередньо при його транспортуванні за даних параметрів робочого органу на визначену відстань, що визначається добутком довжини шнека на кількість проходжень матеріалу в конвеєрі.

Результати порівняльних експериментальних досліджень при транспортуванні зернового матеріалу жорстким шнеком (суцільна лінія) та шнеком з еластичною поверхнею (штрихова лінія) при різних зазорах між шнеком і направляючою трубою (δ = 2; 6 мм), кутах нахилу шнека β та частотою його обертання *n* представлено на рис.5.

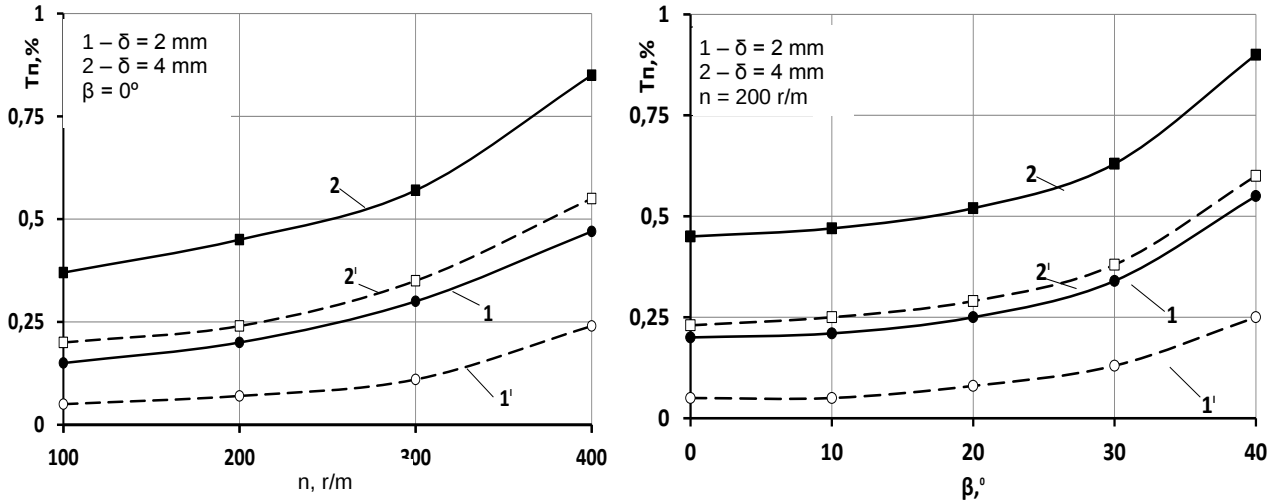


Fig. 5 – Graphic depending of grain material damage T_n % with reciprocating screw (solid line) and with flexible surface reciprocating screw (dashed line) at different gaps δ between screw and the guide pipe angles β and screw rotation speed n

CONCLUSIONS

Based on the patent search analysis of screw working parts design and review of literary sources concerning definition of their operation modes, a new design and production method of reciprocating screw with flexible helical surface have been proposed.

The bench for conduction of experimental researches has been developed and produced.

Experimental research findings concerning the definition of influence of width, cantilevered cog size and measuring load mass on the value of flexible sheet deformation.

From characteristic curve analysis as shown in fig. 3, it can be concluded that for the value of cantilevered cog of flexible blade h = 10 mm increasing its width within the range from B = 5 mm to B = 25 mm for providing deformation value of free edge of flexible sheet Δ = 8 mm the bulk of load must be increased by 2,8 times from 180 to 500 g, for h = 15 mm in 4,8 times, for h = 20 mm in 4,2 times, for h = 25 mm in 4,3 times.

It must be admitted that during the decrease of flexible sheet width B characteristic curve of cantilevered cog size h of flexible sheet from bulk of mensuring loads mg are changed from linear to curvilinear.

ВИСНОВКИ

На основі аналізу проведеного патентного пошуку конструкцій гвинтових робочих органів та літературних джерел з визначення режимів їх функціонування запропоновано нову конструкцію шнека з еластичною гвинтовою поверхнею та спосіб його виготовлення.

Розроблено та виготовлено стенд для проведення експериментальних досліджень.

Наведено результати експериментальних досліджень з визначення впливу на величину деформації вільного кінця секції еластичної пластини її ширини, величини консольного виступу та маси мірних вантажів.

З аналізу графічних залежностей, які зображено на рис. 3 можна зробити висновок, що для величини консольного виступу еластичної пластини h = 10 мм збільшення її ширини в межах від B = 5 мм до B = 25 мм для забезпечення величини деформації вільного кінця еластичної пластини Δ = 8 мм маса вантажу повинна зрости у 2,8 рази від 180 до 500 гр, для h = 15 мм у 4,8 рази, для h = 20 мм у 4,2 рази, для h = 25 мм у 4,3 рази.

Слід зазначити, що при зменшенні ширини еластичної пластини B характер графічних залежностей величини консольного виступу h еластичної пластини від маси мірних вантажів $m_{вр}$ змінюється від лінійного до криволінійного.

Characteristic curve analysis depicted in fig.5 has shown that application of flexible covers on the reciprocating screw surface in comparison with rigid reciprocating screw provides reduction of grain damage degree, which with rotational rate of working part 100...400 r/m is within the range of 1,55...3,0 times and for reciprocating screw working member angles to the pitch of 0...40° is set within 1,63...4,0 times.

Obtained findings can be applied in the development of different types of reciprocating screw working parts with flexible working surfaces taking into account rheological properties of bulk agricultural material and admissible effort value which leads to its damage.

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Аналіз графічних залежностей, які зображені на рис. 5 показав, що застосування еластичних накладок на поверхні шнека у порівнянні з жорстким шнеком забезпечує зменшення степеня пошкодження зернового матеріалу, яке для частоти обертання шнекового робочого органу 100...400 об/хв знаходиться в межах 1,55...3,0 рази, а для кутів нахилу шнекового робочого органу до горизонту 0...40° знаходиться в межах 1,63...4,0 рази.

Отримані результати можуть бути застосовані при проектуванні різних типів шнекових робочих органів з еластичними робочими поверхнями виходячи з реологічних властивостей транспортованих сипких сільськогосподарських матеріалів та допустимих значень зусиль, які призводять до їх руйнування.

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ANALYSIS OF LASER-CLADDING REPAIR PERFORMANCE OF WORN UNIVERSAL JOINT SURFACES IN AGRICULTURAL VEHICLES
/
农用车十字轴磨损表面的激光熔覆修复性能分析

Ph.D. Stud. Che Lei [1)], Prof. Ph.D. Sun Wenlei [1)], Lect. Ph.D. Chao Yongsheng [1)], Ph.D. Stud. Huang Yong [1)], Prof. Ph.D. Weng Yuting[2)]
[1)] School of Mechanical Engineering, Xinjiang University, Urumqi / China;
[2)] Industrial Engineering Department, SMENT-Chile, Las Condes-158, Santiago / Chile
Tel: +86 135 2355 5830; E-mail: xjdx@yeah.net

Abstract: *In order to solve the remanufacturing and repairing of universal joint in agricultural vehicles against surface peeling and evident indentation, laser cladding technology was applied to prepare Fe 314 alloy cladding layer on the journal surface of the universal joint. Metallographic structure of the cladding layer was observed with metalloscope and its hardness was tested by Vickers hardness tester. Moreover, a finite element model of the universal joint load in agricultural vehicles was established. After load and boundary constraint were applied, the cloud chart of displacement changes before and after the cladding was concluded. The universal joint repaired through laser cladding was installed onto agricultural vehicles, presenting no surface peeling and cracking more than eight months later. Test results demonstrated that the cladding layer combines with the substrate well and the hardness of the universal joint improves from 170HV0.025 to 560HV0.025. Abrasive resistance of the cladding position is improved significantly and the displacement decreases by 10.8% compared to that before cladding. Laser cladding could improve performances of the universal joint and prolong its service life.*

Keywords: *agricultural vehicles, universal joint, journal, laser cladding, hardness, performance analysis*

INTRODUCTION

As one of the most important equipment in agricultural production, agricultural vehicles mainly serve in farmlands and rural regions with poorer road conditions than urban areas. Furthermore, they bear heavy freight volume. Therefore, the universal joint in the drive system of agricultural vehicles suffer transient impact loads and huge pressure frequently, thus showing surface peeling and evident indentation failures after being used for 1.5-2 years. Both surface peeling and indentation will enlarge space of the universal joint, thus easy to cause fracture failure at the journal and increasing impact on the main drive system, and even threatening operation safety of the main driving equipment and the whole agricultural vehicle. The installation position and working principle of universal joint in agricultural vehicles are shown in Fig.1.

摘要: *为了解决农用车十字轴表面剥落和压痕明显现象的再制造修复问题，采用了激光熔覆技术在十字轴轴颈表面制备Fe314合金熔覆层。利用金相显微镜和维氏硬度计进行了十字轴样品的熔覆层金相组织观察和硬度测试，并建立农用车十字轴载荷的有限元模型，施加载荷及边界约束后，得到了熔覆前和熔覆后位移的变化云图。激光熔覆修复后的十字轴装配在农用车上，从事日常工作8个多月未出现表面脱落、开裂等问题。试验结果表明：熔覆层和基体结合良好，硬度由170HV0.025提高到560HV0.025，熔覆部位耐磨性得到明显提高，位移量比熔覆前减小了10.8%，达到了改善十字轴性能并延长十字轴使用寿命的目的。*

关键词: *农用车，十字轴，轴颈，激光熔覆，硬度，性能分析*

引言

农用车作为现在农业生产中最重要的设备之一，主要工作在田间和路面质量不及城市的农村地区，路况差，环境恶劣，再加上农用车承载运输量较大，其传动系统中的十字轴频繁承受瞬时冲击载荷和极大的压力，一般使用 1.5-2 年表面就会出现剥落和压痕明显的失效情况。剥落和压痕使十字轴承的间隙增大，进而在轴颈处极易发生断裂失效，更加重主传动系统的冲击，甚至危及主传动设备和整个农用车行车安全。图 1 为农用车十字轴的安装位置和工作原理。

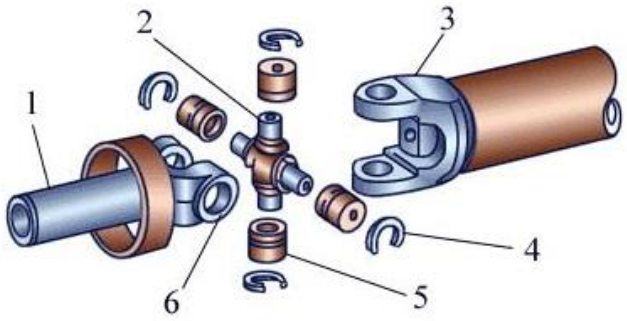


Fig.1- Installation position and working principle of universal joint in agricultural vehicles
1, 3: universal joint yoke; 2: universal joint; 4: spacer; 5: bearing; 6: holes above the universal joint yoke

Many studies have been conducted on the surface peeling and indentation failure of universal joints in recent years. Jin et al. [3] made a digital simulation of a universal joint by using DEFORM software. Although this simulation shortens the development period to a certain extent, it fails to improve the performance of the universal joint. Liu et al. [7] believed that the surface peeling of the universal joint is related to material properties. They suggested the use of imported and more advanced alloy-carburizing steel. However, this approach will increase costs and goes against popularization. Wu et al. [10] reported that although increasing the space between the end faces of the universal joint and the bearing cap can reduce friction heat, this method can easily cause the surface peeling of the universal joint. Tian et al. [9] indicated that optimizing the circular transition at the journal root can improve the performance of the universal joint to a certain extent but not significantly. Liao [5] declared that the simple mechanical re-processing of a surface-peeled universal joint can recover its surface hardness and roughness and prolong the service life of the universal joint. However, this method only fixes the damage and does not address the cause.

Laser cladding is a flexible, advanced manufacturing technology that can create high-performance surfaces on low-cost substrates [6]. In laser cladding, coating materials are placed on the substrate surface simultaneously or in advance. The coating materials are then melted with the substrate surface simultaneously through irradiation of high-energy density laser beams. Thereafter, a cladding layer with compact metallurgical bonding is solidified quickly, thus significantly improving the hardness, wear resistance, and corrosion resistance of the substrate material surface. Laser cladding can repair damaged positions directly and quickly to realize the size and shape reproduction and high-performance repair of damaged parts. Laser cladding is superior to other remanufacturing technologies because of its characteristics of quick cooling, low-rate coating dilution, resource saving, small thermal deformation of the substrate, availability of high-performance metallurgical bonding coating, automatic process, and few follow-ups of mechanical processing cuttings. Yao et al. [11], Feng et al. [2], and Cheng [1] reproduced surface-damaged bent axles and gear thrust surfaces by laser cladding and achieved good results. Ma et al. [8] and Lei et al. [4] made simulation studies on the temperature field and dynamics of laser cladding and achieved some progress. A simulation analysis and experimental verification of laser cladding were implemented on the basis of universal joints with surface peeling and evident indentation in agricultural vehicles. The microstructure and hardness of the cladding layer were observed and tested. Stress-induced deformation was calculated by using the finite element method.

近年来，众多学者对十字轴表面剥落和压痕失效处理进行了大量的研究工作。金广柱等[3]应用 DEFORM 软件对十字轴进行了数字模拟，一定程度上缩短了开发周期，但并没有提高十字轴的性能。刘雪燕等[7]认为，十字轴表面剥落和选材不当有关，应该选用进口的更高级别的合金渗碳钢，但是成本增加，不利于推广。吴石等[10]认为增大十字轴端面和轴承盖之间的间隙，这样虽然可以降低摩擦发热量，但是很容易因为间隙增大而脱落。田辉等[9]认为优化轴颈根部的圆角过渡处，这样可以起到一定的作用，但是效果不明显。廖永锋[5]认为重新简单的机械加工表面剥落的十字轴，恢复其表面硬度和粗糙度，可以延长十字轴的使用寿命，这本身就是一种治标不治本的方法。

激光熔覆是一种柔性化的先进制造技术，可以在低成本基体上制成高性能表面的表面工程技术[6]。激光熔覆就是在基体表面同步或预置涂层材料，经高能量密度激光束辐照，使涂层材料和基体表面同时熔化，并快速凝固形成具有致密冶金结合的熔覆层，从而显著改善基体材料表面的硬度、耐磨、耐腐蚀等性能，可根据受损部位的形状直接进行快速修复，最终实现受损零件外形尺寸重现和高性能修复。相对于其他再制造技术，激光熔覆具有冷却速度快、涂层稀释率低、节约资源、基体热变形较小、可获得高性能冶金结合涂层、工艺过程易于实现自动化、后续机加工切削量少等优点。姚成武等[11]、封慧等[2]、成凯华[1]对表面损伤的曲轴、齿轮推力面进行了激光熔覆再制造，获得了良好的效果。马琳等[8]、Lei Yiwen 等[4]对激光熔覆温度场、动力学进行了仿真研究，取得了一定进展。

利用激光熔覆的方法对表面剥落和压痕明显的农用车十字轴进行了仿真分析和实验验证。观察熔覆后的熔覆层的显微组织和硬度，用有限元的方法对受力产生的变形量做了计算。

MATERIAL AND METHOD

Laser cladding of the universal joint sample and universal joint

The laser-cladding test used a YLS-4000-S2 fiber laser, a Siasun XSL-PF-01B-2 double-bin negative pressure powder feeder, and a KR30HA robot made by KUKA (Germany). The cladding parameters include 2200 W laser power, 600 mm/min scanning speed, 3.4 mm spot diameter; 28.5 g/min powder feeding rate, and 1.7 mm multiple welding landing.

Hardening and tempering 45# steel with the same material as the universal joint was used, and the components of this steel are listed in Table 1. The cladding material will have good wettability because of the similar coefficient of thermal expansion and melting point between the cladding material and substrate metal. Considering the requirement on hardness of the cladding layer, Fe314 alloy was used as cladding material; its chemical composition is shown in Table 2. Before the experiment, the sample surface was polished by sandpaper, and then the rust, oxide film and greasy dirt on the sample surface should be eliminated by using acetone and high-purity ethyl alcohol. Samples were preheated to 250 °C for 2 h before laser cladding.

材料与方法

对十字轴样品和十字轴进行激光熔覆

激光熔覆试验采用 YLS-4000-S2 型光纤激光器，新松 XSL-PF-01B-2 双料仓负压式送粉器，德国 KUKA 公司 KR30HA 机器人。熔覆时采用的参数：激光功率为 2200W，扫描速度为 600mm/min，光斑直径为 3.4mm，送粉量为 28.5g/min，采用多道搭接，搭接度为 1.7mm。

用与十字轴材料相同的，经过调质的 45#号钢，成分如表 1。根据熔覆材料与基体金属热膨胀系数和熔点相近原则，熔覆材料应当具有良好的润湿性，以及对于熔覆层硬度的要求，选择熔覆材料 Fe314 合金，其化学成分见表 2。试验前，先用砂纸将样品表面打磨，然后采用丙酮和高纯酒精进行清洗，将表面的铁锈、氧化膜和油污去除干净，并预热到 250℃，保温两小时后激光熔覆。

Table 1

Composition of substrate material (mass fraction/%)

Elements	C	Si	Mn	P	S	Cr	Ni	Cu	Fe
45#	0.42-0.50	0.17-0.37	0.50-0.80	≤0.035	≤0.035	≤0.25	≤0.25	≤0.25	Bal.

Table 2

Composition of cladding powder material (mass fraction/%)

Elements	Cr	Ni	Si	B	C	Fe
Fe314	14.82-15.24	9.22-11.12	0.93-1.14	0.92-1.14	0.09-0.11	Bal.

Fig. 2 presents a universal joint journal with surface peeling and indentation deeper than 0.1 mm. However, this universal joint journal cannot be used normally. In this paper, this universal joint was mechanically cleaned to remove the coating and fatigue layers, and it was laser cladded by using the same equipment and method as stated above. To obtain a good cladding layer, the distance from the laser head to the universal joint journal surface should be fixed, the traveling speed of laser spot relative to the universal joint journal should be constant, and the laser beam should be kept at the top of the universal joint journal. The inconsistent matching between the laser beam and universal joint journal will change the laser power, thus influencing the morphology of the cladding layer. Fig. 3 shows the laser cladding to the universal joint with surface peeling and evident indentation. The cladding layer on the universal joint journal after cladding is shown in Fig. 4.

图 2 为表面剥落和压痕深度超过 0.1 mm 的十字轴轴颈，该十字轴已不能正常使用。对其进行机械清理，去除镀层和疲劳层，并采用与上述相同的激光熔覆设备和熔覆方法对该十字轴进行激光熔覆。熔覆过程中，为获得良好的熔覆层必须满足以下条件：激光头到十字轴轴颈表面的距离不变，激光光斑与十字轴轴颈相对运行速度恒定，激光束要始终处于十字轴轴颈的最上端。若激光束和十字轴轴颈的运行速度没有匹配好，会引起激光功率的改变，从而影响熔覆层的形貌。图 3 为对表面剥落和压痕明显的十字轴进行激光熔覆，熔覆后的轴颈表面的熔覆层如图 4 所示

Fig.2 - Universal joint journal with surface peeling and evident indentation

Fig.3 - Laser-cladding process

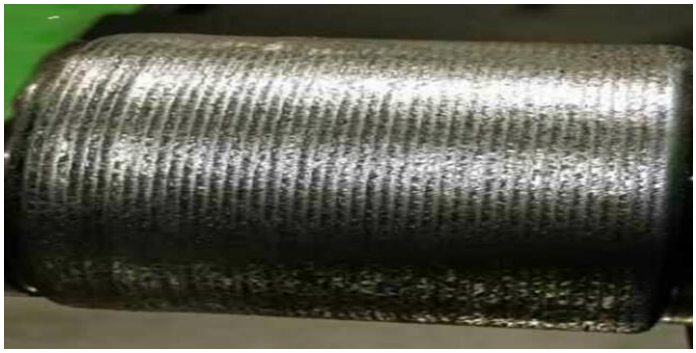


Fig.4 - Universal joint journal surface after cladding

RESULTS ANALYSIS

Cladding layer microstructure of the universal joint sample

Fig. 5 shows the universal joint sample after laser cladding. The sample was cut into 60 mm × 60 mm × 30 mm pieces and then polished to make metallographic samples. The microstructure of the cladding layer was observed by using an optical microscope. The cross-section morphology of the cladding layer is displayed in Fig. 6. The cross-section is divided into three parts, namely, cladding layer, interface layer, and substrate. The cladding layer has a compact and uniform structure without cracks and pores. Furthermore, the cladding layer forms a suitable metallurgical bonding with the substrate.

结果分析

十字轴样品熔覆层显微组织

图 5 为激光熔覆后的十字轴样品。把熔覆后的十字轴样品切割成 60mm×60mm×30mm，并对其进行研磨抛光，制作成金相样品。采用光学显微镜观察样品熔覆层的显微组织。图 6 为熔覆层的横截面形貌，从图中可以看出，横截面分为 3 部分，即熔覆层、结合区和基体。熔覆层组织致密、均匀，未出现裂纹、气孔等缺陷，熔覆层与基体实现了良好的冶金结合。

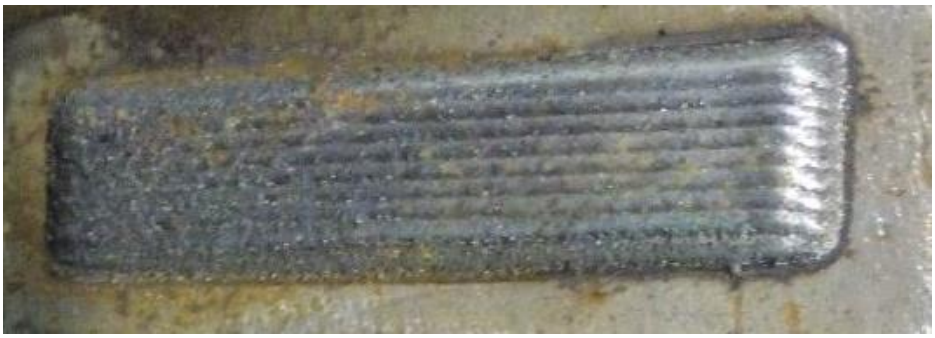


Fig.5- Laser-cladding sample

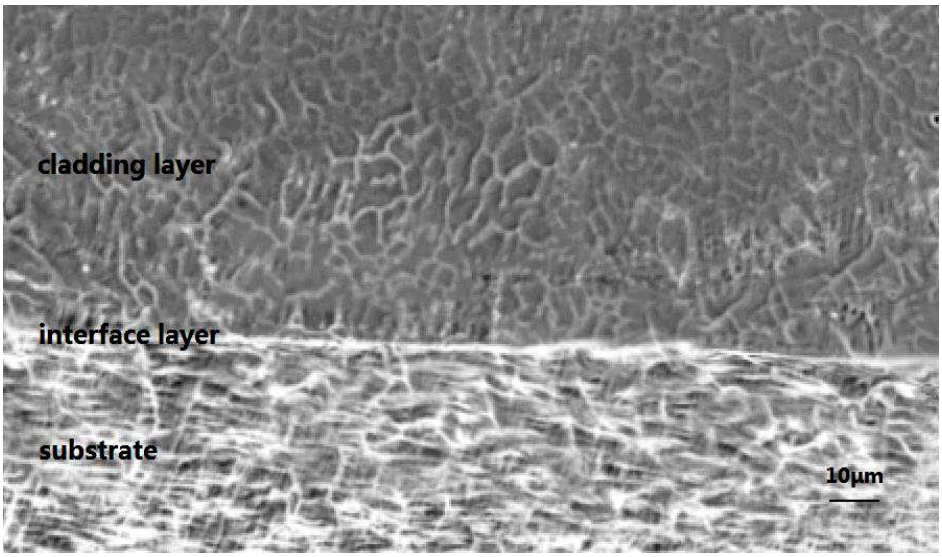


Fig.6- Cross-section morphology of the cladding layer

Hardness of the cladding layer of the universal joint

The micro-hardness of the cladding layer and substrate of the universal joint sample were measured by using a DHV-1000 Vickers hardness tester under a 0.245 N load (25 gf) and 10 s loading time. Each sample was measured at least five times and the mean measured value was taken as the final value. Fig. 7 is the variation curve of the cross-section hardness of the specimen. The horizontal axis is the vertical distance from the measuring point to the cladding layer surface, and the vertical axis is the hardness of the measuring point.

十字轴样品熔覆层硬度

使用 DHV-1000 维氏硬度计测量十字轴样品熔覆层和基体的显微硬度，所加载荷为 0.245N（即 25gf），加载时间为 10s，测量至少 5 次，取平均值。图 7 为试样块横截面硬度的变化曲线。横坐标为被测点到熔覆层表面的垂直距离，纵坐标为被测点的硬度值。

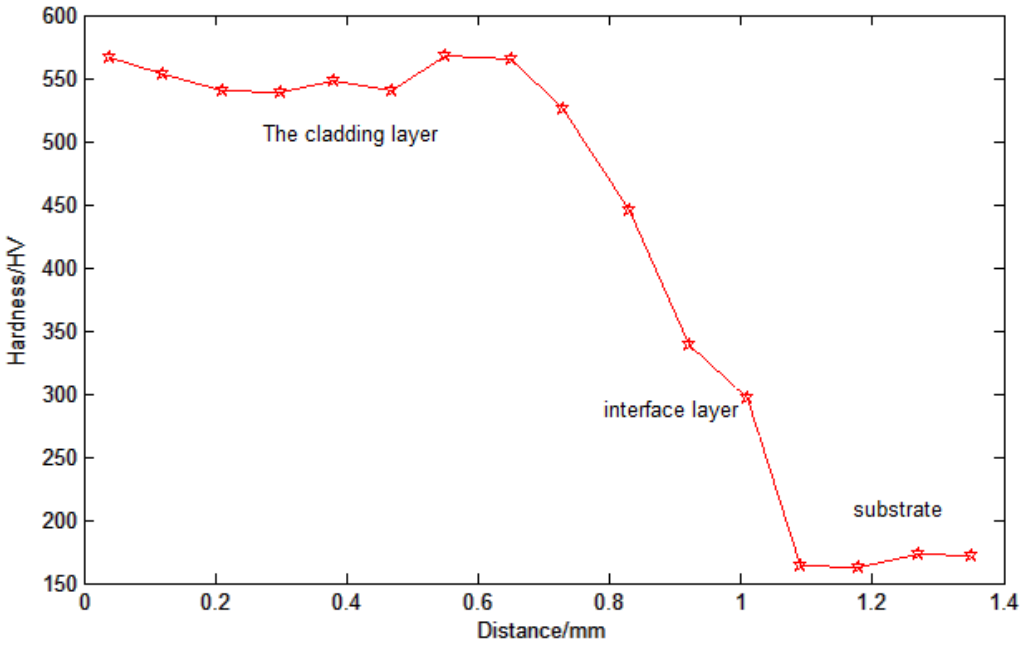


Fig.7- Hardness of the cladding layer, interface layer, and substrate cross-section

In Fig. 7, the hardness of the cladding layer increases from approximately 170HV0.025 of the substrate to approximately 560HV0.025. This increase is mainly caused by the quick solidification of the molten pool and

从图 7 中可以看出，熔覆层的硬度由基体的 170HV0.025 左右提高到 560HV0.025 左右，这主要是因

the refinement of the grains of the cladding layer during laser cladding, thus, compacting the structure and enhancing the grain boundary well. Furthermore, the wear resistance of the cladding position is improved significantly.

为激光熔覆过程中熔池快速凝固使熔覆层的晶粒细化，组织致密，起到了很好的晶界强化作用，熔覆部位耐磨性亦得到明显提高。

Stress analysis of the cladding layer

Stress analysis of the universal joint

熔覆层的应力分析

十字轴的受力分析

The tolerable rated moment of the universal join installed on the Shifeng SF354 agricultural vehicles is expressed as follows:

对安装在时风 SF354 型号农用车上的十字轴，所能承受的额定力矩为：

$$T = 9549 \times \frac{P}{n} = 322.91\text{Nm} \quad (1)$$

where P=25.7kW, and the engine power of the agricultural vehicle n=760 r/min is the rated speed.

The driving force acts on the middle cylindrical surface of the driving shaft neck of the universal joint. The resultant force on the shaft neck F is then expressed as follows:

其中：P=25.7kW，为农用车发动机功率；

n=760 r/min，为额定转速。

传动力作用于十字轴主动轴轴颈的圆柱面上，取轴颈的中间位置施加作用力，则轴颈所受到的合力 F 为：

$$F = \frac{T}{L} = 10091\text{N} \quad (2)$$

where L is the straight-line distance from the F acting point to the geometric center of the universal joint, and L = 0.032 m.

The dynamic model of universal joint is shown in Fig. 8.

其中：L— F 作用点到十字轴几何中心的直线距离，L =0.032m。

十字轴受力模型如图 8 所示。

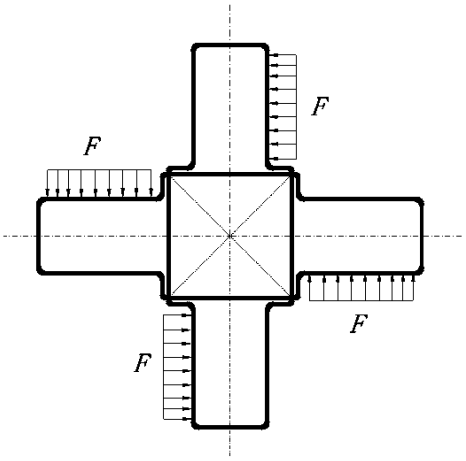


Fig.8 - Dynamic model of uniformly distributed load on the universal joint

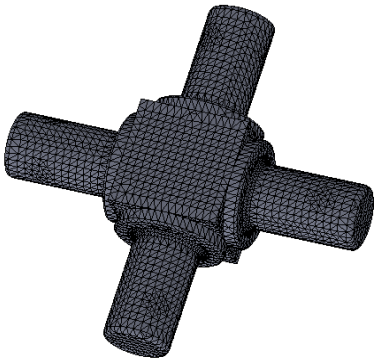


Fig.9 - Gridding result of the universal joint

Finite element simulation of the universal joint

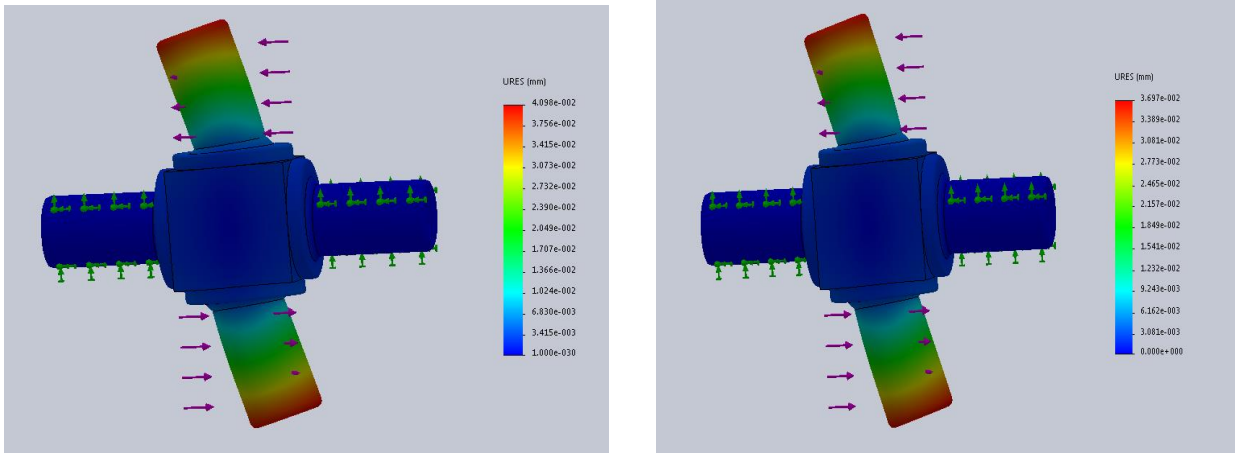
The universal joint model was established in SolidWorks and then entered into SolidWorks Simulation for gridding and simulation analysis. The universal joint model has a complicated structure and cannot be gridded by using default technology. This model has to cut parts before gridding. According to the stress analysis of the universal joint, the universal joint was divided into two symmetric parts. A total of 68,957 units were divided through the free gridding technique, including 100,050 nodes. The gridding result of the universal joint is shown in Fig. 9.

对十字轴有限元仿真

在 SolidWorks 中创建十字轴模型，并将其导入 SolidWorks Simulation中进行网格划分和仿真分析。十字轴模型结构复杂，无法采用默认技术划分网格，需要对部件进行分割，再划分网格。根据十字轴的受力分析，将十字轴分割为对称的两部分。采用自由网格划分技术，共划分有68957个单元，100050个节点。十字轴网格划分效果如图9所示。

The displacement effect after a 10091 N force and boundary constraint that were applied to the original universal joint neck, is exhibited in Fig. 10(a). The displacement effect after a 10091 N force and boundary constraint which was applied to the cladding universal joint is shown in Fig. 10(b). Figs. 10(a) and 10(b) show that after the load and boundary constraints were applied, the maximum deformation before cladding is 4.098×10^{-2} mm but decreases by 10.8% to 3.697×10^{-2} mm after cladding. The performance and service life of the universal joint are improved and prolonged.

对原十字轴的轴颈施加 10091 N 的力及边界约束条件后，显示位移效果如图 10（a）所示。对激光熔覆后的十字轴同样施加 10091 N 的力及边界约束条件后，显示变形量效果如图10（b）。从图10（a）中可以看出，熔覆前施加载荷和边界约束条件后十字轴最大变形量为 4.098×10^{-2}mm，从图 10（b）中可以看出，熔覆后施加载荷及边界约束条件后十字轴最大变形量减小为 3.697×10^{-2}mm，减小了 10.8%，达到了改善十字轴性能并延长十字轴使用寿命的目的。



(a) Universal joint before cladding (b) Universal joint after cladding

Fig.10 - Cloud chart of universal joint deformation

The cladding universal joint was repeatedly polished to the aimed request of the original size and then installed on a Shifeng SF354 agricultural vehicle in Sandaoba Town, Midong District, Urumqi Municipality, Xinjiang, on May 12, 2014. The agricultural vehicle was used in daily farmland work and the transportation of agricultural products. Fig. 11 shows the testing agricultural vehicle with the cladding universal joint. The universal joint disassembled from this agricultural vehicle on January 20, 2015, is shown in Fig. 12. No peeling and cracks were observed, thus indicating that laser cladding is a feasible repair method for universal joints in agricultural vehicles.

熔覆后的十字轴颈经过反复机械修整，达到其原始尺寸精度后，于 2014 年 5 月 12 日装配在新疆乌鲁木齐市米东区三道坝镇的时风SF354型号农用车上，从事日常的田间地头劳作和农产品的运输工作。图 11 为装配熔覆后十字轴的试验农用车。图 12 为 2015 年 1 月 20 日，从装配该熔覆后十字轴的试验农用车上拆卸下来的十字轴。对该十字轴进行仔细检查，并未出现脱落、开裂等现象，说明此方法对农用车十字轴修复是可行的。

Fig.11 - Testing agricultural vehicle with the cladding universal joint

Fig.12 - Disassembled universal joint

CONCLUSIONS

(1) A laser-cladding test is conducted on the universal joint samples of the same material and shows a good metallurgical bonding between the cladding layer and substrate.

(2) The microstructure of the cladding layer is compact without defects. Hardness is improved from 170HV0.025 to 560HV0.025. The wear resistance of the cladding position is significantly improved.

(3) A finite element simulation on universal joint before and after cladding is implemented, concluding that deformation after cladding is 10.8% less than that before cladding.

(4) A universal joint with surface peeling is processed with laser cladding and grinding and is used in a Shifeng SF354 agricultural vehicle for more than eight months, thus confirming the feasibility of laser cladding in repairing surface-worn universal joints.

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结论

（1） 对十字轴的同材质的样品进行了激光熔覆试验。试验表明：熔覆层和基体之间形成了良好的冶金结合。

（2） 样品熔覆层的显微组织致密无缺陷，硬度由170HV0.025 提高到 560HV0.025，熔覆部位耐磨性得到明显提高。

（3） 对十字轴熔覆前和熔覆后分别进行了有限元仿真，得到熔覆后的变形量比熔覆前减小了 10.8%。

（4） 对表面剥落的十字轴激光熔覆后，经过磨削加工，装配在时风 SF354 农用车上，正常运行 8 个多月，验证了此方法对修复表面磨损十字轴的可行性。

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ESTIMATION OF SOIL'S SORPTION CAPACITY TO HEAVY METALS IN ALGERIAN MEGACITIES: CASE OF ALGIERS AND ANNABA

ESTIMATION DE LA CAPACITE DE SORPTION DU SOL AUX METAUX LOURDS DANS LES MEGAPOLES ALGERIENNES: CAS D'ALGER ET ANNABA

Ph.D. Stud. Benselhoub A.[1)], Prof. PhD. Kharytonov M.[1)], Prof. PhD. Bounouala M.[2)], Ph.D. Stud. Chaabia R.[2)], Ph.D. Stud. Badjoudj S.[2)]

[1)] Department of Ecology and Environment Protection, State Agrarian and Economic University, Dnipropetrovsk / Ukraine

[2)] Laboratory of Mining Resources valorization and Environment, Mining Department, Badji Mokhtar University, Annaba / Algeria

E-mail: benselhoub@yahoo.fr

Abstract: *Soils contamination with heavy metals is a major concern and common problem in Algerian megacities. The case of Algiers and Annaba which have known in last years a rapid urbanization and increasing of industrialization. These activities were synonymous with economic and social progress. Moreover, they led to many ecological problems, due to different urban pollution: waste disposal, noise pollution, atmospheric, industrial, soils pollution etc. It is well known that heavy metal contamination is a serious threat to the environment. In fact, large concentrations of heavy metals introduced into the environment may represent a potential toxicity for all living organisms, including humans. The present study was conducted to determine the features of heavy metals adsorption by soils collected in Algiers and Annaba. Wherefore the soil adsorbency to heavy metals was assessed by plotting the isotherms and determining the maximum adsorbency. Whereas results study on sorption isotherms of Algiers soils show that the tested elements can be arranged in the following descending order: Pb> Cu> Zn> Cd. According to study results, the highest value of maximum adsorption capacity of soils taken in four zones of Annaba in relation to lead, zinc, cadmium and copper, were respectively 7; 6; 4.5 and 3 times higher than the minimum. These findings could play a key role to effective assessment of soil pollution with heavy metals in the study area.*

Keywords: *adsorption isotherms, soil pollution, heavy metals, sorption capacity, Algeria*

INTRODUCTION

Soil pollution with heavy metals has been an ever growing concern due to the potential threat to food safety and its detrimental effects on human and animal health. Heavy metals are introduced into soils and environment through both natural and anthropogenic sources. The natural inputs of heavy metals in soils are attributed to geological parent materials. On the other hand, the anthropogenic sources of heavy metals have become more complex in recent decades, including metalliferous mining and smelting, chemical industry, fossil fuel combustion, waste incineration, agricultural activities, and atmospheric deposition [3, 6].

Résumé: *La contamination des sols par les métaux lourds est une préoccupation majeure et un problème commun dans les mégapoles algériennes. Le cas d'Alger et Annaba qui ont connu dans les dernières années une urbanisation rapide et augmentation de l'industrialisation. Ces activités étaient synonymes de progrès économique et social. En outre, ils ont conduit à nombreux problèmes écologiques, en raison des différentes pollutions urbaines: l'élimination des déchets, la pollution sonore, atmosphérique, la pollution industrielle et des sols, etc. Il est bien connu que la contamination par les métaux lourds est une grave menace pour l'environnement. En fait, fortes concentrations des métaux lourds introduits dans l'environnement peuvent représenter une toxicité potentielle pour tous les organismes vivants, y compris les êtres humains. La présente étude a été menée afin de déterminer les caractéristiques d'adsorption des métaux lourds par les sols recueillis à Alger et Annaba. C' est pourquoi la capacité d'adsorption des sols aux métaux lourds été évaluée en traçant les isothermes et déterminant la capacité d'adsorption maximale. Tandis que les résultats d'étude des isothermes de sorption des sols d'Alger montrent que les éléments testés peuvent être classés dans l'ordre décroissant suivant: Pb> Cu> Zn> Cd. Selon les résultats de l'étude, la plus grande valeur de la capacité d'adsorption maximale des sols prélevés dans les quatre zones d'Annaba par rapport au plomb, zinc, cadmium et de cuivre étaient respectivement 7; 6; 4,5 et 3 fois plus élevés du minimum. Ces conclusions pourraient jouer un rôle clé pour l'évaluation efficace de la pollution des sols par les métaux lourds dans la zone d'étude.*

Mots-clés: *adsorption isothermes, pollution des sols, métaux lourds, la capacité de sorption, Algérie*

INTRODUCTION

La pollution des sols par les métaux lourds a été une préoccupation sans cesse croissante en raison de la menace potentielle pour la sécurité alimentaire et ses effets néfastes sur la santé humaine et animale. Les métaux lourds sont introduits dans les sols et l'environnement à travers les sources naturelles et anthropiques. Les intrants naturels de métaux lourds dans les sols sont attribués à des matériaux parentaux géologiques. D'autre part, les sources anthropiques de métaux lourds sont devenues plus complexes au cours des dernières décennies, y compris les mines métallifères et la fonte, l'industrie chimique, la combustion des carburants fossiles, l'incinération des déchets, les activités agricoles, et les dépôts atmosphériques [3,6]. Les métaux lourds ne sont pas biodégradables et peuvent mener à

Heavy metals are not biodegradable and can lead to accumulation in living organisms, causing various diseases and disorders [4].

It is well known that some metals are harmful to life, such as antimony, chromium, copper, lead, manganese, mercury, cadmium, etc., they are significantly toxic to human beings and ecological environments [16].

Development of urbanization, growth in the number of industrial facilities, permanent increase in the density of urban transport in Algiers accompanied by a number of negative phenomena, and, above all, the excessive accumulation in the atmosphere of various gas and vapor contaminants. The main components of receipt of harmful substances into the atmosphere are emissions from high-temperature combustion products (exhaust gas vehicles, aircraft, industrial emissions and thermal power plants) [2, 7].

Several studies in industrial cities of the northern part of Algeria, including determination of the heavy metals total amount, were carried out repeatedly [1,5,9].According to these studies it was found that the priority pollutants in the metropolis of Algiers are more associated with heavy vehicular traffic.

The main objects of air pollution in Annaba are: fertilizers plant FERTIAL, power plants and El Hadjar metallurgical plant which is under the financial control of the company ARCELOR MITTAL. However, the factors affecting the sorption of heavy metals by soils of these cities are poorly understood.

Many researches have accumulated a lot of information on the effect of different soil components on the adsorption characteristics of heavy metals, mainly on the basis of model experiments in mono- and bi-component systems or in experiments with the introduction of various model components in soil samples from the outside [8,11,15]. This can be explained by the fact that the amount of organic matter does not plays a leading role in adsorption process, as qualitative composition of organic and mineral formations as carriers of sorption capacity.

MATERIALS AND METHODS

Description of the study area

The present study is carried out in two major cities of the northern part of Algeria (Algiers and Annaba) (Fig.1). Algiers is the capital city situated between latitudes 36 ° 43 'and 36 ° 49' North and longitudes 2 ° 58 'and 3 ° 12' East. The altitude varied between 50 and 400 m. The average annual rainfall is around 600 mm / year. As for the temperatures, average Min T = 10 ° C, average Max T= 26.3 ° C. So the climate is Mediterranean, hot sub humid winter. Prevailing winds are west and north-west. The total estimated population of 2,562,428 inhabitants (1998). Car traffic reached 674,570 vehicles in 2003[13]. In Topographical terms, the Algiers region is characterized by a heterogeneous terrain. The eastern part, which includes Fort de l'eau, El Harrach , Hussein Dey ,Belcourt is flat (altitude between 0 and 100 m). Contrariwise, the massive of Bouzaréa, culminating at 400 m and the eastern and northern catchment of this massif are very rugged. The central part of Algiers is a plateau (altitude between 100 and 200 m) intersected Parun network deep

l'accumulation dans les organismes vivants, provoquant diverses maladies et affections [4].

Il est bien connu que certains métaux sont nuisibles à la vie, tels que l'antimoine, le chrome, le cuivre, le plomb, le manganèse, le mercure, le cadmium, etc., ils sont significativement toxique pour les êtres humains et les milieux écologiques [16].

Développement de l'urbanisation, la croissance du nombre d'installations industrielles, augmentation permanente de la densité du transport urbain à Alger accompagné d'un certain nombre de phénomènes négatifs, et, surtout, l'accumulation excessive dans l'atmosphère des gaz divers et les contaminants en phase vapeur. Les principaux composants de la réception des substances nocives dans l'atmosphère sont les émissions des produits de combustion à haute température (les gaz d'échappement des véhicules, les avions, les émissions industrielles et les centrales thermiques) [2,7]. Plusieurs études dans les villes industrielles de la partie nord de l'Algérie, y compris la détermination de la quantité totale des métaux lourds, ont été effectuées à plusieurs reprises [1, 5, 9].

Selon ces études, il a été constaté que les polluants prioritaires dans la métropole d'Alger sont plus associés à la forte circulation automobile. Les principaux objets de la pollution de l'air à Annaba sont: l'usine des engrais FERTIAL, les centrales électriques et l'usine métallurgique d'El Hadjar qui est sous le contrôle financier de la société ARCELOR MITTAL. Cependant, les facteurs qui influent sur la sorption des métaux lourds par les sols de ces villes sont mal compris.

De nombreuses recherches ont accumulé beaucoup d'informations sur l'effet des différentes composantes du sol sur les caractéristiques d'adsorption des métaux lourds, principalement sur la base des expériences du modèle dans les systèmes mono et bi-composants ou dans des expériences avec l'introduction de divers composants de modèle dans des échantillons de sol du l'extérieur[8, 11,15]. Ceci peut être expliqué par le fait que la quantité de matière organique ne joue pas un rôle prépondérant dans le processus d'adsorption, que la composition qualitative des formations organique et minérale comme supports de la capacité de sorption.

MATERIELS ET METHODES

Description de la zone d'étude

La présente étude est réalisée dans deux grandes villes de la partie nord de l'Algérie (Alger et Annaba) (Fig.1). Alger est la capitale située entre les latitudes 36° 43' et 36° 49' Nord et les longitudes 2° 58' et 3° 12' Est. L'altitude variée entre 50 et 400m. Les précipitations moyennes annuelles sont à l'ordre de 600 mm/an. Quant aux températures, T Min moyenne= 10°C, T Max moyenne= 26.3°C. Le climat donc est de type méditerranéen, subhumide à hiver chaud. Les vents dominants: W et NW. La population totale est estimée de 2 562 428 habitants (1998). Le trafic automobile atteint 674 570 véhicules en 2003[13]. Du point de vue topographique, la région d'Alger est caractérisée par un relief hétérogène. La partie Est qui comprend Fort de l'eau, El Harrach, Hussein Dey et Belcourt est plane (altitude entre0 et 100 m). Par contre, le massif de Bouzaréa, culminant à 400 m d'altitude, et les versants Est et Nord de ce massif sont très accidentés. La partie centrale de la région d'étude correspond à un plateau (altitude entre 100 et 200 m) recoupé par un

talwegs and visible in Hydra and Birmouradrais. Finally, much of the West Coast and the South of the region is represented by more or less horizontal planes (trays, Piedmont), with altitudes ranging between 200 and 300 m [10].

The wilaya of Annaba is located in eastern Algeria, between latitudes 36 ° 30 N and 37 ° 30 N and longitude 7 ° 20 E and 8 ° 40 E. Its area is 1411.98 km^2; its population has increased in recent years to 650. 000 inhabitants. It is bounded to the south by the wilaya of Guelma, to the west by the wilaya of Skikda, in the east by the wilaya of El Tarf (Tunisian border) and to the north by the Mediterranean Sea [14]. The climate is typically Mediterranean, with an average annual temperature of 18 °C and an annual rainfall ranging from 650 to 1000 mm with a winter peak and a deficit during summer .The city is bounded to the north and the west by the Edough massif (highest altitude: 850 m), the Mediterranean Sea to the east and the Seybouse alluvial plain to the south. The Edough massif is characterized by a Primary metamorphic rock platform of gneiss, schist, and micaschist. The alluvial plain is characterized by Tertiary gravelly and sandy-clayed layers at depth and arable Quaternary clay cover. The dominant wind comes from the north north-east, to a lesser extent, from the north and the west [9].

réseau de talwegs profonds et visibles à Hydra et Birmouradrais. Enfin, la grande partie de l'Ouest et du Sud de la région est représentée par des plans plus au moins horizontaux (plateaux, piémont), dont l'altitude varie entre 200 et 300 m [10].

La wilaya d'Annaba est situé dans l'est de l'Algérie, entre les latitudes 36 ° 30 N et 37 ° 30 N et la longitude 7 ° 20 E et 8 ° 40 E. Sa superficie est de 1411,98 km2; sa population a augmenté au cours des dernières années à 650. 000 habitants. Il est délimité au sud par la wilaya de Guelma, à l'ouest par la wilaya de Skikda, à l'est par la wilaya d'El Tarf (frontière tunisienne) et au nord par la mer Méditerranée [14]. Le climat est typiquement méditerranéen, avec une température annuelle moyenne de 18 ° C et des précipitations annuelles allant de 650 à 1000 mm avec un pic en hiver et un déficit au cours de l'été .La ville est délimitée au nord et à l'ouest par le massif Edough (altitude la plus élevée: 850 m), la mer Méditerranée à l'est et la plaine alluviale Seybouse au sud. Le massif Edough est caractérisé par une plate-forme de roche métamorphique primaire de gneiss, de schiste et micaschiste. La plaine alluviale est caractérisée par graveleux tertiaire et des couches de sable argileux-en profondeur et la couverture d'argile Quaternaire arables. Le vent dominant vient du nord-nord-est, dans une moindre mesure, du nord et de l'ouest [9].

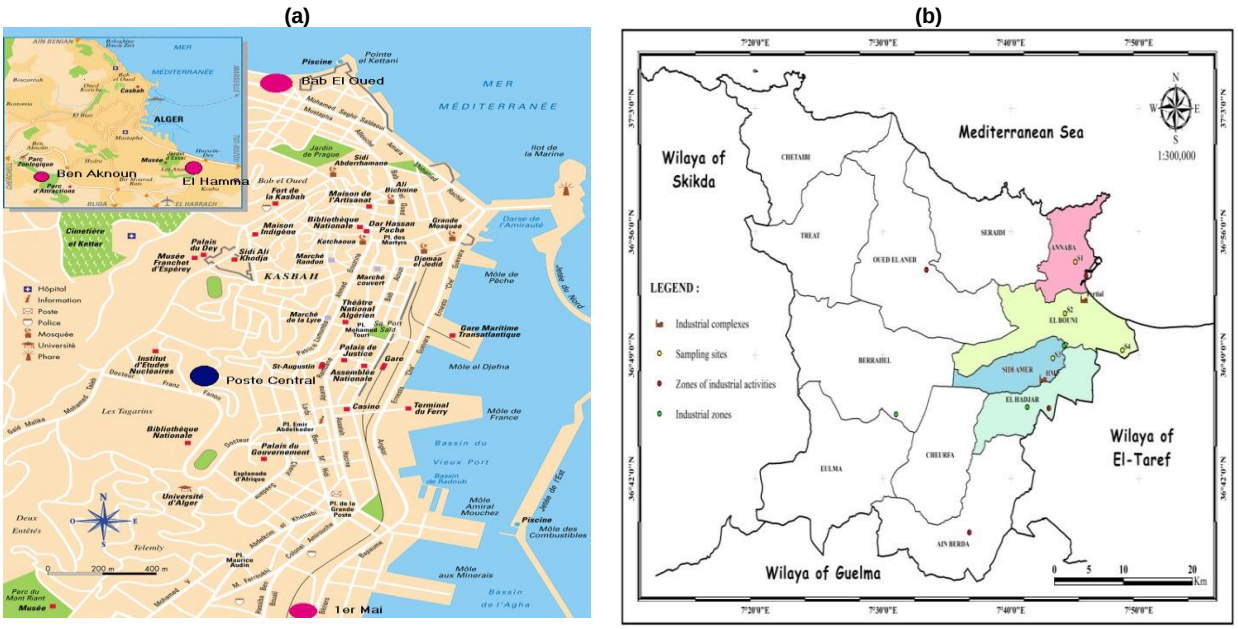

Fig. 1 – Map of study area location.(a) Map of Algiers with sampling sites:1er Mai, Bab El Oued, Ben Aknoun,El Hamma. (b) Map of Annaba showing the sampling sites: Annaba Center, El Bouni, Sidi Amar, Airport.

Air quality monitoring

In environmental terms since 2002 have been installed four networks of air quality monitoring baptized SAMASAFIA [12]. These networks are located in four major cities of Algeria namely: Algiers, Annaba, Oran and Skikda.

- Algiers: Network consists of 04 stations connected to a central station
- Annaba: Network consists of 04 stations are connected to a central station.
- Oran: Network of stations 03 connected to a central station.

La surveillance de la qualité de l'air

En termes environnemental depuis 2002 ont été installés quatre réseaux de surveillance de la qualité de l'air baptisés SAMASAFIA [12]. Ces réseaux sont situés dans quatre grandes villes de l'Algérie à savoir: Alger, Annaba, Oran et Skikda.

- Alger: réseau constitué de 04 stations reliées à une station centrale
- Annaba: réseau constitué de 04 stations sont reliées à une station centrale.
- Oran: réseau de stations 03 connectés à une station centrale.

- Skikda: Network of stations 03 connected to a central station.

These networks have the role of measurement, operation and information for the public and to the authorities concerned for monitor the level of pollution due to the different indicators relating to road traffic pollution (NO_x, NO, CO, CO_2, O_3, SO_x, suspended particulate matter PM-10 and heavy metals).

- Detect pollution peaks and periods during which the limit thresholds are exceeded;
- Establish the air quality forecasts using simulation models;
- Alert authorities during critical situations of pollution;
- Inform people of the measures to be taken to reduce the health impacts.

The air quality monitoring networks of Algiers and Annaba include four sites consists of automatic measuring stations working continuously (24h / 24, 7 days/7). Network's stations are located at the following sites in each city according to Table.1:

- Skikda: réseau de stations 03 connectés à une station centrale.

Ces réseaux ont le rôle de la mesure, l'exploitation et l'information du public et les autorités concernées pour surveiller le niveau de la pollution due aux différents indicateurs relatifs à la pollution du trafic routier (NOx, NO, CO, CO_2, O_3, SOx, particules en suspension PM-10 et les métaux lourds).

Détecter les pics de pollution et les périodes durant lesquelles les seuils limites sont dépassés ;

- Établir les prévisions de qualité de l'air à l'aide de modèles de simulation;
- Alerter les autorités durant les situations critiques de pollution;
- informer les gens sur les mesures à prendre pour réduire les impacts sur la santé.

Les réseaux de surveillance de la qualité de l'air d'Alger et d'Annaba comprennent quatre sites se compose des stations de mesure automatiques fonctionnant en continu (24h / 24, 7 jours / 7). Les stations de réseau sont situées sur les sites suivants dans chaque ville selon Tableau.1:

Table 1

Monitoring networks location in Algiers and Annaba

CITY	NETWORKS LOCATION
Algiers	1er Mai
	Ben Aknoun
	Bab El Oued
	El Hamma
Annaba	Annaba Center
	El Bouni
	Sidi Amar
	Airport

Soil sampling

In order to bind the observed meteorological data, soil samples were collected nearby the stationary monitoring networks in each city (Fig.1). 5 sub-samples (to obtain a representative sample) were collected in depth 0-5;5-10;10-20 cm within each plot, as close as possible of the center of the plot in a homogeneous pedological area. Soil sampling was performed with the method of "envelope", 800 - 900 g of each sample. In each plot, we selected two samples collected at different directions from monitoring networks. After that, soil samples were dried at room temperature and powdered, impurities and particles have been removed using sieves with holes of different diameter from 5 to 1 mm. To reduce the mass of the sample, we used the method of quartering: the shredded material was thoroughly mixed and scattered smooth a thin layer in the form of a square, divided into four sectors. The content of the two opposite sectors was discarded, and the remaining two were again mixed. After multiple repetitions, soil sample was dried and used for carrying out of procedures of extraction.

Chemical analysis

Soil samples were prepared for chemical analyses using conventional methods. The equilibrium concentration of each element was measured for three days .The instrument setting and operational conditions were done in accordance with the manufacturers'

L'échantillonnage du sol

Afin de lier les données météorologiques observées, des échantillons de sol ont été prélevés à proximité des réseaux de surveillance fixes dans chaque ville (Fig.1). 5 sous-échantillons (pour obtenir un échantillon représentatif) ont été recueillis en profondeur 0-5; 5-10; 10-20 cm, au sein de chaque parcelle, aussi près que possible du centre de la parcelle dans une zone pédologique homogène. L'échantillonnage du sol a été effectué avec la méthode de "l'enveloppe", 800 à 900 g de chaque échantillon. Dans chaque parcelle, nous avons sélectionné deux échantillons prélevés à différentes directions des réseaux de surveillance. Après cela, les échantillons de sol ont été séchés et poudrés à température ambiante, les impuretés et les particules ont été retirées en utilisant des tamis avec des trous de différents diamètres de 5 à 1 mm. Afin de réduire la masse de l'échantillon, nous avons utilisé la méthode du quartage: le matériau déchiqueté était soigneusement mélangés, et dispersés lisser une mince couche sous la forme d'un carré, divisé en quatre secteurs. Le contenu des deux secteurs opposés a été éliminé, et les deux autres ont été à nouveau mélangés. Après multiples répétitions l'échantillon du sol a été séché et utilisé pour la mise en œuvre des procédures d'extraction.

Analyses chimiques

Les échantillons du sol été préparés pour les analyses chimiques en utilisant des méthodes conventionnelles. La concentration de chaque élément d'équilibre a été mesurée pendant trois jours .Le réglage de l'instrument et les conditions opérationnelles ont été réalisées en conformité avec les spécifications du fabricant. Pour les

specifications. For the qualitative and quantitative characteristics of the interaction with the studied elements of soil adsorption complex, sorption isotherms were constructed. The soil sorption properties and mobility of the heavy metals determined at the static and dynamic conditions. In the laboratory, experiments on studying of the physicochemical feature of heavy metals sorption the ratio; soil: solution was equal to 1:100. The metals' concentrations were changed in experimental conditions from 5 to 1000 mg/dm^3. In the course of experiment, the corresponding aliquot of the heavy metal under study was added to the soil sample.

Sorption dynamics of zinc, copper, cadmium and lead from the studied solutions at different concentrations: zinc: 2-200 mg / dm^3; copper: 20-250 mg / dm^3; cadmium 2-100 mg/dm^3; Lead: 20-500 mg/dm^3. Ratio soil: solution - 1: 1000. The content of heavy metals (Mn, Ni, Pb, Zn, Cd and Cu) in samples was determined by flame atomic absorption spectrophotometer (Model S-115, Ukraine).

RESULTS

The agrochemical soils assessment of Algiers and Annaba is shown in Table 2.

caractéristiques qualitatives et quantitatives de l'interaction avec les éléments étudiés de complexe d'adsorption des sols, isothermes de sorption ont été construits. Les propriétés de sorption du sol et la mobilité des métaux lourds déterminés dans les conditions statiques et dynamiques. Au laboratoire, les expériences sur l'étude des caractéristiques physico-chimiques du sorption des métaux lourds le rapport; sol: solution était égal à 1: 100. Les concentrations de métaux été modifiés dans les conditions expérimentales de 5 à 1000 mg / dm^3. Au cours de l'expérience, la partie aliquote correspondante du métal lourd à l'étude a été ajouté à l'échantillon de sol.

La dynamique de sorption du zinc, cuivre, cadmium et plomb des solutions étudiées à différentes concentrations: zinc: 2-200 mg / dm^3; cuivre: 20-250 mg/dm^3; cadmium 2-100 mg / dm^3; Plomb: 20-500 mg / dm^3. Rapport sol: solution - 1: 1000. La teneur en métaux lourds (Mn, Ni, Pb, Zn, Cd et Cu) dans les échantillons a été déterminée par un spectrophotomètre d'absorption atomique flamme (Modèle S-115, Ukraine).

RESULTATS

L'évaluation agrochimiques des sols d'Alger et d'Annaba est présentée dans le Tableau 2.

Table 2

Agrochemical soil assessments of Algiers and Annaba

City	Sampling district	pH	Humus,%	Ca + Mg, mmol / 100 g of soil
Algiers	1er Mai	8.4	3.3	76.5
	Ben Aknoun	8.3	2.6	94.5
	Bab El Oued	8.1	4.45	90.0
	El Hamma	8.5	1.7	61.4
Annaba	Annaba Center	8.0	3.0	61.0
	El Bouni	8.6	1.2	86.0
	Sidi Amar	8.4	2.7	104.5
	Airport	8.4	2.7	122.5

Corresponding analysis of Table 2 showed that in the top 5 cm layer of soil sampled in different areas of the cities of Algiers and Annaba, the pH of the aqueous extract is in the range 8.0-8.6 and humus content in the range 1.2-4.45. The greatest value of the sum of exchangeable bases recorded in two districts of Annaba city (Sidi Amar and Airport).To study the mechanisms of zinc fixing by soils, the sorption dynamics was analyzed (Fig.2).

L'analyse correspondante du Tableau 2 a montré que dans le top 5 cm de la couche du sol prélevé dans les différentes zones des villes d'Alger et Annaba, le pH de l'extrait aqueux est dans la gamme 8,0-8,6 et la teneur de l'humus est dans la gamme de 1.2-4 .45. La plus grande valeur de la somme des bases échangeables enregistrées dans deux districts de la ville d'Annaba (Sidi Amar et l'Aéroport) .Pour étudier les mécanismes de fixation de zinc par les sols, la dynamique de sorption a été analysée (Fig. 2).

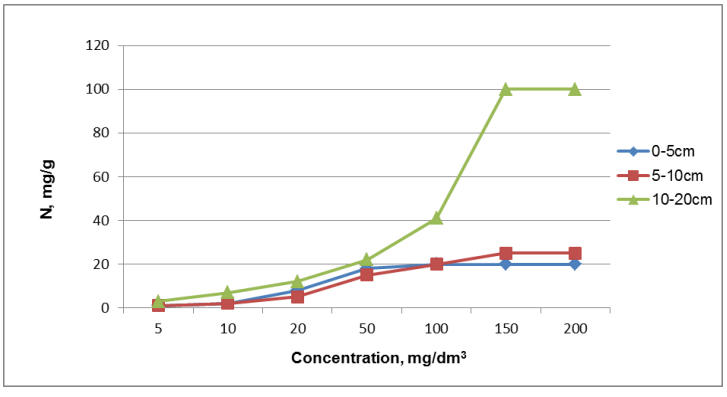

Fig.2 - Dynamics of zinc sorption by soils of Algiers

From the analysis of Fig.2 we found that most of zinc adsorbed by soil in the selected zone of 1er Mai at a concentration in a solution of 100 mg /dm^3. In general, the best affinity of soil for zinc differs from the area of Ben Aknoun. It is known that contaminated soil containing a large number of non-silicate iron is adsorbed a greater absolute amount of zinc than non-contaminated soil [15]. Sorption isotherms of copper, cadmium and lead are shown in figures 3-5.

De l'analyse de la Fig.2 on a trouvé que la plupart du zinc adsorbé par le sol dans la zone sélectionnée du 1er Mai à une concentration dans une solution de 100 mg/dm^3. En général, la meilleure affinité du sol pour le zinc diffère de la zone de Ben Aknoun. On sait que le sol contaminé contenant un grand nombre de fer non-silicate est adsorbé une plus grande quantité absolue de zinc du sol non contaminé [15]. Les isothermes de sorption de cuivre, cadmium et du plomb sont représentés dans les figures 3-5.

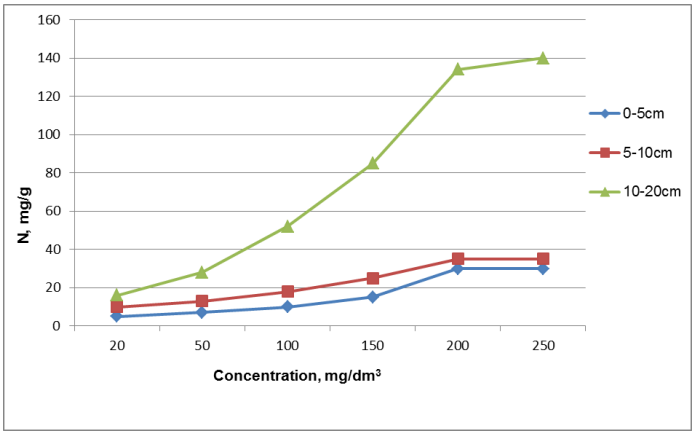

Fig.3 - Dynamics of copper sorption by soils of Algiers

In the area of concentration of working solution of copper from 150 to 200 mg / dm^3, copper adsorption held sufficiently intensive. The saturation of the soil solution by this element has come to achieve the concentration of 200 mg/dm^3.

Dans la concentration de 150 à 200 mg / dm^3 de la solution de cuivre, l'adsorption de cuivre maintenue suffisamment intensif. La saturation de la solution du sol en cet élément est venu de parvenir à la concentration de 200 mg / dm^3.

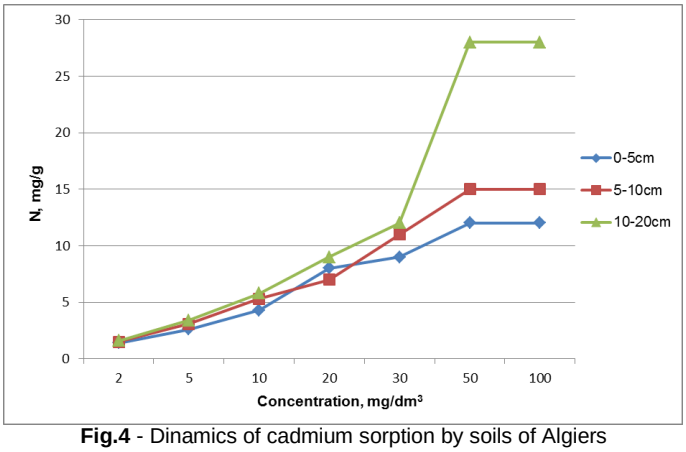

Fig.4 - Dinamics of cadmium sorption by soils of Algiers

Saturation of the cadmium soil solution recorded at 50 mg / dm^3.

La saturation de la solution du sol de cadmium enregistré à 50 mg / dm^3.

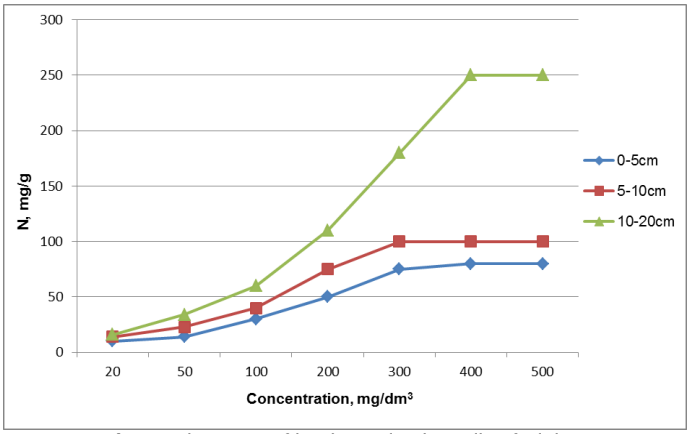

Fig.5 - Dinamycs of lead sorption by soils of Algiers

Table3

Limiting adsorption capacity mg/g

Sampling site	Mn	Ni	Pb	Zn	Cd	Cu
Annaba center	15	25	160	20	10	60
El Bouni	20	25	85	25	35	65
Sidi Amar	15	15	60	25	45	40
Airport	35	30	410	125	45	190

To saturate the lead soil solution it was needed to bring the level up to the element concentration 400 mg / dm^3.

Our studies confirm the results of Rogova O. B and Vodyanitskiy Y.N to study the sorption of heavy metals, according to which the processes of surface adsorption dominated the first two days of interaction [11].The results studies of limiting adsorption capacity to heavy metal for soil samples taken in the four designated areas of Annaba city are shown in Table 3.

Based on the data obtained and presented in Table 3 the studies of soils limiting adsorption capacity taken in four zones of Annaba city to heavy metals, showed a significant differences with respect to certain metals. The maximum value of adsorption capacity of soil samples to lead, zinc, cadmium and copper, are respectively 7; 6; 4.5 and 3 times higher than the minimum. Characteristically, the greatest value of adsorption capacity for all heavy metals is fixed for the area of the Airport.

CONCLUSIONS

From the analysis and interpretation of results obtained in the present research the following points should be emphasized:

1. In the top 0-5 cm layer of soil sampled in different areas of the city of Algiers and Annaba, the pH of the aqueous extract is in the range 8, 0-8, 6, and humus content in the range 1. 2 – 4.45. The greatest value of the sum of exchangeable bases recorded in two districts of Annaba city (Sidi Amar and Airport).

2. It was found that most of the zinc adsorbed by the soil in the selected zone 1er Mai at a concentration in a solution of 100 mg / dm^3. In general, the best affinity of soil for zinc differs from the area of Ben Aknoun.

According to study results, the highest value of maximum adsorption capacity of soils taken in four zones of Annaba in relation to the lead, zinc, cadmium and copper, were respectively 7; 6; 4.5 and 3 times higher than the minimum. Characteristically, the greatest value of the maximum adsorption capacity of all heavy metals is fixed for the area of the Airport.

The findings in this study could play a key role to effective assessment of soil pollution with heavy metals in the study area.

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Pour saturer la solution du sol de plomb, il était nécessaire pour amener le niveau jusqu'à la concentration de l'élément de 400 mg / dm^3.

Nos études confirment les résultats de Rogova O. B et Vodyanitskiy Y.N pour étudier la sorption des métaux lourds, selon laquelle les processus d'adsorption de surface ont dominé les deux premiers jours de l'interaction [11]. Les résultats des études de limitation de la capacité d'adsorption des métaux lourds pour les échantillons de sol prélevés dans les quatre régions désignées de la ville d'Annaba sont montrés dans le Tableau 3.

Basant sur les données obtenues et présentées dans le Tableau 3, les études des sols limitant la capacité d'adsorption pris en quatre zones de la ville d'Annaba pour les métaux lourds, ont montré une différence significative par rapport à certains métaux. La valeur maximale de la capacité d'adsorption des échantillons de sol au plomb, zinc, cadmium et cuivre, sont respectivement 7; 6; 4,5 et 3 fois plus élevé que le minimum. Caractéristiquement, la plus grande valeur de capacité d'adsorption de tous les métaux lourds est fixée pour la zone de l'Aéroport.

CONCLUSIONS

À partir de l'analyse et l'interprétation des résultats obtenus dans la présente étude les points suivants doivent être soulignés:

1. Dans le top 5 cm de la couche du sol prélevé dans les différentes zones des villes d'Alger et d'Annaba, le pH de l'extrait aqueux est dans la gamme 8,0-8,6 et la teneur de l'humus est dans la gamme de 1.2 – 4.45. La plus grande valeur de la somme des bases échangeables enregistrées dans deux districts de la ville d'Annaba (Sidi Amar et l'Aéroport).

2. On a constaté que la majeure partie du zinc adsorbé par le sol dans la zone sélectionnée du 1er Mai à une concentration dans une solution de 100 mg / dm^3. En général, la meilleure affinité du sol pour le zinc diffère de la zone de Ben Aknoun.

Selon les résultats de l'étude, la valeur la plus élevée de la capacité d'adsorption maximale des sols prises dans les quatre zones de Annaba par rapport au plomb, zinc, cadmium et du cuivre, étaient respectivement de 7; 6; 4,5 et 3 fois plus élevé que le minimum. Caractéristiquement, la plus grande valeur de la capacité d'adsorption maximale de tous les métaux lourds est fixée pour la zone de l'Aéroport.

Les conclusions de cette étude pourraient jouer un rôle clé pour l'évaluation efficace de la pollution des sols par des métaux lourds dans la zone d'étude.

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ANALYSIS OF PROFITABILITY OF IMPLEMENTING THE MISCANTHUS ENERGETIC CROP TECHNOLOGY FOR RHIZOMES CAPITALIZATION
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ANALIZA RENTABILITĂŢII IMPLEMENTĂRII TEHNOLOGIEI DE CULTURĂ A PLANTEI ENERGETICE MISCANTHUS ÎN VEDEREA VALORIFICĂRII RIZOMILOR

PhD. Stud. Eng. Sorică E.
University Politehnica of Bucharest / Romania
E-mail: postelnicu.elena@yahoo.com

Abstract: *Within the biomass, Miscanthus crop is one of the best bioenergy future prospects. Although the Miscanthus plant was extensively studied in Europe and US, the production cost of Miscanthus rhizomes in Romania is unknown. Present study is estimating this cost for evaluating the economic profitability of producing rhizomes in Romania, in order to trade them and establish new cultures. Therefore, the main contribution of this study is finding out the breakeven point, breakeven price and profit for activity of producing Miscanthus rhizomes based on data referring to production, selling cost and specific costs in Romania.*
Study on economic efficiency of Miscanthus crop, in order to capitalize its rhizomes, will have a practical usefulness for farmers wanting to invest in energetic crops both for obtaining biomass and trading the rhizomes for establishing of new cultures.

Keywords: *Miscanthus, analysis of profitability, breakeven point, breakeven price.*

INTRODUCTION

One of multiple effects of technological progress of human society in the last century is the growth of energy consumption and human being's strong dependency on fossil fuels consumption, especially petroleum-based products, natural gases and coal. These classical power sources represent a major factor of risk because of polluting emissions during combustion and also their exhaustion.

Member states have committed to reduce by 20% the greenhouse effect gas emissions (GES), increase up to 20% the share of energy coming from renewable sources within the EU energy mix and ensure the energy efficiency growth by 20% till 2020.

One of the most efficient solutions for reducing the CO_2, emissions level is the use of renewable energy, characterized by a reduced level of these emissions.
Main renewable energy sources in Romania are: biomass, solar energy, wind energy and geothermal energy. Within biomass, Miscanthus crop represents one of the best prospects for bio-energy production.

The Miscanthus plant (fig. 1), as renewable source produces a quantity of 15…20 t/ha of dry substance and is widely cultivated in certain soils, which are less appropriate for other cultures; it has a perennial growth up to 10-15 years, uses efficiently the nitrogen, water and other resources, is resistant to illnesses, and requires less fertilizers, pesticides and other chemicals [9]. The net caloric value, comparing to dried mass is of 17 MJ/kg or 4.75 kW/kg.

Rezumat: *În cadrul biomasei, una din cele mai bune perspective pentru producția de bioenergie este reprezentată de cultura de Miscanthus. Deși planta Miscanthus a fost studiată extensiv în Europa și SUA, costul de producție al rizomilor de Miscanthus în Romania este necunoscut. Prezentul studiu estimează acest cost, în scopul evaluării fezabilității economice a producerii de rizomi în Romania, în vederea comercializării și înființării de noi culturi. Prin urmare, principala contribuție a acestui studiu este determinarea pragului de rentabilitate, a prețului de rentabilitate si profitului pentru activitatea de producere a rizomilor de Miscanthus, pe baza datelor privind producția, prețul de vânzare și costurile specifice României.*

Studiul privind eficiența economică a culturii de Miscanthus, în vederea valorificării rizomilor, va avea utilitate practică pentru fermierii care vor să investească în culturi energetice atât în scopul obținerii de biomasă cât și în scopul comercializării rizomilor în vederea înființării de noi culturi.

Cuvinte cheie: *Miscanthus, analiza rentabilității, prag de rentabilitate, preț de rentabilitate*

INTRODUCERE

Unul din efectele dezvoltării tehnologice a întregii societăți umane, din ultimul secol, este creșterea tot mai pronunțată a consumurilor de energie, dar și dependența tot mai accentuată a omenirii, de consumul combustibililor fosili, în special produse petroliere, gaze naturale și cărbuni. Aceste surse de energie clasice reprezintă un foarte mare factor de risc datorită emisiilor poluante din timpul arderii, cât și datorită epuizării lor.

Statele membre s-au angajat să reducă cu 20% emisiile de gaze cu efect de seră (GES), să crească la 20% ponderea energiei din surse regenerabile în cadrul mixului energetic al UE si să îndeplinească obiectivul de creștere a eficientei energetice cu 20% până în 2020.

Una din cele mai eficiente soluții pentru reducerea nivelului emisiilor de CO_2, o reprezintă utilizarea energiilor regenerabile, caracterizate printr-un nivel extrem de redus al acestor emisii.

Principalele surse de energie regenerabilă în România sunt: biomasa, energia solară, eoliană şi energia geotermală. În cadrul biomasei, una din cele mai bune perspective pentru producția de bioenergie este reprezentata de cultura de Miscanthus.

Planta Miscanthus (fig. 1), ca resursă regenerabilă produce o cantitate de 15…20 t/ha substanță uscată, se cultivă extensiv pe anumite soluri mai puțin indicate pentru alte culturi, are o creștere perenă de 10-15 ani, utilizează eficient azotul, apa și alte resurse, este rezistent la boli, iar pentru întreținere necesită puține cerințe pentru fertilizanți, pesticide și alte chimicale [9]. Valoarea netă calorică, raportată la biomasa uscată este de 17 MJ/kg sau 4,75 kW/kg.

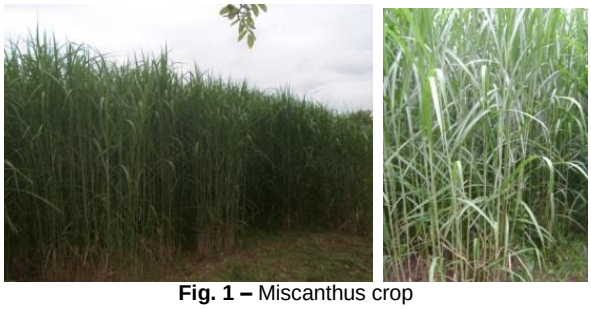

Fig. 1 – Miscanthus crop

The use of high quality material is essential for obtaining a good crop establishment. Rhizomes must be purchased from Miscanthus fields especially designed to obtain biological material. At the same time, they have to be harvested from young plants category and not from an old harvest. The main method of propagation is the rhizome division. For planting in field, young rhizomes (of 3 years, at most), which have to be healthy, without mechanical damages, of 10…15 cm length and 40…60 weight, having at least 3…4 viable buds, are used (fig. 2).

Folosirea materialului de calitate este esențială pentru obținerea unor bune înființării a culturii. Rizomii trebuie procurați din câmpuri de Miscanthus special dedicate obținerii de material biologic. De asemenea, aceștia trebuie să fie recoltați din categoria plantelor tinere, nu dintr-o recoltă înaintată și îmbătrânită. Principala metodă de propagare este divizarea rizomului. Pentru plantare în câmp se folosesc rizomi tineri (cel mult de trei ani), sănătoși, fără vătămări mecanice, cu lungimea de 10…15 cm și greutatea de 40…60 g, având cel puțin 3…4 muguri viabili (fig. 2).

Fig. 2 – Miscanthus rhizomes

Biomass obtained can be used both for electric/thermal energy producing and source of fibres in different industries.

Taking into account those above, *Miscanthus sp.* presents an interesting potential for our country, all the more as Romania owns an agricultural potential not totally exploited, and in rural environment the main source of heating during winter is the wood biomass, coming from forestry areas.

Previous studies, especially in Europe Europa [1, 2, 3, 5, 7, 8, 9, 10] and in USA [4, 6, 13], have examined the economic aspects of Miscanthus as energetic plant. Conclusions of these studies have shown a substantial regional variation of production potential, as well as of input costs and opportunity of Miscanthus planting.

Economic feasibility of Miscanthus has not been previously studied in context of Romania, where potential of obtaining energy from Miscanthus is taken into consideration nowadays not only for producing electric energy, but also as a source of thermal energy for final consumers. As the economic feasibility studies on Miscanthus plant were performed in other countries, their results cannot be directly applied in Romania because of regional variation of production factors and other economic concerns.

Even though Miscanthus plant was widely studied in Europe and US, the rhizomes production cost in Romania is unknown. Present study estimates this cost, for evaluating the economic feasibility of rhizome producing for trading them and establishing new crops. Therefore, this study differs from previous studies, which were

Biomasa obținută poate fi folosită atât pentru producerea energiei electrice și/sau termice cât şi ca sursă pentru fibre în diverse industrii.

Ținând seama de cele prezentate anterior, *Miscanthus sp.* prezintă un potențial interesant și pentru țara noastră, cu atât mai mult cu cât România deține un potențial agricol neexploatat în totalitate, iar în mediul rural principala sursă de încălzire în cursul iernii este reprezentată de biomasa lemnoasă, provenită din zonele forestiere.

Studii anterioare, în special din Europa [1, 2, 3, 5, 7, 8, 9, 10] și din SUA [4, 6, 13], au examinat aspectele economice ale plantei Miscanthus ca și plantă energetică. Concluziile acestor studii indică o variație regională substanțială a potențialului de producție, precum și a costurilor de intrare și de oportunitate pentru Miscanthus.

Fezabilitatea economică a plantei Miscanthus nu a fost examinată anterior în contextul României, unde potențialul de obținere a energiei din Miscanthus este în prezent luat în considerare, nu doar pentru producerea de energie electrică, dar si ca o sursă de energie termică pentru consumatorii finali. Datorita faptului ca studiile de fezabilitate economică privind planta Miscanthus au fost efectuate în alte țări, rezultatele acestor studii nu pot fi aplicate direct în Romania datorită variației regionale a factorilor de producție și din alte considerente economice.

Deși planta Miscanthus a fost studiată extensiv în Europa și SUA, costul de producție al rizomilor de Miscanthus în Romania este necunoscut. Prezentul studiu estimează acest cost, în scopul evaluării fezabilității economice a producerii de rizomi în Romania, în vederea comercializării și înființării de noi culturi. Ca atare, acest studiu diferă de studiile anterioare, care s-au concentrat numai asupra determinării costurilor de producție sau

focused only on determination of costs of production or profitability of Miscanthus [4, 5, 8, 10] or used these costs for evaluating the economic aspects of Miscanthus plant for producing energy [6]. Therefore, the main contribution of this study is finding out the breakeven point, breakeven price and profit for rhizomes production, based on data referring to production, selling costs and costs specific to Romania.

Study on economic efficiency of Miscanthus crop, aiming to capitalize its rhizomes will have a practical usefulness for farmers willing to invest in energetic crops both for obtaining biomass and trade the rhizomes for establishing new crops.

MATERIAL AND METHOD

In this study were analyzed the costs necessary for applying the crop technology of Miscanthus energetic plant, taking into account of the size of agricultural enterprise, agricultural operations aimed within the technology, technical characteristics of equipment used, seeds quality, technical service personnel etc. At the same time, it was aimed to determine the economic efficiency of Miscanthus crop, in order to capitalize Miscanthus rhizomes, taking into account of usual effects and efforts made for a production cycle of 2 - 3 years (period necessary for obtaining viable rhizomes).

In order to achieve the proposed works, technical and economic data were used both for existing technical equipment for big crops and new technical equipment, specific to Miscanthus.

Having in view the crop technology proposed for capitalizing Miscanthus rhizomes (Table 1), the necessary costs referring to 1 ha surface, will be calculated.

rentabilității plantei Miscanthus [4, 5, 8, 10] sau au folosit aceste costuri pentru evaluarea aspectelor economice ale plantei Miscanthus pentru producerea de energie [6]. Prin urmare, principala contribuție a acestui studiu este determinarea pragului de rentabilitate, a prețului de rentabilitate si profitului pentru activitatea de producere a rizomilor de Miscanthus, pe baza datelor privind producția, prețul de vânzare și costurile specifice României.

Studiul privind eficienţa economică a culturii de Miscanthus, în vederea valorificării rizomilor, va avea utilitate practică pentru fermierii care vor să investească în culturi energetice atât în scopul obținerii de biomasă cât și în scopul comercializării rizomilor în vederea înființării de noi culturi.

MATERIAL ŞI METODĂ

În cadrul acestui studiu au fost analizate costurile necesare pentru aplicarea tehnologiei de cultura a plantei energetice Miscanthus, ținând seama de mărimea exploatației agricole considerate, lucrările agricole propuse în cadrul tehnologiei, caracteristicile tehnice ale echipamentelor utilizate, calitatea materialului săditor, personalul de deservire tehnică a echipamentelor etc. De asemenea, s-a urmărit determinarea eficienţei economice a culturii de Miscanthus, în vederea valorificării rizomilor, ținând seama de efectele obținute şi eforturile depuse pe un ciclu de producție de 2 - 3 ani (perioada necesară pentru obținerea unor rizomi viabili).

Pentru realizarea lucrărilor propuse, s-au utilizat date tehnico-economice, atât pentru echipamente tehnice existente în exploatare pentru cultura mare cât şi pentru echipamente tehnice noi, specifice culturii de Miscanthus. Ținând seama de tehnologia de cultură propusă în vederea valorificării rizomilor de Miscanthus (Tabel 1), se vor calcula costurile necesare, raportate la o suprafață de 1 ha.

Table 1

Crop technology of Miscanthus energetic plant, for rhizomes capitalization

Stage	Year	Month	Agro-technical operations
Preparing works	Previous year	IX…XII	- Applying organic fertilizers - Autumn plough, at 25...30 cm
Establishment	1	I	- Applying herbicides for fighting against perennial weeds, starting with 15 I.
		III	- Preparing the germinating bed
		III – 20.IV	- Planting
Maintenance	2	III IV IV...VI	- Applying nitrogenous fertilizers - Applying pre-emergent and post emergent herbicides - Irrigations
Harvesting	3	II..III	- Dry stems harvesting - Transport of chopped stems - Destroying vegetal waste - Miscanthus rhizomes harvesting - Transport of Miscanthus rhizomes

Taking into account the information gained up to this very moment, several input data necessary to develop the case study, shall be established. In this context, the following hypotheses were set:

- surface cultivated with Miscanthus at which all the indicators will be reported, shall be of 1 ha;
- planting will be made with the planting machine on 3 rows, with a distance between rows of 100 cm and the distance between plants on row will be also of 100 cm;
- amount of rhizomes shall be established by approx. 10 % bigger than the theoretical number calculated, so 10000 rhizomes/ha x 1.10=11000 rhizomes/ha;

Având în vedere informațiile structurate până în acest moment, se vor stabili câteva date de intrare necesare derulării studiului de caz. În acest context s-au stabilit următoarele ipoteze:

- suprafața cultivată cu Miscanthus la care se vor raporta toți indicatorii va fi de 1 ha;
- plantarea se va realiza cu mașina de plantat pe 4 rânduri, având distanța între rânduri de 100 cm iar distanța între plante pe rând va fi de asemenea de 100 cm;
- necesarul de rizomi va fi stabilit cu aproximativ 10 % mai mare decât numărul teoretic calculat, astfel 10000 rizomi/ha x 1,10=11000 rizomi/ha;

- organic fertilizers applied in the year before establishing Miscanthus crop will be considered available to farmer from own sources;
- having in view that the majority of technical equipment operating owned by farmers is obsolete, surpassing the usual operating time, according to classification catalogue and normal operating duration of fixed assets, we considered that this equipment enters the farmer's endowment, so any expenses of acquisition and liquidation will not be involved;
- technical equipment appropriate to Miscanthus: technical equipment for planting Miscanthus ETPM, harvesting combine for Miscanthus CRM and technical equipment for harvesting rhizomes of Miscanthus ERM, shall be purchased by the farmer and will involve both an acquisition cost and liquidation during the normal operating period;

Determination of amortization and reparation costs shall be made by approximation according to equipment acquisition price, normal operating time (according to classification catalogue and normal operating time of fixed assets), number of operating hours per year and scrap value.

Taking into account the fact that Miscanthus is an energetic plant cultivated only in recent years in Romania, its capitalization chain not being developed yet, 3 hypothetical scenarios of annual utilization at an agricultural farm, were considered

- îngrășămintele organice administrate în anul premergător înființării culturii de Miscanthus se vor considera ca fiind disponibile fermierului din surse proprii;
- având în vedere faptul că majoritatea echipamentelor tehnice existente în exploatare la fermieri sunt de generație mai veche, care au depășit durata normală de funcționare, conform catalogului privind clasificarea şi duratele normale de funcționare a mijloacelor fixe, am considerat că aceste echipamente sunt în dotarea fermierului şi ca urmare nu vor implica cheltuieli de achiziție şi amortizare;
- echipamentele tehnice specifice culturii de Miscanthus: echipamentul tehnic de plantat Miscanthus ETPM, combina de recoltat Miscanthus CRM şi echipamentul tehnic de recoltat rizomi de Miscanthus ERM, vor fi achiziționate de fermier şi va implica atât un cost de achiziție cât şi amortizare pe perioada normală de funcționare;

Determinarea costurilor de amortisment şi reparații se va realiza estimativ, în funcție de prețul de achiziție a echipamentului respectiv, durata normală de funcționare (conform catalogului privind clasificarea şi duratele normale de funcționare a mijloacelor fixe), numărul de ore de funcționare pe an şi valoarea reziduală.

Ținând seama de faptul că Miscanthus este o plantă energetică cultivată de numai câțiva ani în România, nefiind dezvoltat întregul lanț de valorificare al acesteia, s-au considerat 3 scenarii ipotetice de utilizare anuală la o fermă agricolă, astfel:

Table 2

Hypothetical scenarios of annual utilization of technical equipment designed to Miscanthus crop

New technical equipment	Scenario 1	Scenario 2	Scenario 3
	Annual utilization period [hours]		
Miscanthus technical planting equipment ETPM	20	50	100
Harvesting combine for Miscanthus CRM	10	25	50
Technical equipment for harvesting rhizomes of Miscanthus ERM	10	20	50

Costs involved in technical revisions and reparations during the operation have been approximated at 125 % out of purchasing price.

Scrap value represents the amount of money which can be recovered from equipment shelving, after the utilization period. Average price for 1 kg of scrap iron was of 0.75 lei.

Calculation of amortization and reparations costs [12, 15] were found out from formula:

Costurile cu reviziile tehnice şi reparațiile pe durata de serviciu s-au aproximat la o valoare de 125 % din prețul de cumpărare.

Valoarea reziduală reprezintă suma de bani care poate fi recuperată din vânzarea echipamentului ca fier vechi, după perioada de utilizare. Prețul mediu pentru 1 kg de fier vechi a fost considerat de 0,75 lei.

Calculul costurilor de amortisment şi reparații [12, 15] s-a realizat utilizând formula:

$$CAR = \frac{PN + CRR - VR}{DS} \text{ [lei/hour]} \quad (1)$$

where: CAR is amortization and reparation cost [lei per hour];
PN – new price of equipment [lei];
CRR – costs of technical revisions and reparations during the operation hours [lei];
VR – scrap value [lei];
DS – working time [hours].
Scrap value can be calculated with the formula:

unde: CAR este costul de amortisment şi reparații [lei/h];
PN – prețul de nou al utilajului [lei];
CRR - costuri revizii tehnice şi reparaţii pe durata de serviciu [lei];
VR – valoare reziduală [lei];
DS – durata de serviciu [ore].
Valoarea reziduală se poate calcula cu formula:

$$VR = M \cdot PFV \text{ [lei]} \quad (2)$$

where: VR is scrap value [lei];
M – mass of equipment [kg];
PFV – price of 1 kg of scrap iron [lei/kg].

unde: VR este valoarea reziduală [lei];
M – masa utilajului [kg];
PFV – prețul unui kg de fier vechi [lei/kg].

Reparations of different levels of equipment require important costs, but in most cases they cannot be evaluated per working ha, operating hour, etc. The expenses in terms of reparations cannot be precisely calculated, but estimations may be given to farmer, which are useful in substantiation of costs and drawing the technical and economic estimates for crops [11].

For the works within the technology proposed, a tractor of 80 HP is used, for which, according to table 5, we shall have costs per operating hour (reparations and tyres) of approx. 1.20 – 1.40 euro [12], respectively 5.33 – 6.21 lei (BNR from 04.06.2015, 1 euro=4.4375 lei). Taking into account the fact that the tractor has a larger utilization level for all agricultural works within the technology, including other works from vegetable farm, we shall consider the costs per operating hour (reparations and tyres) at the minimum value of 5.33 lei/hour.

For the other equipment, the values will adapt according to equipment complexity and utilization level estimated.

Costs designed to fuels and lubricants are mainly estimated taking into account of Diesel oil consumption of tractor-machine aggregate for performing the agricultural work on surface considered [14], respectively 1 ha in case of this study. Price of one litre of Diesel oil is considered to be the pump price on 04.06.2015 (PETROM), respectively 5.7 lei/l. of Diesel oil.

In order to analyze the profitability of implementing energetic plant Miscanthus crop technology, for rhizomes capitalization, the breakeven point, breakeven price and profit, will be analyzed.

Breakeven point, also named critical point or balance point, marks the production dimension at which the total costs are equal to receipts coming from production selling and the price is null. Activity becomes profitable when breakeven point is surpassed. Up to this level of production, the unit registers losses.

View the evolution of variable costs, directly proportional to production volume, within this study is used the linear evolution model of variable costs and revenues.

Reparațiile de diferite grade ale utilajelor necesită costuri însemnate dar în cele mai multe cazuri acestea nu pot fi evaluate pe ha de lucrare, ora de funcționare, etc. Nu se pot indica cu certitudine cheltuielile cu reparațiile dar se pot oferi fermierului estimări care pot fi utilizate pentru fundamentarea costurilor și elaborarea devizelor tehnico-economice pe culturi [11].

Pentru lucrările din cadrul tehnologiei propuse, se utilizează un tractor de 80 CP pentru care, conform tabelului 5, vom avea costuri pe ora de funcționare (reparații şi pneuri) de aproximativ 1,20 – 1,40 euro [12], respectiv 5,33–6,21 lei (curs BNR din data de 04.06.2015, 1 euro=4,4375 lei). Ținând seama că tractorul are un grad mare de utilizare la toate lucrările agricole din cadrul tehnologiei, inclusiv la alte lucrări din cadrul fermei vegetale, vom considera costurile pe ora de funcționare (reparații şi pneuri) la valoarea minimă de 5,33 lei/ora.

Pentru celelalte echipamente se vor adapta valori, în funcție de complexitatea echipamentelor şi de gradul de utilizare estimat.

Costurile pentru combustibili şi lubrefianți se estimează în principal ținând seama de consumul de motorină al agregatului tractor+masină agricolă pentru efectuarea lucrării agricole pe suprafața considerată [14], respectiv 1 ha în cazul acestui studiu. Prețul unui litru de motorină s-a considerat prețul la pompă în data de 04.06.2015 (PETROM), respectiv 5,7 lei/litru de motorină

În scopul analizei rentabilității implementării tehnologiei de cultură a plantei energetice Miscanthus în vederea valorificării rizomilor, se vor analiza pragul de rentabilitate, prețul de rentabilitate și profitul.

Pragul de rentabilitate, numit şi punct critic sau punct de echilibru, marchează acea dimensiune a producției la care costurile totale sunt egale cu încasările din vânzarea producției, iar rezultatul este nul. Activitatea devine rentabilă după pragul de rentabilitate. Până la acest nivel al producției unitatea înregistrează pierderi.

Ținând seama de evoluția costurilor variabile, direct proporțional cu volumul producției, în cadrul studiului se utilizează modelul liniar de evoluție a costurilor variabile și a veniturilor.

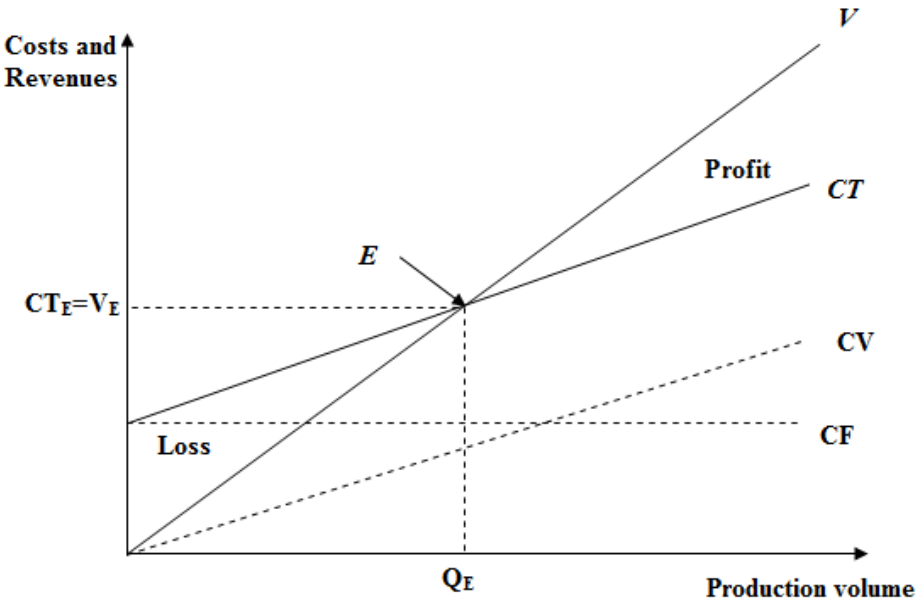

Fig. 3 – Breakeven point

In point E, revenues (V) are equal to total expenses (CT), and profit is null and represents the minimum level of production allowed.
V = CT and P = 0 or Q_E x p = CF + CV_E= CF + Q_E x Cvp, resulting:

În punctul E, veniturile (V) sunt egale cu cheltuielile totale (CT), iar profitul este nul, și reprezintă nivelul minim de producție admis.
V = CT şi P = 0 sau Q_E x p = CF + CV_E= CF + Q_E x Cvp, rezultând:

$$Q_E = \frac{CF}{p - Cvp} \quad (3)$$

where: Cvp represents variable expenses per product (genetic material, herbicides, fertilizers, mechanical operator's payment, fuel and lubricants);
Q_E – size of physical production suitable to breakeven point (E).
Q_E is the production level for which the enterprise does not have profit, but only recovers fixed costs and variable costs.
For a production (volume of activity) bigger than Q_E profit is obtained, while for a production smaller than QE appear losses.
Main advantages offered by profitability analysis method based on critical point are:

- it allows to establish the dimension at which the production becomes profitable;
- it indicates the production volume necessary to obtain a certain profit;
- it emphasizes the correlations between the production dynamics, respectively revenues and dynamics of costs classified as fixed costs and variable costs;
- it allows to determine the level of utilization of production capacity according to a certain profit aimed.

Another value related to profitability is the ***breakeven price***. It represents the selling price of a product, for which, at a certain volume of production, the revenues assure only the expenses recovering, and the profit is obtained only at a higher selling price.

unde: Cvp reprezintă cheltuieli variabile pe unitatea de produs (material genetic, erbicide, fertilizanți, retribuția mecanizatorului, combustibili şi lubrefianți);
Q_E - mărimea producției fizice corespunzătoare pragului de rentabilitate (E).
Q_E este nivelul de producție pentru care unitatea nu înregistrează profit, ci din vânzarea acestei cantități se obține numai recuperarea cheltuielilor fixe și variabile.
Pentru o producție (volum de activitate) mai mare decât Q_E se realizează profit, în timp ce pentru o producție mai mică decât Q_E se obțin pierderi.
Principalele avantaje pe care le oferă metoda de analiză a rentabilității pe baza punctului critic sunt:

- permite stabilirea dimensiunii la care producția devine rentabilă;
- indică volumul producției necesar pentru a obține un anumit profit;
- pune în evidența corelațiile dintre dinamica producției, respectiv a veniturilor și dinamica costurilor grupate pe costuri variabile și fixe;
- permite determinarea gradului de utilizare a capacității de producție în corelație cu un anumit profit dorit.

O alta mărime legata de rentabilitate este reprezentată de ***prețul de rentabilitate***. Acesta reprezintă prețul de vânzare al unui produs, pentru care, la un anumit volum al producției, veniturile asigură numai recuperarea cheltuielilor, iar profit se obține numai la un preț de vânzare superior.

$$p = \frac{CF}{Q_E} + Cvp \quad (4)$$

In order to estimate the total expenses, necessary to capitalize one ha of Miscanthus, the expenditure of raw material and materials (genetic material, herbicides, and fertilizers) shall be considered.
In this context, after a market research, it has found that the average price of one rhizome of Miscanthus is of 0.10-0.12 euro. At the same time, it has found that when harvesting the rhizomes, can be obtained a rhizomes multiplying degree framed between 10 and 40, that is to say that for a planted rhizome will be obtained in 2 or 3 year of culture, between 10 and 40 viable rhizomes, ready to be traded. For this case study, we shall consider a multiplying factor of 10.

Pentru estimarea cheltuielilor totale, necesare exploatării unui ha de Miscanthus, vor trebui luate în considerare şi cheltuielile cu materiile prime şi materialele (material genetic, erbicide, fertilizanți).
În acest context, în urma prospectării pieței, s-a constatat că prețul mediu pentru un rizom de Miscanthus este de 0,10-0,12 euro. De asemenea, s-a constatat că la recoltarea rizomilor se poate obține un grad de multiplicare cuprins între 10 si 40, aceasta însemnând că dintr-un rizom plantat, se vor obține în anul 2 sau 3 al culturii, între 10 si 40 de rizomi viabili, gata de a fi comercializați. Pentru acest studiu de caz vom considera un factor de multiplicare de 10.

RESULTS

Considering the selling prices, working time and annual utilization periods, the costs related to the three equipment designed to Miscanthus crop, are presented in table 3.

REZULTATE

Ținând seama de preturile de vânzare, duratele de serviciu şi perioadele anuale de folosire, costurile asociate celor trei echipamente tehnice dedicate culturii de Miscanthus, sunt prezentate în tabelul 3.

Table 3

Costs related to the three technical equipment designed to Miscanthus crop

Indicators	M.U.	Technical equipment for planting Miscanthus ETPM	Harvesting combine for Miscanthus CRM	Technical equipment for harvesting Miscanthus rhizomes ERM
1.Delivering price	lei	24096	26718	25507
Operation time	years	8	8	8
Annual period of utilization	hours	20	10	10
		50	25	20
		100	50	50
Operating hours during the whole working program	hours	160	80	80
		400	200	160
		800	400	400
2.Costs of technical revisions and reparations during the working program (1.25 x price)	lei	30120	33398	31884
3. Scrap value (mass x scrap iron price lei/kg)	lei	850x0.75=637.5	2060x0.75=1545	565x0.75=423.75
WHOLE TOTAL (1+2 – 3)	lei	53578.5	58571	56967.25
4.Amortization and reparations	lei/hour	334.86	732.13	712.09
		133.94	292.86	356.04
		66.97	146.42	142.41

Wages of mechanical operators were considered about 150 % out of average gross salary per economy (2415 lei in year 2015). In this context, for an average number of 170 hours/month, the hour salary will be of (2415x1.5)/170=21.30 lei/h.

Having in view the data above, it has determined the total cost necessary to implement the technology, for three possible scenarios (depending on annual utilization period estimated of the new equipment).

Retribuția mecanizatorilor a fost considerată aproximativ 150 % din salariul mediu brut pe economie (2415 lei în anul 2015). În acest context pentru un număr mediu de 170 ore/lună, retribuția orara va fi (2415x1,5)/170=21,30 lei/h.

Având în vedere datele prezentate anterior, s-a realizat determinarea costului total necesar implementării tehnologiei, pentru trei scenarii posibile (in funcție de perioada anuală estimată de folosire a celor trei echipamente noi).

Table 4

Total cost required to implement the crop technology, for capitalizing Miscanthus rhizomes

Indicator	Annual utilization period		
	Scenario 1	**Scenario 2**	**Scenario 3**
	Costs for 1 ha		
Cost of rhizomes	11000 pcs. x 0 .10 euro/pc. x 4.4375 lei/euro= **4881.25 lei**	11000 pcs. x 0.10 euro/pc. x 4.4375 lei/euro= **4881.25 lei**	11000 pcs. x 0.10 euro/pc. x 4.4375 lei/euro= **4881.25 lei**
Cost of herbicide applying	763.44 lei		
Amortization and reparations	3072.22	1429.59	666.51
Fuel and lubricants	765.51		
Mechanical operator's salary	213.4		
Total Cost , out of which:	**9772.82 lei** (2202.33 euro)	**8130.19 lei** (1832,16 euro)	**7367.11 lei** (1660,19 euro)
- variable costs	- genetic material: 4881.25 lei -herbicides: 763.44 lei -mechanical operator's salary: 213.4 lei - fuel and lubricants: 765.51 lei Total CV: **6700.6 lei**		
- fixed costs	- amortization: **3072.22 lei**	- amortization: **1429.59 lei**	- amortization: **666.51 lei**

Based on values shown in table 4, the breakeven point, breakeven price and profit when rhizomes are sold at market price, have been determined.

Pe baza valorilor prezentate în tabelul 4, s-au determinat pragul de rentabilitate, prețul de rentabilitate şi profitul când se vând rizomii la prețul pieței.

Table 5

Breakeven point, breakeven price and profit, determined for the 3 scenarios proposed

Indicators	Annual utilization period		
	Scenario 1	Scenario 2	Scenario 3
	For an agricultural exploitation of 1 ha		
Breakeven point $Q_E = \frac{CF}{p - Cvp}$ p=0.4438 lei/pcs. Cvp=CV/Nr. Nr=100000 rhizomes	Q_E=**8154 pcs**. Cvp=6700.6/100000= **0.0670 lei**	Q_E=**3794 pcs**. Cvp=6700.6/100000= **0.0670 lei**	Q_E=**1769 pcs**. Cvp=6700.6/100000= **0.0670 lei**
Breakeven price $p = \frac{CF}{Q_E} + Cvp$ Q_E=Nr=100000 pcs. Cvp=CV/Nr.	p=**0.0977 lei;** (0.0220 euro) Cvp=6700.6/100000= **0.0670 lei**	p=**0.0813 lei;** (0.0183 euro) Cvp=6700.6/100000= **0.0670 lei**	p=**0.0737 lei;** (0.0166 euro) Cvp=6700.6/100000= **0.0670 lei**
Total Cost CT	**9772.82 lei** (2202.33 euro)	**8130.19 lei** (1832.16 euro)	**7367.11 lei** (1660.19 euro)
Gross income VB	100000 pcs. X 0.10 euro/pc. X 4.4375 lei/euro= **44375 lei**		
Profit/Loss =VB-CT	**34602.18 lei** (7797.67 euro)	**36244.81 lei** (8167.84 euro)	**37007.90 lei** (8339.81 euro)

Using Excel program, it has achieved a simulation of model previously developed, for production volumes appropriate to a cultivated surface ranged between 1 and 50 ha. The fixed costs, the variable costs, the total costs, revenues and breakeven points in the context of the 3 scenarios, were emphasized. In figure 4, only the initial zone of the graphic was emphasized, from an appropriate scale representation reason.

Utilizând programul Excel s-a realizat o simulare a modelului dezvoltat anterior, pentru volume de producție corespunzătoare unor suprafețe cultivate cuprinse între 1 si 50 ha. S-au pus în evidență, grafic, costurile fixe, costurile variabile, costurile totale, veniturile şi pragurile de rentabilitate în contextul celor 3 scenarii propuse. În figura 4 s-a evidențiat numai zona inițială a graficului, din considerente de reprezentare la o scară corespunzătoare.

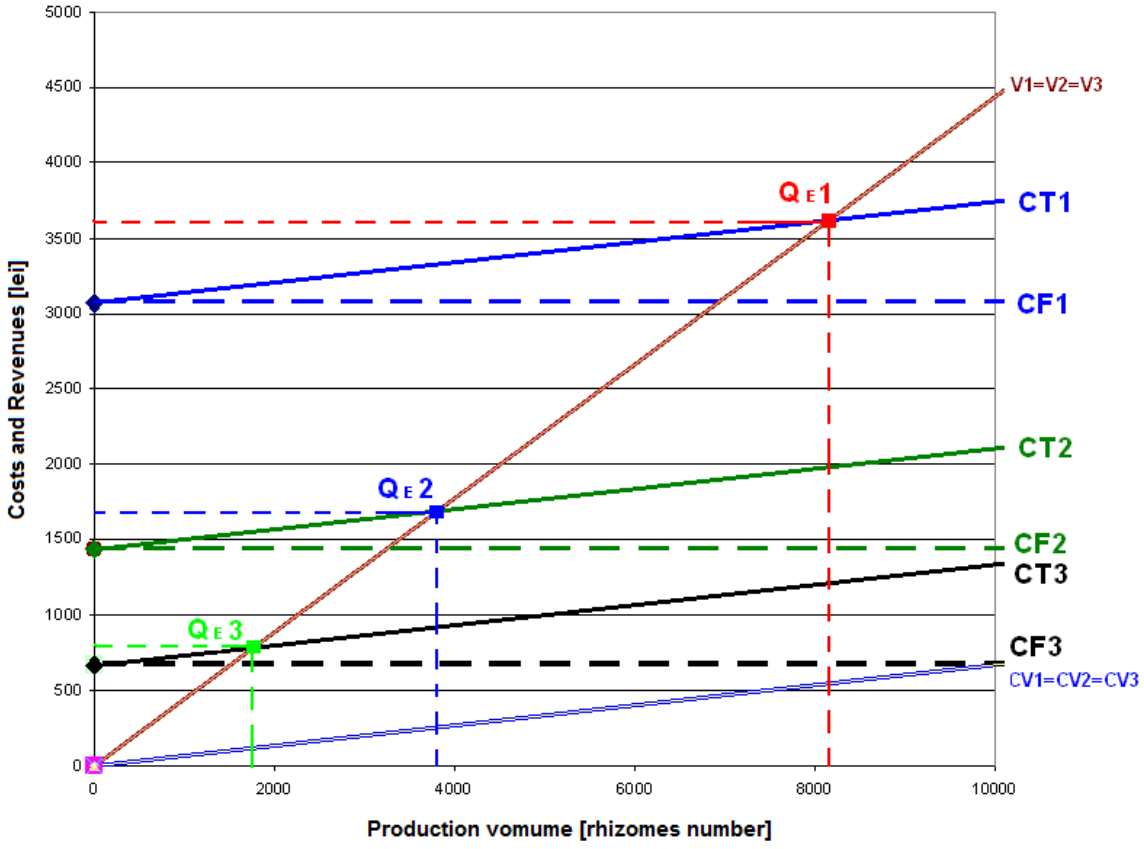

Fig. 4 – Breakeven point determined for the 3 scenarios proposed (initial zone of graphic)

CONCLUSIONS

Miscanthus crop, even though it proved to be a reduced input culture (because of efficiency of mechanisms of utilization of water, nourishing substances and light), requires a rather big investment when establishing. This aspect can be discouraging for potential farmers wanting to invest in this crop. Problem appears because of lack of documentation related to categories of expenditure in terms of seeds purchasing, field preparation, establishment, maintenance and harvest of crop during the whole period of exploitation, as well as poor analysis of revenues obtained from crop capitalization.

Following the study of case achieved, a total cost per hectare for implementing the technology for a 3 year- production cycle, of 9772.82 lei (2202.33 euro), 8130.19 lei (1832.16 euro) respectively 7367.11 lei (1660.19 euro), was calculated, according to scenarios tackled.

Reduction of fixed costs can be obtained by performing agricultural services by other farmers or using of new technical equipment for other cultures too, at which this equipment could be adapted.

For an agricultural exploitation of 1 ha, the breakeven point has emphasized a volume of production of 8154 pcs., 3794 pcs, respectively, 1769 pcs., in compliance with scenarios tackled within the study. At the same time, the breakeven price calculated has been of 0.0977 lei/pc. (0.0220 euro), 0.0813 lei/pc., (0.0183 euro) respectively 0.0737 lei/pc. (0.0166 euro), according to tackled scenarios.

For the same agricultural exploitation of 1 ha, the profit calculated based on the three scenarios was of 4602.18 lei (7797.67 euro), 36244.81 lei (8167.84 euro) respectively 37007.90 lei (8339.81 euro).

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CONCLUZII

Cultura de Miscanthus, deşi s-a dovedit a fi o cultura cu inputuri reduse (datorită eficienței mecanismelor de utilizare a apei, nutrienţilor şi luminii), totuși necesită o investiție relativ mare la înființarea culturii. Acest aspect poate fi descurajant pentru potențialii fermieri care doresc să investească în această cultură. Problema apare datoriată insuficientei documentări a categoriilor de cheltuieli ocazionate de procurarea materialului săditor, pregătirea terenului, înființarea, întreținerea şi recoltarea culturii pe întreaga durată de exploatare, precum şi slabei documentări a veniturilor încasate din valorificarea culturii.

În urma studiului de caz realizat, s-a calculat un cost total la hectar pentru implementarea tehnologiei pe un ciclu de producție de 3 ani, de 9772,82 lei (2202,33 euro), 8130,19 lei (1832,16 euro) respectiv 7367,11 lei (1660,19 euro) în funcție de scenariile abordate în cadrul studiului.

Reducerea costurilor fixe se poate obține prin realizarea de servicii agricole şi către alți fermieri sau utilizarea echipamentelor tehnice noi şi la alte culturi agricole la care s-ar putea adapta.

Pentru o exploatație agricole de 1 ha, pragul de rentabilitate evidențiază un volum al producției de 8154 buc., 3794 buc. respectiv 1769 buc., în funcție de scenariile abordate în cadrul studiului. De asemenea, prețul de rentabilitate calculat s-a situat la nivelul de 0,0977 lei/buc. (0,0220 euro), 0,0813 lei/buc. (0,0183 euro) respectiv 0,0737 lei/buc. (0,0166 euro), în condițiile scenariilor elaborate.

Pentru aceeași exploatație agricole de 1 ha, profitul calculat pe baza celor trei scenarii, a fost de 34602,18 lei (7797,67 euro), 36244,81 lei (8167,84 euro) respectiv 37007,90 lei (8339,81 euro).

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COMPREHENSIVE EVALUATION MODEL OF AGRICULTURAL DROUGHT DISASTER RISK /
农业干旱灾害风险综合评估模型

Prof. LI Yanbin, M.E. LI Jia, ASS. Prof. You Feng, ASS. Prof. Zhang Zezhong
North China University of Water Conservancy and Hydroelectric Power, 450011, Zhengzhou, China
Tel: 037165790680; E-mail: liyb101@sina.com

Abstract: *The paper established the model of agricultural drought disaster risk evaluation and assessment index system, defined disaster risk threshold value by using the grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning method in the case of Xiuwen, Rongjian, Yinjiang, Meitan,Nayong and Xingren County in Guizhou province. Considering factors of natural, social economic, hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body and drought resistance ability, guided by theory of meteorology, agricultural science, disaster science, natural disaster risk science and other multi-disciplinary theories, scientific of the model is verified by relevance analysis of crop yield losses estimated on the base of agricultural drought disaster temporal series and drought disaster risk index. The result can provide directions and guidance for drought forecast and risk management in Guizhou province and the similar area.*

Keywords: *agricultural drought disaster; risk evaluation; disaster risk threshold value; Guizhou*

INTRODUCTION

Drought is the most common natural disasters. According to estimates, the global economic loss caused by drought is as high as $6-8 billion dollars every year, far more than the other meteorological disasters [10]. The IPCC in its series assessment report pointed out that drought risk has a rising trend in the future [1]. Drought disaster is one of the major natural disasters in Guizhou province. Since the fall of 2009, precipitation in Yunnan, Guizhou and Sichuan provinces has decreased by 30% ~ 50% compared with all the year round, the average temperature is also increased by more than 1 ℃. According to the latest statistics, as of the beginning of 2010, cultivated land area of the drought in China have been 6.45 million hectares, increased more nearly 1.8 million hectares than previous years. There are about more than 20 million people for drinking water difficultly due to drought. The southwest is the severe drought disaster area. As reservoir leakage, rivers dry rot, wells dry, farmland irrigation can't be satisfied. Guizhou province suffered the worst droughts in recent years. Drought risk assessment is an effective method to know the risk, which is the premise and foundation of risk control and risk management. Therefore, the natural disaster risk theories combined with risk quantification, risk assessment technology are of great significance for drought disaster relief, risk management.

MATERIAL AND METHOD

Research methods

The index system is selected based on the elements of drought risk (hazard, exposure, vulnerability and drought resistant ability) and analysis of rationality,

摘要: 以贵州省的修文、榕江、印江、湄潭、纳雍和兴仁为典型区，以气象学、农业学、灾害学、和自然灾害风险科学作为理论指导，综合考虑典型区自然、社会经济现状，从影响农业干旱灾害的风险四要素致灾因子危险性、承灾体的暴露性和脆弱性以及抗旱能力的方向出发，利用灰色关联度、层次分析法、加权综合法和自然灾害指数法、Fisher 最优分割法，构建了农业干旱灾害风险评估体系模型，建立干旱灾害风险评价概念框架及指标体系，确定了灾害风险阈值。根据农业灾情时序数据对作物产量损失进行估算并与干旱灾害风险指数进行相关性分析，以验证干旱综合风险模型的科学性。研究结果可为贵州及类似地区农业干旱灾害预警，以及相关部门的干旱灾害风险管理提供理论依据和指导。

关键词: 农业干旱灾害；风险评估；风险阈值；贵州省

引言:

旱灾是全球最为常见的自然灾害。据测算，每年因干旱造成的全球经济损失高达 60-80 亿美元，远远超过了其它气象灾害[10]。IPCC 在其系列评估报告中指出，未来干旱风险有不断增加的趋势[1]。干旱灾害是贵州省主要的自然灾害之一。2009 年秋季以来，云贵川三省降水量与常年相比减少 30%~50%，平均气温也增长了 1℃以上。据最新资料统计，截至 2010 年初，中国已有受旱耕地面积 645 万公顷，比往年的受旱面积增加了近 180 万公顷，因干旱导致的饮水困难约有 2000 多万人，其中，西南地区就是干旱灾害严重地区。随着水库出现渗漏现象、河流开始干枯、农田灌溉无法满足、水井开始干涸，贵州省地区市遭遇了近年来最为严重的的特大干旱。旱情风险评价是认识风险的有效方法，是风险控制和风险管理的前提和基础，准确的灾害风险评价是风险管理的决策依据，是防治灾害的重要内容。因此，研究将自然灾害风险理论与风险量化、风险评价技术相结合研究贵州农业干旱风险对该地区旱情风险管理, 防灾抗灾工作具有重要意义。

研究方法和数据来源

研究方法

根据旱灾风险的组成要素（危险性、暴露性、脆弱性和抗旱能力），基于研究区的资料合理性、科学性和实用性选取适当的指标，通过由灰色关联度、层次分析法、加权

scientific, practical utility of research data. The agricultural drought disaster risk values are calculated by synthesis analysis method formed from the grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning method. The risk value locates at some interval after a dimensionless processing. The interval is divided into four classes, corresponding to different types of risk.

The analytic hierarchy process (ahp)

The analytic hierarchy process (AHP) is a method system used to calculate weight coefficient of the complex multiple indexes [8]. By this approach, we can do quantitatively and qualitatively analysis of indicators. The indicator weight coefficients are calculated on the base of one-to-one index important comparison. In the paper nine distinguish grades are used to evaluate drought risk. The weight coefficient according to every index is different due to differentiation of influence level of every index to subject investigated.

The grey correlation

The grey correlation is used to research the relation between two series increase speed. The correlation is indicated with the area in two series polygonal line.

The weighted synthesis method

The weighted synthesis method distributes the weight coefficient of evaluation index respectively, which is based on differentia importance of impact of the evaluation indexes for evaluating the total target [13]. Add the result that quantitative index multiply corresponding weighted index to donate the level of drought disaster risk. The formula is as follows:

综合法、自然灾害指数法、Fisher 最优分割法所组成的综合分析方法计算研究区农业干旱灾害的风险值。经过无量纲处理之后，典型区的农业干旱灾害的风险值都在某一区间之内。将该区间分成四级，分别对应不同的风险类型。同时通过这种等级划分，也可以分别得到危险性、暴露性、脆弱性和抗旱能力的相应风险类型。

层次分析法

层次分析法(AHP) [8]是一种用来计算复杂系统多元指标所对应权重系数的方法，这种方法可以对指标进行定量定性的分析。通过对研究体系的影响因素分析，并根据每个指标的紧密程度进行一对一的比较、分析和计算。本文通过九种判别等级来评价，通过量化分析每个指标，因为每指标对研究对象的影响轻重程度不同，所以每个指标对应的权重值也各不相同。

灰色关联度

灰色相对关联度主要研究的是两序列增长速度之间的关系，用两条序列折线间所夹的面积大小来衡量两序列的关联性的大小。

加权综合法

加权综合评价法[13]是根据评价指标对于评价总目标所影响的重要程度的不同，分别对评价指标进行权重系数的分配。将量化后的指标与相应权重相乘后再相加，根据每个指标对干旱灾害风险值的正负相关程度不同利用加权综合的方式系统地加以集中，以表示干旱灾害风险的高低。用公式表示如下：

$$P=\sum_{i=1}^{n} A_i W_i \quad (1)$$

In equation (1): P is the overall evaluation value of the research object; Ai is the quantitative values of the i index; Wi is the weight coefficient of i index ($W_i \geq 0, \sum_{i=1}^{n} W_i = 1$); n is the number of evaluation index.

Each index plays the role of "positive" or "reverse" on evaluated subject, and the corresponding dimension is not identical. The data is normalized in order to calculate conveniently. Specific methods are as follows [9]: Maximum optimal type: the larger the index is, the higher the risk values, indicating "positive role".

式中：P 为研究对象所对应的总评价值；A_i 为某系统第 i 项指标的量化值($0 \leq A \leq 1$)；W_i 为某系统第 i 项指标的权重系数($W_i \geq 0, \sum_{i=1} W_i = 1$)；n 为评价体系指标的个数。

每个指标对研究对象起到“正向”或是“反向”的作用，并且对应的单位也各不相同，为了计算方便，一般对数据进行归一化处理，具体方法如下[9]：最大最优型：指标值越大，风险值越高，呈“正向”作用。

$$X_{ij}^{'} = \frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}} \quad (2)$$

Minimum optimal type: the larger the index is, the lower the risk values, indicating “reverse role".

最小最优型：指标值越大，风险值越低，呈“反向”作用。

$$X_{ij}^{'} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \quad (3)$$

In equations: X_{ii} is the jth index of the ith object; X'_{ii} is the j[th] index of the i[th] object after dimensionless processing; $X_{\max}$ and $X_{\min}$ are the maximum and the minimum of the index respectively. So we can get $X'_{ii} \in [0,1]$.

The natural hazards index method

The natural hazards index method analyzes drought risk through the research on serious degree and probability of drought disaster occurrence in the future [12]. Scholars pointed out that the natural disaster risk is mainly composed of hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body in previous. But the influence degree that drought resistant ability exerts on natural disaster risk value is increasing gradually with people awareness of natural disasters increasing. So the four subsystems of drought disaster risk that is hazard of disaster-causing factors(H), exposure (E) and vulnerability (V) of hazard bearing body, and drought-resistant ability (RE), is essential in researching on the drought disaster forming, the synthesis action of these leads to drought disaster.

Fisher optimal partitioning method

The optimal partitioning method was proposed by Fisher in 1958. The method make the segmentation deviation square sum in grades minimum, in the condition of no damage the ordering sample. The base idea is making n sample one class, then increasing classes in base of error function classified.

RESEARCH MATERIAL

Data sources

The weather and climate data in the paper is cited from China meteorological science data sharing service web, hydrological data is from water resources gazette in Guizhou and the water resources annals in Guizhou, and social economic data is from Guizhou province statistical yearbook.

The general situration in the study areas

The study area mainly includes Xiuwen, Meitan and Xingren County three typical areas. Xiuwen County is located in the middle part of Guizhou province ,with a total area of 1075.70 square kilometers, an average elevation of 1250 meters, mostly in the hilly terrain, the annual average temperature of 16ºC, annual rainfall of 1293 mm. Meitan County is in northern part of Guizhou province with a total area of 1864 square kilometers, an average elevation of 972.7 meters, the annual average temperature 14.9ºC, annual average rainfall of 1141 mm. Xingren county is located in the middle of Guizhou province Qianxinan, land area of 1785 square kilometers, an average elevation of 1253 meters, the annual average temperature 15.2ºC, annual average rainfall of 1332.1 mm. Nayong county is located in the west north of Guizhou province with a total area of 2448 square kilometers, the annual average temperature 13.6ºC, annual average rainfall of 1243.5 mm. Yinjiang county is located in the east north of Guizhou province with a total area of 1969 square kilometers, the annual average temperature 16.8ºC, annual average rainfall of 1100 mm. Rongjiang county is located in the east south of Guizhou province with a total area of 3315.8 square kilometers, abundant plant resource. The coverage rate 68.8% is highest in Guizhou province.

Six typical areas belong to subtropical monsoon climate, no cold winter and no hot summer. But due to

式中：X_{ij} 为第 i 个对象的第 j 项指标；X'_{ij} 为无量纲化处理后第 i 个对象的第 j 项指标值；$X_{\max}$ 和 $X_{\min}$ 分别为该指标的最大值和最小值。通过上式可以看出，$X'_{ij} \in$ [0，1]。

自然灾害指数法

自然灾害风险指数法是通过研究未来若干年内可能达到的灾害程度及其发生的可能性而对旱情风险进行分析[12]。早先学者指出自然灾害风险主要由危险性、暴露性和脆弱性组成。但近几年研究发现随着人们对自然灾害的认识，抗旱能力对于自然灾害风险值的影响正在逐年增加，因此本次研究将抗旱能力也作为重要的因素之一加以考虑。干旱灾害的造成是致灾因子的危险性(H)、暴露性(E)、脆弱性(V)和抗旱能力(RE)综合作用的结果。

Fisher 最优分割法

最优分割法是费舍尔（Fisher）在1958年提出的，主要是在不破坏有序样本的前提下，使其分割的级内离差平方和最小，而级间的离差平方和为极大的一种聚类分级方法。它的基本思想是先将 n 个样品看成一类，然后依据分类的误差函数逐渐增加分类。

研究资料

数据来源

本文所用气象和气候数据来自中国气象科学数据共享服务网，水文数据来自《贵州省水资源公报》和《贵州水利年报》，社会经济数据来自《贵州省统计年鉴》。

研究区概况

研究区主要包括贵阳市的修文县、遵义市的湄潭县和铜仁地区的兴仁县三个典型区。修文县地处黔中，总面积1075.70 平方公里。境内平均海拔 1250 米，地势丘陵居多，年平均气温为 16℃，年降雨量达 1293 毫米。湄潭，位于贵州省北部，总面积 1864 平方公里，平均海拔 972.7 米，年平均气温 14.9℃，年均降雨量 1141 毫米。兴仁县位于贵州省黔西南州中部，国土面积1785平方公里，平均海拔 1253 米，年平均气温 15.2℃，年均降雨量 1332.1 毫米。纳雍县位于贵州省西北，总面积2448平方公里，年平均气温13.6℃，年均降雨量1243.5毫米。印江县位于贵州省黔东北，总面积 1969 平方公里，年均气温 16.8℃，年降雨量 1100mm 左右。榕江县位于贵州省东南部，面积 3315.8 平方公里，榕江森林资源丰富，森林覆盖率达 68.8%，居全省之冠。

六个典型区都属于亚热带季风气候，冬无严寒，夏无酷暑。但由于贵州独特的喀斯特地形地貌，以及土壤石漠化

the unique karst topography and serious soil desertification in Guizhou, severe drought disasters influence and damage to the local production and life.

RESULTS

Agricultural drought disaster risk index selection

Drought disasters are adverse results in the event of people's effort on drought resist and relief hazard due to vulnerability of hazard-affected bodies. Exposure of hazard-affected body is the contact area of the risk of disaster-inducing factors and the vulnerability of hazard-affected bodies, which is the precondition of vulnerability. Hazard and vulnerability is the basic reason of the drought disaster. The greater the hazard, vulnerability and exposure are, the greater drought disaster risk is, vice versa. Drought-resistance ability is people's efforts and action to resist drought disasters, which is "reverse" for drought disaster risk. Agricultural drought disaster risk in typical area is mainly composed of four essential factors (figure 1).

严重，导致干旱灾害严重，给当地的生产生活造成影响和损失。

结果

农业干旱灾害风险指标选取

干旱灾害是在承灾体的脆弱性下发生的具有危险性的干旱事件，在人类进行抗旱减灾的努力下，产生的不利结果。其中，承灾体的暴露性是致灾因子危险性和承灾体脆弱性的接触面，是脆弱性的先决条件。危险性和脆弱性则是旱灾发生的根本原因。危险性、脆弱性、暴露性越大、干旱灾害风险越大，反之，三者越小则干旱灾害风险越小。抗旱能力则是人们为了抵抗干旱灾害所付出的努力和行动，抗旱能力对干旱灾害风险呈“反向”作用。一个典型区的农业干旱灾害风险主要由这风险四要素组成（如图1）。

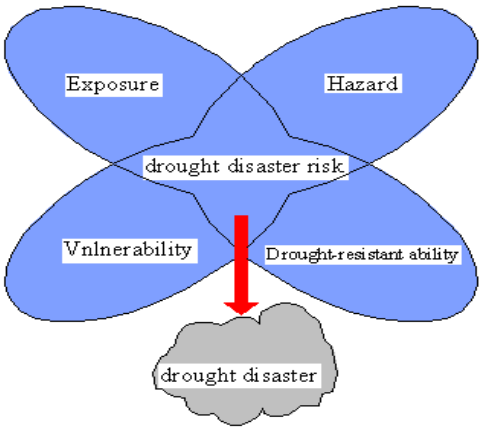

Fig.1-The formation factors of agricultural drought disaster risk

Agricultural drought is a kind of extremely complex natural disasters, which involves climate, atmosphere, farming crops, social economic, and natural resources. Therefore index selection is premise and key of agricultural drought risk evaluation [5]. These principles that include purposiveness, systematicness, scientificity, comparability and operability are considered to select indexes, combining with physical circumstances at the same time [2]. Guizhou is typical karst landform, precipitation infiltrates underground and directly outflow, so it can't be used efficiently. The speeds of soil desertification accelerate, soil layer become shallow, water and soil erosion is serious. At the same time, the correlation degree between indexes and crop yield loss. In the paper, 15 indexes are selected as evaluation indexes totally. The result of correlation degree analysis are shown in table 1, which show selecting the indexes being reasonable.

Hazard is denoted by precipitation from February to September in crop growth period, by continuous no rain days in this time interval which reflects precipitation uniformity or drought duration and by drought frequency that reflects possibility of the drought occur. Exposure is denoted by agricultural crop sown area and density of population , the larger sown area and density of population are, and the greater the exposure for crops is [6]. Vulnerability is denoted by the population density, the drought area and crop yield per unit area, which reflects degree of crop vulnerability in

农业干旱灾害风险是多因素共同作用的结果，它涉及到气候、大气、耕种作物[5]以及人类对资源所造成的积极和消极的影响等各方面因素。所以农业干旱是一种极其复杂的自然灾害，它不仅是一种物理过程，同时也与气候变化、自然资源、社会经济相关。由于农业干旱的复杂性和多变性，指标的选取就成为农业干旱风险评价的前提和关键。综合考虑指标体系的目的性、系统性、科学性、可比性和可操作性原则，结合实际操作情况和资料获取的难易程度选取指标[2]。根据指标选取的原则，基于干旱灾害风险组成四要素（危险性、脆弱性、暴露性和抗旱能力）对农业干旱灾害风险的影响，同时考虑贵州地区的农业干旱不同于一般的农业干旱，其典型的喀斯特地形地貌形成地下以及山体内部岩溶地形，降水或形成地表径流直接流走或渗入地下不能很好地储存和利用，土壤的石漠化速度快，土层浅薄，水土流失较为严重，以及通过分析各指标同作为损失状况的相关性，共选取 16 个指标作为评价指标。所选取的各项指标与作物的损失状况进行灰色关联度分析，结果如表 1 所示，说明选择这些指标是合理的。

危险性主要根据气象资料中 2～9 月降水量表示粮食作物生长期内降水的多少，2～9 月连续无雨日数表示降雨的均匀程度或者干旱持续时间；干旱频率反映了干旱发生的可能性。暴露性主要表现在农作物的播种面积[6] 和人口密度，对于农作物来说，播种面积越大，人口密度越大，暴

the study area [4]. Drought-resistant ability is denoted by yields rates of drought or waterlogging and water saving rate in technology level; which is denoted by per capita income and investment in economic level; which is denoted by drought irrigation area and solving temporary population of drinking water in policy and management level.

Establishment of agricultural drought disaster risk model

According to the mechanism of agricultural drought disaster risk [7], considering four risk factors and indexes in the typical areas, drought disaster risk evaluation system is established by using the analytic hierarchy process (AHP) and weighted synthesis methods (Table 1).

露性越大；选用因旱粮食损失、受旱面积和农作物单位面积产量[4]作为脆弱性指标，来表征研究区的易损程度；抗旱能力在技术层面上选取旱涝保收率和节水率为指标，在经济层面上选取人均收入和抗旱投入资金为指标，在政策与管理层面上选取抗旱灌溉面积和解决临时饮水人口为指标。

农业干旱灾害风险模型的建立

根据农业干旱灾害风险形成机制[7]，综合考虑典型区的风险要素 4 个因子及其指标，利用层次分析法和加权综合法，建立如下贵州典型区农业干旱灾害风险评价体系（表 1）。

Table 1

Index system and weights of agricultural drought disaster risk assessment

	Factor	Index system	Weight	Correlation degree to crop yield loss
Index system of agricultural drought disaster risk assessment	Hazard(H) 0.387	Precipitation （mm）	0.417	0.661
		Evaporation （mm）	0.241	0.663
		Drought index	0.097	0.698
		Drought frequency （%）	0.089	0.646
		Soil type	0.157	0.679
	Exposure（E） 0.155	Agricultural crop sown area （ha）	0.750	0.715
		Density of population (number/km^2)	0.250	0.613
	Vulnerability（V） 0.265	The drought area ratio （%）	0.443	0.723
		Crop yield loss because of drought	0.387	0.735
		Drop yields （kg/ha）	0.170	0.810
	Drought resistant ability （RE） 0.193	The drought and flood insurance yield （%）	0.192	0.677
		Per capital net income （Yuan/person ）	0.087	0.592
		Water-saving percentage（%）	0.073	0.611
		Irrigation area （10^3ha）	0.183	0.800
		Drought relief funds （Yuan/ha）	0.108	0.622
		Irrigation rate （%）	0.357	0.712

Drought disaster risk reflects the potential risk and direct harm of natural disasters exerting on hazard-affected bodies. The models are established based on the theory of disaster risk assessment, considering hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body and drought resistance ability, totally [3]. Formula as follow:

干旱灾害风险反映了自然灾害对承灾体的潜在危险和直接危害，依据灾害风险评估技术理论体系，综合考虑了致灾因子危险性、承灾体的暴露性和脆弱性以及抗旱减灾能力[3]，公式如下：

$$Risk = \left(H^{WH}\right) + \left(E^{WE}\right) + \left(V^{WV}\right) + \left(RE^{WR}\right) \quad (4)$$

$$H = \sum_{i=1}^{n=5} X_{hi} W_{hi} \quad (5)$$

$$E = \sum_{i=1}^{n=1} X_{ei} W_{ei} \quad (6)$$

$$V = \sum_{i=1}^{n=3} X_{vi} W_{vi} \quad (7)$$

$$RE = \sum_{i=1}^{n=6} X_{ri} W_{ri} \quad (8)$$

In equations, Risk is an agricultural drought disaster value, which is used to represent the drought disaster risk degree; H, E, V and RE represent values of hazard, exposure vulnerability and drought resistant ability respectively; W_h, W_e, W_v, W_r represent values of index weight coefficient of hazard, exposure,

上式中，Risk 是农业干旱灾害风险值，用于表示干旱灾害风险程度；H、E、V、RE 的值相应的表示危险性、暴露性、脆弱性和抗旱能力因子的值；Wh、We、Wv、Wr 表示危险性、暴露性、脆弱性和抗旱能力的权重；Xi 为各

vulnerability and drought resistant ability respectively; X_i is the quantitative value of each index; W_i is weight coefficient of each evaluation index [14].The comprehensive drought risk value is calculated by those equations in these typical areas, which reflect drought risk level directly.

Agricultural drought disaster risk evaluation and risk threshold determination

Selecting period from 1990 to 2007 as time scales of research, agricultural drought disaster risk values are gotten in typical areas based on the indexes selected and the model built. The risk values show the risk state.

The risk class and threshold are ascertained by using optimal partitioning method. The scatter diagram of error function and classification grade is drawn in order to decided optimal class. As shown in figure 2. The inflection point is located 4 partitions. The error function doesn't increase obviously with classification numbers increasing. So, the optimal classification grade is 4, low risk, middle risk, high risk, very high risk. The threshold values are shown in figure 2.

评价指标的量化值，Wi 为各评价指标的权重系数[14]。通过上式得到兴仁、修文、湄潭三个典型区的旱灾综合风险值，风险值的大小直接体现了该地区的旱灾风险高低。

农业干旱灾害风险评估与风险阈值确定

对研究区进行农业干旱灾害风险评价的过程中，选取 1990-2007 年为时间尺度进行分析研究，根据前文选取的指标和构建的模型，得出典型区的农业干旱灾害综合风险值，风险值的大小直接体现了该地区的旱灾风险高低。

运用最优分割法来确定干旱灾害风险的最优划分等级和阈值。为确定最优分割等级，做出误差函数与分类等级的散点图如图 2 所示。从图中可以看出拐点在 4 分割处，如果分类数继续增加，误差函数的变化也不大，因此最优分割等级为 4 等级，依次是低风险、中风险、高风险、极高风险。由最优分割法确定的具体界限值如表 2 所示。

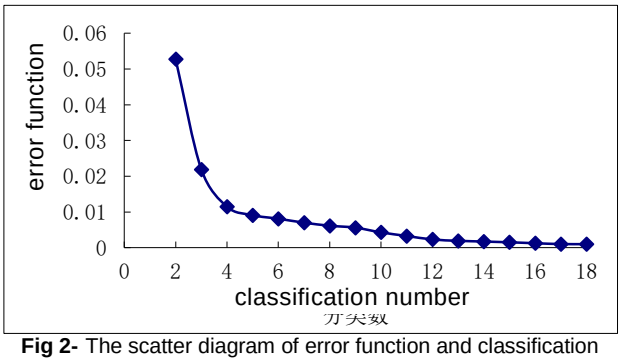

Fig 2- The scatter diagram of error function and classification grade

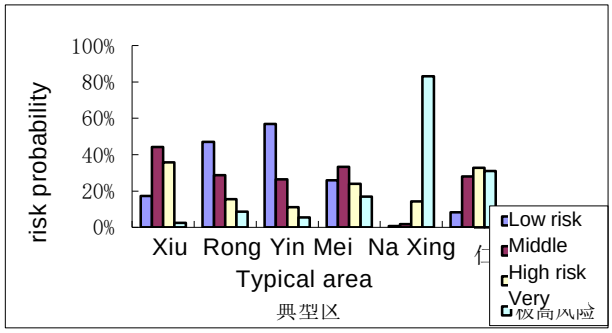

Fig 3 -The drought disaster risk probability in typical areas

Table 2

Threshold value and different risk types of agricultural drought disaster risk

Risk type	Low risk	Medium risk	High risk	Very high risk
Threshold value	≤0.385	0.385~0.452	0.452~0.510	≥0.510

Drought disaster comprehensive risk probability analysis in areas

The risk degrees are divided of sample years in typical areas in case of comprehensive risk threshold value. The risk probability can be drawn based of risk class and information diffuse theory, as shown in fig.3.

We can know from figure 3 that different degree drought risk probabilities are different in typical areas. The numbers of middle risk years is most in Xiuwen, but least very high risk. Yinjiang has most low risk years, and Rongjiang takes second place. But Yinjiang has least high risk. Meitan has much middle risk. Nayong has most years of very high risk, but least years of low and middle risk. Xinren has least years of low risk, differs little in middle risk, high risk and very high risk.

典型区各等级旱灾综合风险发生的概率分析

根据综合风险阈值对典型区样本年进行风险程度的划分，根据信息扩散理论模型和划分的风险等级，可以得到研究区各等级旱灾综合风险发生的概率，如图 3 所示。

从图 3 中可以得出：典型区各县处于不同程度干旱风险的概率不同。对于修文，处于中风险的年份最多，在各典型县中也是最多的；但是处于极高风险的年份却是各个典型县最少的。榕江处于低风险的年份最多，在各个典型县中仅次于印江，比其他典型县大。印江处于低风险的年份最多，在各典型县中也是最多的；但是处于高风险的年份却是各个典型县最少的。湄潭处于中风险的年份较多，在各个典型县中仅次于修文，比其他典型县大。纳雍处于极高风险的年份最多，在各典型县中也是最多的；但是处于低、中风险的年份却是各个典型县最少的。兴仁处于低风

The probability of high risk is next to Xiuwen, and the probability of very high risk is next to Nayong.

Drought disaster comprehensive risk analysis in areas

The average comprehensive risk value can be got by caculating average value of comprehensive risk value from 1990 to 2007 in typital areas. As shown in table 3 and figure 4.

We can know from the result that Yinjiang has low risk; Xiuwen, Rongjiang and Meitan have midle risk; Xinren has high risk; Nayong has very high risk. West north and west south are hightest, middle and north are next, and east is lowest. Nayong has biggest risk value with biggest exposure and vulnerability; Rongjiang has less risk value because other factors' risk values are low level but hazard. So drought disk is the result of four factors comprehensive doing not single factor doing. In very high risk year, we should improve agricultural produce level and increase drought resistance strength to resist effectively disaster influence to crops, in order to insure food security. In middle risk years, the disaster-causing factors have lower risk in typical areas, the vulnerability of disaster bodies should be strengthened to resist natural disaster.

险的年份最少，在各典型县中也是最少的；处于中、高、极高风险的概率相差不大，处于高风险的概率仅次于修文，比其他典型县大；处于极高风险的概率仅次于纳雍，比其他典型县大。

典型区旱灾综合风险分析

将各典型区 1990-2007 年的旱灾综合风险值求均值，得到多年的平均风险值如表 3 和图 4 所示。

根据各地多年综合风险均值可知，印江处于低风险；修文、榕江、湄潭处于中风险；兴仁处于高风险；纳雍处于极高风险。从整体来看，西北、西南最高，中部和北部次之，东部最低。其中，纳雍的暴露性、脆弱性因子值最大，其他因子值也处于较高值，故其风险值最大；榕江虽危险性风险值最大，但其他因子风险均处于较低水平，故风险值较低。故典型区的干旱灾害风险并不是由单一因素如致灾因子危险性、承灾体暴露性和脆弱性以及抗旱减灾能力决定的，而是四个方面因素的综合作用影响的结果，因此在极高风险年份除去客观因素的影响下，应当考虑提高农业生产水平、加大抗旱减灾力度以便能够有效地抵御灾害对农业的产生的影响，保证区域粮食安全。而对于中风险的年份来说，典型区表现出较低的致灾因子风险性，同样在去除客观因素的影响下，建议从承灾体脆弱性方面加强，对抵抗自然灾害起到加强保护作用。

Tabel 3

Comprehentive risk value of many years in typical

Typical area	Xiuwen	Rongjiang	Yinjiang	Meitan	Nayong	Xinren
Comprehensive risk value	0.433	0.394	0.383	0.436	0.567	0.481

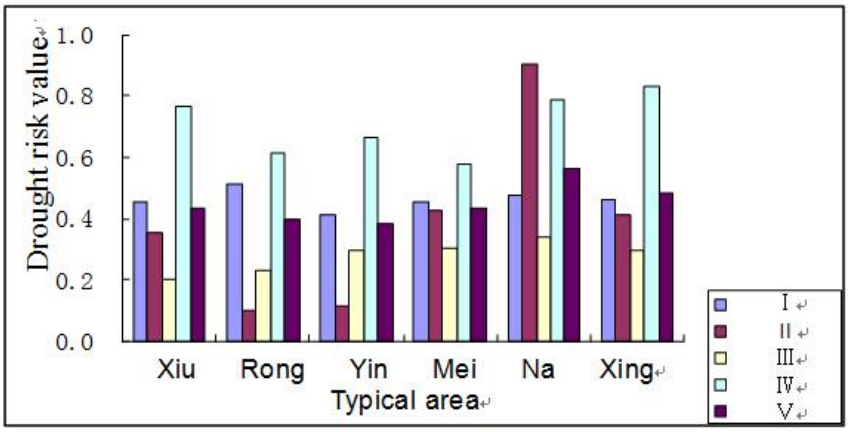

Fig 4- Comprehentive risk value of many years in typical

Ⅰ—Hazard Ⅱ—Exposure Ⅲ—Vulnerability Ⅳ—Drought resistant ability Ⅴ—Comprehensive risk value

Correlation of drought risk indexes and disaster loss

Drought disaster risk indexes can be got based on indexes factors quantized value by using natural disaster risk index method, but crop loss that is core factor of agricultural system. So, we research the

典型区旱灾风险指数与灾害损失相关性分析

根据各指标因子的量化值，运用自然灾害风险指数法得到典型区的干旱灾害风险指数，但是没有考虑到农业系统的核心因子——作物的损失状况。进行自然风险

correlation of drought risk indexes and history disaster loss data of drought disaster occurred. Crop loss rate due to drought is used to represent disaster loss according to agricultural disaster data which are given by statistic department of Guizhou province [11, 15].

Fomular as follow:

评估的目的就是为了研究灾害损失，因此，依据各典型区干旱灾害风险指数和已发生干旱灾害的历史灾情损失资料，对两者间的相关性进行研究。根据贵州统计部门提供的农业灾情统计数据，选择因旱粮食损失率来表述灾害损失[14,15]，具体公式如下。

$$F = \Delta Y / Y \tag{9}$$

$$L=(D_1-D_2)\times 0.2+(D_2-D_3)\times 0.55+D_3\times 0.9 \tag{10}$$

In equations, F is crop loss rate due to drought; ΔY is crop loss yield due to drought; Y is normal crop yield. L is comprehensive coefficient of crop loss; D_1 is the ratio of crop afflicted area to plant area; D_2 is the ratio of crop disaster area to plant area; D_3 is the ratio of crop no any output area to plant area.

式中：F 为因旱粮食损失率；ΔY 为因旱粮食损失产量；Y 为正常状况下粮食产量。

式中: L 为综合减产系数；D_1 为作物受灾面积占播种面积的比例；D_2 为作物成灾面积占播种面积的比例；D_3 为作物绝收面积占播种面积的比例。

Correlation analysis of drought risk indexes and crop loss ratio due to drought

In the base of computing crop loss ratio due to drought from 1990-2007 in each typical area, analyzing the correlation of drought disaster risk index and crop loss ratio due to drought, the result is shown in figure 5 to figure 10. The correlation equation of drought risk index and crop loss ratio due to drought can be got in each typical area.

旱灾风险指数与因旱粮食损失率相关性分析

逐年计算 1990-2007 年各典型区因旱粮食损失率，并与之前得到的各典型区的干旱灾害风险指数进行相关性分析，如图 5 到 10 所示，得到各典型区旱灾风险指数与因旱粮食损失率的相关方程。

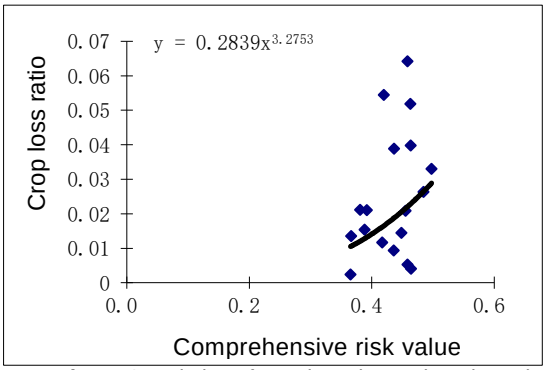

Fig.5 - Correlation of crop loss due to drought and risk index in Xiuwen

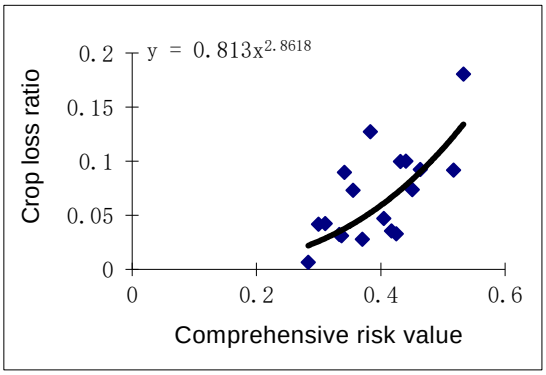

Fig.6 - Correlation of crop loss due to drought and risk index in Rongjiang

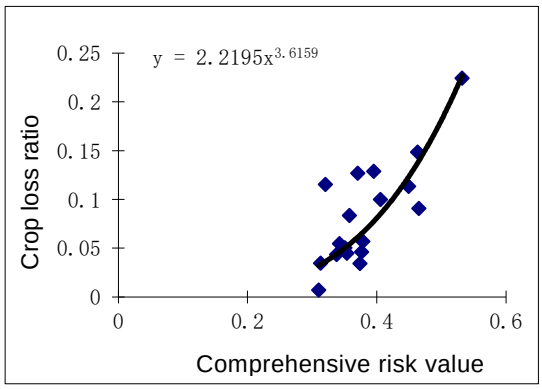

Fig.7 - Correlation of crop loss due to drought and risk index in Yinjiang

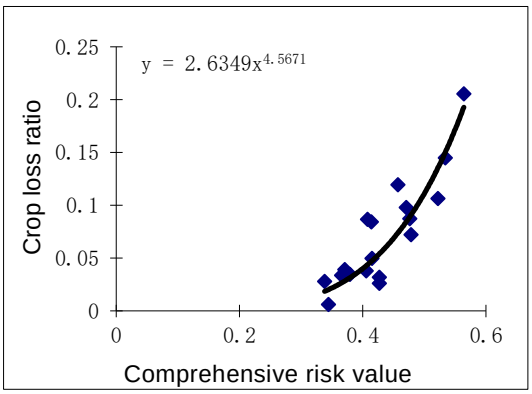

Fig.8 - Correlation of crop loss due to drought and risk index in Meitan

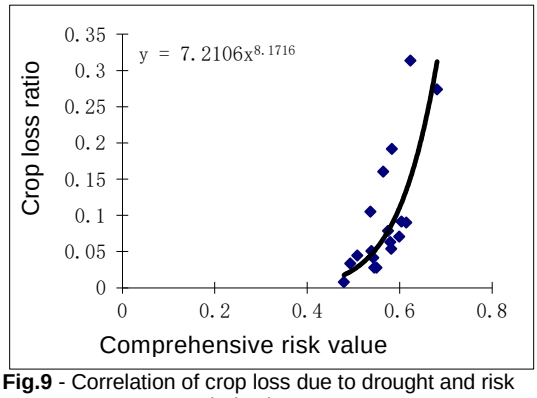

Fig.9 - Correlation of crop loss due to drought and risk index in Nayong

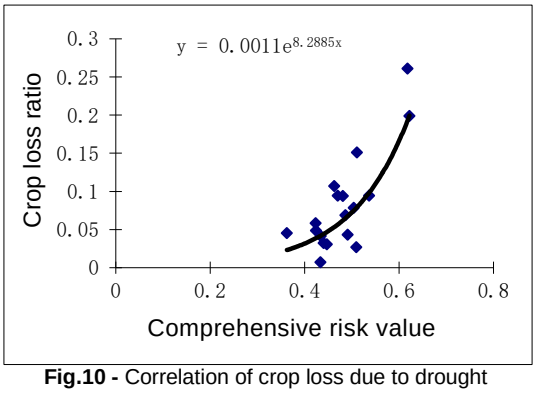

Fig.10 - Correlation of crop loss due to drought and risk index in Xinren

From the figure 5 to figure 10, we can know that drought disaster risk index is positive correlation with crop loss ratio due to drought, the correlation coefficient are 0.341、0.678、0.693、0.821、0.787、0.651 in Xiuwen, Rongjiang, Yinjiang, Meitan, Nayong, Xinren. The results indicate the evaluation model is reasonable that is builded by using the grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning method. The evaluation result is objective. The model can be used to evaluate agricultural drought disaster risk in certain area. The relation of risk index and crop loss ratio is builded by correlation equation, and the crop loss yield can be predicted by drought disaster risk index in certain area in the future.

CONCLUSIONS

In the paper agricultural drought disaster risks are evaluated using the method of natural disaster index, which provide reference for the relevant departments to formulate the drought early warning and risk management. Select drought time intensity and frequency of drought as disaster-causing factors, crop sown area and agricultural production level as hazard bearing body, those are research subject. Hazard of disaster-causing factors, exposure and vulnerability of hazard bearing body, and drought resistance ability are selected as evaluation indexes. Natural and social factors are considered in selecting indexes, materials of precipitation, disaster statistics and social economic are used fully. The risk class and threshold are ascertained by using optimal partitioning method. Analytic hierarchy process (AHP) is used to analyze the factor indexes weights, which make agricultural drought risk assessment results have rationality and reference. The relation of risk index and crop loss ratio is built by correlation equation, and the crop loss yield can be predicted by drought disaster risk index in certain area in the future.

We can know from the result that Yinjiang has low risk; Xiuwen, Rongjiang and Meitan have midle risk; Xinren has high risk; Nayong has very high risk. Drought disk is the result of four factors comprehensive doing not single factor doing. In very high risk year, we should improve agricultural produce level and increase drought resistance strength to resist effectively disaster influence to crops, in order to insure food security. In middle risk years, the disaster-causing factors have lower risk in typical areas, the vulnerability of disaster bodies should be strengthened to resist natural disaster. In a world, the model builded is reasonable, that can be used evaluate agriculture drought disaster risk in Guizhou province.

从图中可知，典型区修文、榕江、印江、湄潭、纳雍、兴仁的旱灾风险指数与因旱粮食损失率之间存在明显的正相关关系，它们的相关系数分别达到0.341、0.678、0.693、0.821、0.787、0.651。这说明本研究通过指标选取,利用灰色关联度分析、自然灾害风险指数法、层次分析法、加权综合评价法、Fisher最优分割法等方法建立模型进行农业干旱灾害风险评价是合理的，其评价结果也具有一定的客观性，可以依据此模型来评价不同区域农业生产受到干旱灾害影响的风险大小。同时，通过各典型区旱灾风险指数与因旱粮食损失率的相关方程，建立起旱灾风险指数与因旱粮食损失率的联系，可以通过得到的旱灾风险指数来预估典型区的粮食损失状况。

结论

利用自然灾害指数法对农业干旱灾害风险进行评价,为相关部门制定干旱预警、风险管理等方面提供借鉴作用。本文以贵州干旱时间强度和干旱频率为致灾因子,以作物播种面积和主要粮食作物生产水平为承灾体作为研究区农业干旱灾害风险评评价的研究对象,选取致灾因子危险性、承灾体暴露性和脆弱性以及抗旱能力作为评价因子，从指标的选取方面考虑了以自然因素和社会因素相结合的角度来研究农业干旱风险的问题较为全面。充分利用了降水资料、灾害统计资料和社会经济背景资料等。利用最有分割法确定风险等级和阈值。利用层次分析法对各因子指标进行权重分析,使得农业气象干旱风险评估结果具有合理性和参考性。通过各典型区旱灾风险指数与因旱粮食损失率的相关方程，建立起旱灾风险指数与因旱粮食损失率的联系，可以通过得到的旱灾风险指数来预估典型区的粮食损失状况。

根据各地多年综合风险均值可知，印江处于低风险；修文、榕江、湄潭处于中风险；兴仁处于高风险；纳雍处于极高风险。典型区的干旱灾害风险并不是由单一因素如致灾因子危险性、承灾体暴露性和脆弱性以及抗旱减灾能力决定的，而是四个方面因素的综合作用影响的结果。因此在极高风险年份除去客观因素的影响下，应当考虑提高农业生产水平、加大抗旱减灾力度以便能够有效地抵御灾害对农业的产生的影响，保证区域粮食安全。而对于中风险的年份来说，典型区表现出较低的致灾因子风险性，同样在去除客观因素的影响下，建议从承灾体脆弱性方面加强，对抵抗自然灾害起到加强保护作用。总之，本文所建立的干旱评估模型是合理的，可以据此对贵州的农业干旱灾害风险进行评估。.

ACKNOWLEDGMENTS

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HARVESTING SCHEDULING OPERATIONS FOR THE MACHINERY OWNERS UNDER MULTI-FARMLAND, MULTI-TYPE SITUATION WITH TIME WINDOW --AN EMPIRICAL STUDY ARISING IN AGRICULTURAL CONTEXTS IN CHINA /

基于时间窗的多农机点、多农田作业点、 多机型的混合农机资源调度问题研究

Lect. Ph.D. Xiaoning Zhu[1)] , Lect. Ph.D. Rui Yan[2)] , M. Ec. Hongli Wang[1)]

[1)] School of Economic and Management, University of Science and Technology Beijing, Beijing / China

[2)] School of Economic and Management, Beijing Information Science & Technology University, Beijing / China

Tel: +861062333854; E-mail: zhuxiaoning@ustb.edu.cn

Abstract: *Harvesting scheduling operations and allocations are very important for the agricultural machinery owners and the farmers regarding to finish the harvesting work. Most of the machinery owners schedule their farm machinery by experience, which is a big waste of the agriculture resources. This paper is an attempt to schedule the agricultural machinery for the machinery resource centers under multi-farmland, multi-type machinery situation with time window constrain in order to maximize efficiency of resource utilization. A novel modelling method with improved genetic algorithm is presented. An empirical study of an agricultural machinery association in Hebei province in China is illustrated and the results show that the models and the scheduling algorithm proposed in this study can improve agricultural utilization of the farm machinery resource centers and reduce the costs of agricultural machinery usage.*

Keywords: *scheduling operations, agricultural machinery, time window，multi-type machinery*

INTRODUCTION

China, as one of the biggest agricultural countries in the world, has achieved rapid development, with high rates of agricultural mechanization and the continuous progress of agricultural modernization. As a result, there are more and more agricultural machinery cooperation organizations or agricultural machinery associations in China. However, Most of the machinery owners schedule their farm machinery by experience, which is a big waste of the agriculture resources, so harvesting scheduling operations and allocations are very important for the agricultural machinery owners and the farmers in order to finish the task of agricultural harvesting on time, as well as improve the utilization efficiency of agricultural machinery and reduce agricultural resource waste.

The paper is organized as follows. The next section is the literature review regarding the schedule operations. Following is the introduction of model for the agricultural machinery scheduling and routing problem for the machinery owners under multi-farmland, multi-type machinery situation with time window constrain. Section 4 illustrates an empirical study of an agricultural machinery association in Hebei province in China. Finally, the analysis results and the conclusions are discussed along with the related managerial implications.

The main concerns about the harvesting scheduling operations are the schedule for the agriculture machinery and the farmland. There have been increasing researches focused on the scheduling of the operations that are

摘要: *合理的农机资源调配方案，对顺利完成农田作业起着非常重要的作用。而在中国，绝大多数的农机主和农场主是按照经验进行农机资源的调度和安排，这无疑对有限的农机资源是一种浪费。本文在实地调研的基础之上，提出一种实际作业中经常会碰到的复杂问题，问题中同时考虑多农机点、多农田作业点、多机型及时间窗约束等因素。本文建立了考虑多农机点、多农田作业点、多机型及时间窗约束的混合农机资源调度数学规划模型，并提出一种改进的模糊遗传算法求解混合农机资源调度模型。本文所提出的模型具有较好的可解性，且算法具有较好的计算结果和计算效率。结合河北省某农机协会，展开初步的应用试验，实证研究的结果表明模型和算法能够实现农机的快速、最低成本调度，大幅提高了某农机组织的农机利用率，并降低农机利用成本。*

关键词: *混合资源调度安排，农业机械资源，时间窗，多种农机车型*

引言

中国作为世界农业大国之一，近年来随着中国农业机械化和农业现代化进程的持续推进，出现了越来越多的农机合作组织、农机专业服务组织、农机行业协会等组织形式。由于农业生产具有较强的时效性和连贯性，对于大范围的农业生产作业，需要对农机资源进行合理配置和有效调度。在中国，依然是农机主凭借经验对农机资源进行调度，这就造成了农机资源的极大浪费，尤其是在对农机资源需求较大的农产品收割时段。因此十分有必要针对中国的实际情况，对农机资源进行合理配置和有效调度，以按时完成农业生产任务，提高农机利用率，避免农作物损失和农机资源浪费。

本文的主要研究思路和论文结构如下：第一章介绍了本文的研究意义和研究背景，下一章对有关农机资源调度的相关文献进行了总结和分析，第三章主要进行了考虑多农机点、多农田作业点、多机型及时间窗约束等因素的混合农机资源调度的模型研究。第四章对河北省某农机协会进行了实证研究，最后，对本文所建立的模型及实证结果进行了分析，并探讨了该模型对农机协会的管理意义。

农机调度的本质是农业机械与农田的资源调度问题，农机调度问题对于农作物收获季农业资源的利用率十分重

carried out when the crops are harvested. Although this area of scheduling has been the focus of some research, solution techniques reported in the open literature appear to be applicable to different situations from that considered in the present paper [4-12，14, 15].

Some of the literature referenced above deals with minimum time lags [1，3，12，13]. There is less literature available on the additional requirement of maximum time lags than there is on minimum time lags. The only exact procedure known to the authors was devised by Neumann and Zimmermann (2000), however it is not capable of solving problems of practical size in reasonable time. There also exist polynomial-time heuristics for solving the scheduling problems [2，11-13]. The last technique is based on a neural network model based on heuristic methods [4，10，16].

Few studies take into account both time factor and spatial factors, however, in agricultural operations, time factor and spatial factors are constraints which appear in the bound form of time period (time window) and network topology, causing difficult in building and solving the model of agricultural [15-17]. In this context, considering multi-agriculture machinery resource center, multi-farmland, multi-type and time window constraints, we establish the mathematical planning models and propose a modified fuzzy hybrid genetic algorithm to solve this kind of scheduling model.

MATERIAL AND METHOD

In this context, we study all farm machinery resources centralized deployment problems under an agricultural machinery association. The agriculture machinery resource refers to the different kinds of agriculture harvester. One agriculture harvester can be arranged to the other farmland after the work in one farmland only if the work in the first farmland is totally finished.

Distribution diagram of agriculture machinery scheduling is shown as follows:

要。现在越来越多的文献关注了农机调度问题，在可查阅到的相关文献内，虽然不同国家的不同学者都对此问题进行了研究，但是模型假设、模型的求解、资源配置等等存在的不同的解决方案[4-12，14,15]。

有些文献考虑了农机资源配置过程中的时间滞后性[1，3，12，13]。更多的文献假定最短时间滞后性，少量文献研究假设最长时间滞后性。Neumann 和 Zimmermann 的研究是为数不多的阐述了农机资源配置的程序的文献，但是在有限时间内解决实际农机资源调配问题仍存在一定的局限性。有一些文献应用启发式算法对该问题进行求解[2，11-13]。最近研究的较多的是基于神经网络的启发式算法来求解农机资源调度问题[4，10，16]。

但是在已有文献中很少综合考虑了时间因素和空间因素，而在农机作业中，时间因素和空间因素均是约束条件，而且以时间段(时间窗) 和网络拓扑的约束形式出现，这为农机调度模型的建立和求解增加了难度[15-17]。本研究同时考虑多农机点、多农田作业点、多机型及时间窗约束等因素，并建立相应的数学规划模型，提出一种改进的模糊遗传算法求解混合农机资源调度模型，通过改进的模糊逻辑控制器实现交叉概率和变异概率的动态调整，以加快算法的收敛速度，且能够有效的避免陷入局部最优解。

模型与方法

本文研究在一个农机组织下所有农机资源集中调配的问题，这里农机资源是指不同规格农业收割机。本文考虑农机在完成一个任务后，在时间和经济允许的前提下前往下一个任务点继续服务。但必须先完成当前农田作业点的全部任务，即不允许农机在作业过程中提前离开。

农机调配示意图如下：

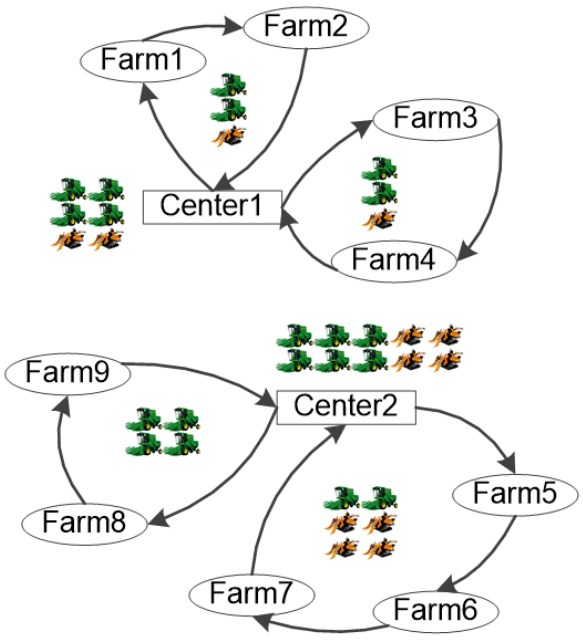

Fig. 1 – Distrubution diagram of agriculture machinery scheduling

The related assumptions are as follows:

(1) There are multiple agricultural machinery resource centers scattering in different position, and the farmland coordinates are known and fixed;

(2) Each agricultural machinery resource center has a certain number of different types of agricultural machinery and equipment, and the number and specifications (speed, fuel consumption, operation ability, etc.)of various types of agricultural machinery equipment are known and fixed;

(3) The farmland are in different positions, and each farmland has a certain number of different types of agricultural machinery equipment;

(4) The location, price, operating time window and the requirements pd agricultural machinery equipment, of each farmland are known and fixed;

(5) All distances between agricultural machinery resource centers and farmland are known, and there is no differences between each of the road;

(6) Take minimizing the farm machinery driving distance as a goal.

本模型作如下相关假设：

（1）在区域内具有多个分散在不同位置的农机点，且农机点的位置坐标已知且固定；

（2）每个农机点有一定数量的不同型号的农机装备，且各类型号农机装备的数量和规格（行驶速度、单位油耗、作业能力等）已知且固定；

（3）在区域内具有多个分散在不同位置的农田作业点，且每个农田作业点均需求一定量不同型号的农机装备；

（4）每个农田作业点的位置、作业价格、作业时间窗以及农机装备需求等参数均已知且固定；

（5）所有农机点和农田作业点之间的道路长度已知且固定，假设所有道路通行状况均相等，道路之间不存在任何差异；

（6）以最小化农机行驶总距离为目标。

Table 1

Explanations for the symbols in the modle

No.	Symbols	Explanation of symbols
1	I	The total number of the agriculture machinery resource centers，i =1, …, I
2	J	The total number of the farmlands，j =1, …, J
3	N	The sum of the number of the agriculture machinery resource centers and the number of the farmlands，n=1, …, N, N=I+J, i =1, …, I，j =1, …, J
4	P	Types of the agriculture machinery，p=1, …, P
5	M_{ip}	The number of *p type of* the agriculture machinery in agriculture machinery resource center i，k=1, …, M_{ip}
6	Q_p	The capacity of the agriculture machinery p
7	A_j	The area of the farmland j，j=1, …, J
8	C_j	The cost per unit area of farmland j，j=1, …, J
9	$[tb_j, te_j]$	The time window for the farmland j，j=1, …, J
10	d_{nn*}	The distance from center n to center n*，n=*1, ..., N, n*=1, ..., N*
11	v_p	The average speeds of the agriculture machinery p，p=1, …, P
12	c_p	The unit mileage cost of the agriculture machinery p，p=1, …, P
13	rd_j	The punishment cost for the late or early arrival for the farmland j，j=1, …, J
14	TF_j	The operations time for the farmland j，j=1, …, J
15	x_{iknn*}	decision variable，$x_{iknn*}=\begin{cases}1, & \text{the machinery } k \text{ of center } i \text{ from n to } n* \\ 0, & \text{others}\end{cases}$，n=1, ⋯, N, n*=1, ⋯, N

The Eq.(1) refers to the objective function: transportation costs plus the operations costs plus the delay or early arrival punishment. The Eq.(2) refers to the numbers of the agriculture machinery constrain. The Eq.(3-5) refer to the requirements that all the farmland tasks must be finished on time. The Eq.(3-5) refer to the decision variable value constrain.

式(1)为模型的目标函数：农机行驶成本+农机作业成本+延迟或提早到达惩罚；式(2)为农机数量约束；式(3)为实际开始时间的计算公式；式(4)为实际结束时间的计算公式，式(3)和式(4)共同实现了农田作业点任务必须全部完成的约束；式(5)为所有农田作业点必须在规定时间之前完成任务；式(6)为决策变量取值范围约束。

$$\min Z = \sum_{i=1}^{I}\sum_{p=1}^{P}\sum_{k=1}^{M_p}\sum_{n*=1}^{N}\sum_{n=1}^{N} x_{ikpnn*}\cdot d_{nn*}\cdot c_p + \sum_{j=1}^{J} A_j\cdot C_j + \left|tb_j - TFb_j\right|\cdot rd_j \quad (1)$$

$$\sum_{j=1}^{J}\sum_{k=1}^{M_p}\sum_{n^*=1}^{N}\sum_{n=1}^{N} x_{ikpnn^*} \le M_{ip}, i=1,\ldots,I, \quad (2)$$

$$TFb_j = \sum_{i=1}^{I}\sum_{k=1}^{M_p}\sum_{n=1}^{N} x_{ikpnj}\left(TFe_n + \frac{d_{nj}}{v_p}\right), j=1,\ldots,J, \quad (3)$$

$$TFe_j = TFb_j + \frac{A_j}{\sum_{i=1}^{I}\sum_{k=1}^{M_p}\sum_{n^*=1}^{N}\sum_{n=1}^{N} x_{ikpnn^*} Q_p}, j=1,\ldots,J, \quad (4)$$

$$TFe_j \le te_j, j=1,\ldots,J, \quad (5)$$

$$x_{ikpnn^*} \in \{0,1\}. \quad (6)$$

This computation is followed by running Genetic Algorithm (GA) operations. Under the consideration of disadvantages of premature convergence and local optimal solutions of GA, an improved fuzzy genetic algorithm is proposed in this paper, the Selection retains the successful solutions, whereas crossover and mutation are included to try to diversify the remaining candidate solutions for the next generations. In the next step, the parameters of the GA are updated by an adaptive fuzzy logic controller to improve the algorithm's performance. The newly adjusted parameters are then used in the next generation. This evolutionary process is repeated until a predefined number of generations is reached. The flow chart of fuzzy genetic algorithm is shown in Fig. 2

本文采用遗传算法（Genetic Algorithm, GA）进行求解。遗传算法作为一种快捷、简便、容错性强的算法，在各类优化问题中显出明显的优势。但遗传算法存在早熟收敛、陷入局部最优解等一些固有缺点。为了克服遗传算法的缺点，本文提出一种改进模糊遗传算法求解农机调配模型。选择操作用于更新种群，交叉和变异用于生成新的染色体。在算法迭代过程中，通过模糊逻辑控制器动态调整交叉概率和变异概率，从而避免早熟收敛并提高收敛速度。根据当前种群的最佳适应度、平均适应度和待交叉、待变异个体适应度之间的关系，来控制交叉概率和变异概率。模糊遗传算法的流程图如图 2 所示：

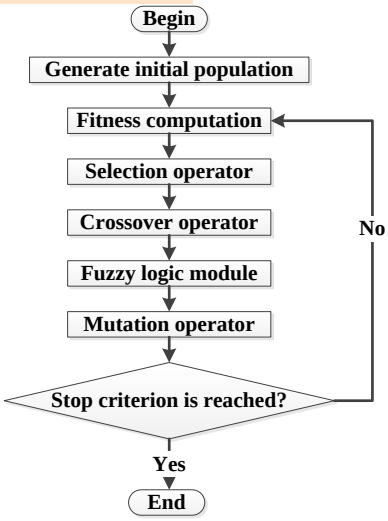

Fig. 2 –The flow chart of fuzzy logic genetic algorithm

(1) Encoding.

Traditionally, a chromosome is a sequence of binary digits, which represents a solution in the problem domain. The bits of the chromosome are referred to as its genes and are mapped to parts of a solution. Binary digit encoding method is used in this paper. There is an example that includes two centers and ten farmlands, and the binary digit encoding of this example is shown in Fig.3.

（1）编码

传统上，一条染色体是一个二进制数字序列，代表在问题领域的一种解答。染色体的位是它的基因，对应与解决方案的一部分。本文使用了二进制数字编码方法。有一个包括两家农机点和十个农场作业点的例子，这个例子的二进制数字编码如图 3 所示。

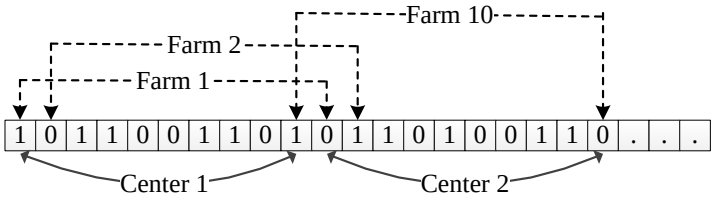

Fig. 3 – Binary digit encoding

(2) Fitness function.

Usually, the reciprocal of objective function is chose as fitness function. But the fitness value will be small and can't be adjust. And the difference of fitness value in different problems is greatly.

(3) Selection operator

Binary tournament selection: In this selection process, two individuals are selected at random from the population and the fittest one is selected for reproduction.

(4) Crossover operator

Order crossover operator (OX): The order crossover operator is designed for order-based permutation problems. Two crossover points are randomly selected and the segment between them is copied to the offspring from the first parent. Starting from the second crossover point in the second parent, copy the elements to the offspring in the order they appear in the second parent, avoiding repetition. The second offspring is created in the same way, reversing the roles of the parents. The steps are shown in Fig. 4 and 5.

（2）适应度函数

通常情况下，目标函数的倒数会作为适应度函数被选择。并且适应度值比较低，且不能调整。不同问题中的适应度值差别非常大。

（3）选择方案

二进制比赛选择：在这个选择过程中，从总量中随机选择两个个体，最合适的那个被选出来用于再交叉。

（4）交叉算子

顺序交叉算子（牛）：顺序交叉算子是用来解决订单排序问题的。两个跨界点是随机选择的，并且它们之间的部分是从第一批复制到后代的。从第二父母的第二个交叉点开始，按照在第二父母中出现的顺序复制到后代中，避免了重复。以相同的方式创建了第二个后代，扭转了父母的角色。步骤如图 4 和 5 所示。

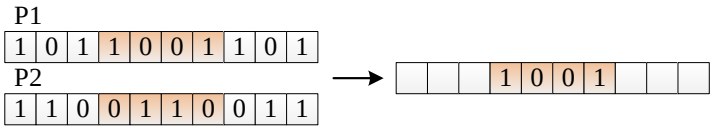

Fig. 4 – Crossover operator

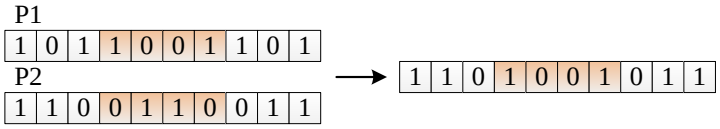

Fig. 5 – Crossover operator

(5) Mutation operator

Invert mutation: This operator works by randomly selecting two positions in the string and reversing the order in which the values appear between those positions (Fig. 6).

（5）变异算子

反转突变：此运算符的工作原理是随机选择两个字符串中的位置并扭转这些位置之间的值的显示的顺序（图 6）。

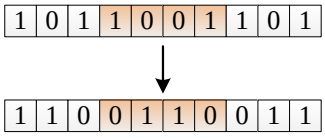

Fig. 6 – Mutation operator

In this context, we propose a fuzzy logic rule according to the chromosome fitness value and the population average fitness value variation. F is the fitness value of current chromosome. $\overline{F_r}$ is the average fitness value of chromosomes of generation r's population. F_{max} is the fitness value of the best chromosome in current population. F_{min} is the fitness value of the worst chromosome in current population. The output parameter is the mutation probability, and the input parameters are shown in table 2.

本文提出一种根据染色体适应度值及种群平均适应度值调节变异（mutation）概率的模糊逻辑规则。F 是当前染色体的适应度值。$\overline{F_r}$ 是在当前人口的染色体适应度的平均值。F_{max} 是当前人口中最好染色体的适应度值。F_{min} 是当前人口中最坏染色体的适应度值。输出的参数是变异的概率，输入的参数如表 2 所示。

Table 2

Input parameters of fuzzy logic module

Input parameter	Parameter explanation
$\Delta\overline{F}$	$\Delta\overline{F}=\frac{\left(\overline{F_r}-\overline{F_{r-1}}\right)}{\overline{F_{r-1}}}$, $\Delta\overline{F}\in[0,1]$, $r>1$
α	$\alpha=\frac{\left(F_{\max}-F\right)}{\left(F_{\max}-F_{\min}\right)}$, $\alpha\in[0,1]$

There are nine sematic values in the fuzzy logic module, which ES means extremely small, VS means very small, S means small, RS means relatively small, M means medium, RL means relatively lager, L means lager, VL means very lager and EL means extremely lager. The triangle membership function is used in this paper. According to the sematic value and triangle membership function, we can get the graphic of membership function as shown in Fig. 7.

在模糊逻辑模块有 9 个语义值,ES 意味着极其微小,VS 意味着非常小,S 意味着小,RS 手段相对较小,M 意味着中间,RL 意味着相对大,L 意味着大,六世意味着非常大和 EL 意味着极其大。本文采用三角形的隶属函数。根据语义值和三角形隶属函数，我们可以得到如图 7 所示的隶属函数的图形。

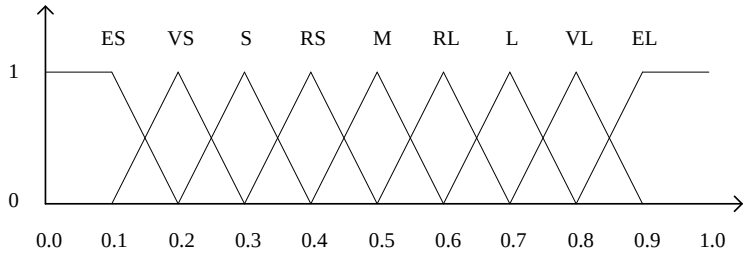

Fig. 7 – The membership function graphic of input and output parameter

According to the fuzzy logic and the membership, we can get the fuzzy logic rules as shown in table 3.

根据模糊逻辑与会员资格，我们可以得到模糊逻辑规则，如表 3 所示。

Table 3

The fuzzy logic rules of mutation probability

γ / $\Delta\overline{F}(t)$	ES	VS	S	RS	M	RL	L	VL	EL
ES	M	RL	RL	L	L	VL	VL	EL	EL
VS	RS	M	RL	RL	L	L	VL	VL	EL
S	RS	RS	M	RL	RL	L	L	VL	VL
RS	S	RS	RS	M	RL	RL	L	L	VL
M	S	S	RS	RS	M	RL	RL	L	L
RL	VS	S	S	RS	RS	M	RL	RL	L
L	VS	VS	S	S	RS	RS	M	RL	RL
VL	ES	VS	VS	S	S	RS	RS	M	RL
EL	ES	ES	VS	VS	S	S	RS	RS	M

RESULTS

An empirical study of an agricultural machinery association in recent five years schedule in Hebei province in China is illustrated. The situations of this asscociation is as follows: there are five agricultural machinery resource centers, and there are 6-10 large-size, medium-size and small-size harvesters in each resource center. There are 9 farmlands (131 thousand mu)in 2010 and 13 farmlands (164 thousand mu)in 2014. The time peirod for harvesting is twelve days. The cost for harvesting is recorded according to the actual values. We compare the actual costs with the optimized costs in recent five years, and the results are shown in Table 4.

结果

结合河北省某大型农机组织近 5 年的收割作业，开展模型的试验和应用。实证分析的基本情况为：该农机组织下设 5 个农机点，每个农机点拥有 6~10 部大、中、小型收割农机；收割作业覆盖的农田作业点有从 2010 年的 9 块增长到 2014 年的 13 块，覆盖面积从 2010 年的 13.1 万亩增长到 2014 年的 16.4 万亩。要求在 12 天之前，将所有农田收割完毕。为了便于对比，每亩单位收割成本等相关费用按当年实际数值计算。将近五年的收割成本与优化后的结果进行对比，对比结果见表 4。

Table 4

The empirical study results

Year	Area (mu)	Costs		Cost reduction (%)
		actual costs	optimized costs	
2010	13.1	1420.5	1253.7	11.74
2011	14.7	1524.4	1337.7	12.25
2012	15.6	1588.1	1405.6	11.49
2013	15.9	1578.8	1386.5	12.18
2014	16.4	1676.8	1451.4	13.44
Average	15.14	1557.7	1366.9	12.22

CONCLUSIONS

This paper is an attempt to schedule the agricultural machinery for the machinery resource centers under multi-farmland, multi-type machinery situation with time window in order to maximize efficiency of resource utilization. A fuzzy logic genetic algorithm is presented to solve this model. An empirical study of an agricultural machinery association in Hebei province in China is illustrated and the results show that the models and the scheduling algorithm proposed in this study can improve agricultural utilization of the farm machinery organizations and reduce the cost of agricultural machinery cost as high as 1980 thousand RMB per year, which accounts for 12.22 percents.

ACKNOWLEDGEMENT

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结论

本文建立了考虑多农机点、多农田作业点、多机型及时间窗约束的混合农机资源调度数学规划模型，并提出一种改进的模糊遗传算法求解混合农机资源调度模型。并对河北省某农机协会进行了实证研究，从实证分析结果能够看出，本文所提出的模型具有较好的可解性，且算法具有较好的计算结果和计算效率。本文设计的农机调度模型，平均每年能够为该农机组织节约资金额度达 190.8 万元，节约资金比例达 12.22%。因此，本文的模型和方法具有非常高的应用推广价值。

致谢

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trecut). Se va utiliza nomenclatura standard iar abrevierile trebuiesc evitate. Nu se vor utiliza citări de lucrări în "rezumat" (font: 9 pt., titlu - *bold italic*; textul rezumatului - *italic*).

Cuvinte cheie: ca urmare a rezumatului, între 3 şi 10 cuvinte cheie trebuiesc listate, aceste oferind referinţe de indexare (font: 9 pt., **bold italic** – titlul şi 9 pt., *italic* - textul).

Trebuie adăugată o listă de abrevieri specifice. În general, aceste abrevieri se folosesc atunci când termenul folosit este foarte lung şi des întâlnit în lucrare. Fiecare abreviere ar trebui introdusă în paranteză pentru prima dată când este folosită în text. Doar unităţi din SI trebuiesc folosite. Autorii trebuie să folosească prezentarea Solidus (mg/ml). Abrevierile standard (ca ATP sau ADN) nu trebuiesc definite.

INTRODUCEREA trebuie să ofere o expunere clară a problemei, esenţa relevantă a subiectului şi abordarea propusă sau soluţia. Aceasta trebuie să poată fi înţeleasă de către colegi din diferite domenii ştiinţifice.

MATERIALE ŞI METODE: trebuie să fie suficient de complete pentru a permite experimentelor să fie reproduse. Totuşi, numai metodele cu adevărat noi trebuie descrise în detaliu; metodele publicate anterior trebuie citate; modificările importante ale metodelor publicate trebuie menţionate pe scurt. Scrieţi cu majuscule denumirile comerciale şi includeţi numele şi adresa producătorilor. Subcapitolele trebuie utilizate. Metodele utilizate în general, nu trebuie descrise în detaliu.

REZULTATELE trebuie prezentate cu claritate şi precizie. Acestea trebuie scrise la timpul trecut, atunci când descriu constatările în experimentele autorilor. Rezultatele trebuie să fie explicite, dar în mare măsură, fără a se face referire la literatura de specialitate. Discuţiile, speculaţiile şi interpretarea detaliată a datelor nu trebuie să fie incluse în rezultate, ci trebuie incluse în capitolul Concluzii. Subcapitolele trebuie utilizate.

CONCLUZIILE trebuie să interpreteze constatările în ceea ce priveşte rezultatele obţinute în această lucrare şi în studiile anterioare pe această temă. Concluziile generale vor fi prezentate în câteva fraze la sfârşitul lucrării. Rezultatele şi discuţiile pot include subpoziţii, şi atunci când este cazul, ambele secţiuni pot fi combinate.

Mulţumirile către oameni, cei care au acordat burse, fonduri, etc., trebuie să fie scurte (dacă este necesar).

Tabelele trebuie menţinute la un nivel minim şi să fie proiectate pentru a fi cât mai simple posibil. Tabelele vor fi scrise la un rând, inclusiv titlurile şi notele de subsol. Fiecare tabel trebuie scris pe întreaga lăţime a paginii, între textul în care se face trimitere; coloanele sunt eliminate - o singură coloană (vezi ataşat modelul). Tabelele trebuie să fie auto-explicative, fără referire la text. Detaliile cu privire la metodele utilizate în experimente trebuie să fie, de preferinţă, descrise în legendă şi nu în text. Aceleaşi date nu trebuie prezentate atât în tabel cât şi sub formă grafică (decât dacă este absolut necesar) sau repetate în text. Titlul tabelului va fi scris centrat, bold (în engleză) şi bold italic (în limba maternă), separate de un slash (/). În tabel, fiecare rând va fi scris în limba engleză (9 pt., normal) / limba maternă (9 pt., italic). Tabelul şi numărul acestuia se scrie aliniat la dreapta, bold - în limba engleză şi bold italic în limba maternă, despărţite de un slash (/).

Figure legends should be typed in numerical order. Graphics should be prepared using applications capable of generating high resolution JPEG before to introducing in the Microsoft Word manuscript file (Insert - From File - ...jpeg). Use Arabic numerals to designate figures and upper case letters for their parts (Figure 1). Begin each legend with a title and include sufficient description so that the figure is understandable without reading the text of the manuscript. Information given in legends should not be repeated in the text. Each figure must be inserted on the entire width of the page, into the text where reference is made, single columns (see attached sample). Leave a space between the figure and the text of figure, size: 3 pt., figure number is written in **Arial bold**, size: 8 pt., followed by what represent the figure or graph, written with Arial, regular, 8 pt. Left to write in English (regular), followed by a separating slash (/) and text in native language (*Arial italic*). Eg:

Fig 1 - Test stand / *Stand de testare* (size: 8 pt.)

The figures should be "*In line with text*" - Center, not "*Square*"; "*Tight*"; "*Behind text*" or "*In front of text*" (from "*Format picture*" - right mouse button on picture and then "*Layout*".

Figurile trebuie scrise în ordine numerică. Grafica trebuie realizată utilizând aplicaţii capabile să genereze JPEG de înaltă rezoluţie, înainte de a introduce în dosarul manuscris Microsoft Word (Insert - From File - ... JPEG). Folosiţi cifre arabe, pentru a desemna cifre şi litere majuscule pentru părţile lor (Figura 1). Începeţi fiecare legendă cu un titlu care să includă o descriere suficientă, astfel încât figura să poată fi înţeleasă, fără citirea textului din manuscris. Informaţiile furnizate în legende, nu trebuie repetate în text. Fiecare figură trebuie introdusă pe întreaga lăţime a paginii, în text, acolo unde se face referire, o singură coloană (vezi ataşat eşantion), centrat. Lăsaţi un spaţiu între figură şi textul figurii, mărimea: 3 pt.; numărul figurii va fi scris cu bold, 8 pct., centrat, urmat de ceea ce reprezintă figura sau graficul, scris cu 8 pt., normal. Prima dată se scrie textul în limba engleză (normal), urmat de un slash (/) apoi textul în limba maternă (italic).

Exemplu:

Fig. 1 - Test stand / *Stand de testare* (mărimea: 8 pt.)

Figurile introduse trebuie să fie "*In line with text*" - Center, nu "*Square*"; "*Tight*"; "*Behind text*" or "*In front of text*" (din "*Format picture*" - butonul dreapta mouse pe figură şi apoi "*Layout*").

Mathematics

Authors must provide instructions on how symbols and equations should be set. Equations should be numbered sequentially in the right-hand side and in parenthesis. They should be referred to in the text as Equation (4) or Eg. (4). Each equation must be written on the entire width of the page, into the text where reference is made, the columns are broken (see attached sample).

Formulele matematice, ecuaţiile: autorii trebuie să furnizeze instrucţiuni privind modul de simbolizare şi de ecuaţii stabilite şi utilizate. Ecuaţiile trebuie numerotate secvenţial, în partea dreaptă şi în paranteze. Ele trebuie menţionate în text ca ecuaţia (4) sau Ex. (4). Fiecare ecuaţie trebuie scrisă pe întreaga lăţime a paginii, în text, acolo unde se face referire, o singură coloană (vezi ataşat model).

REFERENCES: are made in the text; a reference identified by [1], [2], ... [n] is written in the order that was placed at the end of the work - alphabetically.

Example:

[1], [2], [3], ..., [n]

References should be listed at the end of the paper in alphabetical order. Articles in preparation or articles submitted for publication, unpublished observations, personal communications etc. should not be included in the reference list but should only be mentioned in the article text (e.g., A. Danciu, University of Bucharest, Romania, personal communication). Authors are fully responsible for the accuracy of the references.

REFERINŢELE: se fac în text; o referinţă identificată prin intermediul [1], [2], ...[n], se scrie în ordinea în care a fost trecută la sfârşitul lucrării - ordine alfabetică.

Exemplu:

[1], [2], [3], ..., [n]

Referinţele trebuie prezentate la sfârşitul lucrării în ordine alfabetică. Articole în curs de pregătire sau articole trimise spre publicare, observaţiile nepublicate, comunicările cu caracter personal, etc, nu trebuie incluse în lista de referinţă, dar pot fi menţionate în textul lucrării (exemplu, A. Danciu, Universitatea din Bucureşti, România, comunicare personală). Autorii sunt pe deplin responsabil pentru exactitatea referinţelor.

Examples:

Journal / Magazine:

[1]. Nicolescu M.A., (2007) - *Relevant characteristics of alternative liquid fuels aimed at Diesel engines exploitation in polycarburation duty*. INMATEH - Agricultural Engineering, vol. 27, no. 1/2009, ISSN 1583-1019, pg. 50-55;

[2]. Pirna I, Nicolescu M., Marin M., Voicea I., (2009) - *Alternative supply of agricultural tractors with raw oils*. INMATEH - Agricultural Engineering, vol. 29, no. 3/2009, ISSN 1583-1019, pg. 89-92.

Conference / Symposium:

[1]. Bungescu S, Stahli W, Biriş S, Vlăduţ V, Imbrea F, Petroman C., (2009) - *Cosmos programm used for the strength calculus of the nozzles from the sprayers,* Proceedings of the 35 International Symposium on Agricultural Engineering *"Actual Tasks on Agricultural Engineering",* Opatija - Croaţia, ISSN 1333-2651, pg. 177÷184.

Book:

[1]. Vlăduţ V., (2009) - *Studiul procesului de treier în aparatul cu flux axial*, Editura "Terra Nostra", ISBN 973-1888-26-8, Iasi - Romania.

Exemple:

Jurnal / Revistă

[1]. Nicolescu M.A., (2007) - *Proprietăţile relevante ale combustibililor lichizi alternativi vizaţi pentru exploatarea motoarelor Diesel în regim policarburat*, INMATEH - Inginerie Agricolă, vol. 27, nr. 1 / 2009, ISSN 1583-1019, pg. 50-55;

[2]. Pirna I, Nicolescu M., Marin M., Voicea I., (2009) - *Alimentarea alternativă a tractoarelor agricole cu uleiuri vegetale crude,* INMATEH - Inginerie Agricolă, vol. 29, nr. 3 / 2009, ISSN 1583-1019, pg. 89-92.

Conferinţă / Simpozion

[1]. Bungescu S, Stahli W, Biriş S, Vlăduţ V, Imbrea F, Petroman C., (2009) - *Cosmos programm used for the strength calculus of the nozzles from the sprayers,* Proceedings of the 35 International Symposium on Agricultural Engineering *"Actual Tasks on Agricultural Engineering",* Opatija - Croaţia, ISSN 1333-2651, pag. 177÷184.

Carte

[1]. Vlăduţ V., (2009) - *Studiul procesului de treier în aparatul cu flux axial*, Editura "Terra Nostra", ISBN 973-1888-26-8, Iaşi - România.

Book Chapter:
[1]. Vlăduţ V., (2009) - Consideraţii şi ipoteze privind modelarea unui proces de treier şi separare. In: *Studiul procesului de treier în aparatul cu flux axial*, Editura "Terra Nostra", ISBN 973-1888-26-8, pg. 61-69, Iasi - Romania.
Dissertation / Thesis:
[1]. Constantinescu A., (2010) - *Optimizarea agregatelor formate din tractoare de putere mare cu maşini agricole pentru pregătirea terenului în vederea însămânţării*. PhD dissertation, University of Transylvania Braşov, Romania.

Units, Abbreviations, Acronyms

- Units should be metric, generally SI, and expressed in standard abbreviated form.
- Acronyms may be acceptable, but must be defined at first usage.

2. SHORT COMMUNICATIONS

Short Communications are limited to a maximum of two figures and one table. They should present a complete study that is more limited in scope than is found in full-length papers. The items of manuscript preparation listed above apply to Short Communications with the following differences: (1) Abstracts are limited to 100 words; (2) instead of a separate Materials and Methods section, experimental procedures may be incorporated into Figure Legends and Table footnotes; (3) Results and Conclusions should be combined into a single section.

3. REVIEWS

Summaries, reviews and perspectives covering topics of current interest in the field, are encouraged and accepted for publication. Reviews should be concise (max. 8 pages). All the other conditions are similar with regular articles.

Capitol din carte
[1]. Vlăduţ V., (2009) - Consideraţii şi ipoteze privind modelarea unui proces de treier şi separare. În: *Studiul procesului de treier în aparatul cu flux axial*, Editura "Terra Nostra", ISBN 973-1888-26-8, pg. 61-69, Iaşi - România.
Disertaţii / Teze de doctorat
[1]. Constantinescu A., (2010) - *Optimizarea agregatelor formate din tractoare de putere mare cu maşini agricole pentru pregătirea terenului în vederea însămânţării*. Teză de doctorat, Universitatea Transilvania Braşov, România.

Unităţi, Abrevieri, Acronime

- unităţile metrice trebuie să fie, în general, SI, şi exprimate în formă prescurtată standard;
- acronimele pot fi acceptate, dar trebuie să fie definite la prima utilizare.

2. COMUNICĂRILE SCURTE

Comunicările scurte sunt limitate la maxim 2 figuri şi un tabel. Acestea trebuie să prezinte un studiu complet, care este mai limitat decât în cazul articolelor normale (de dimensiuni mai mari). Elementele de pregătire a articolelor normale (manuscriselor) enumerate mai sus se aplică şi la comunicările scurte, cu următoarele diferenţe: (1) Rezumatul este limitat la 100 cuvinte; (2) capitolele Materiale şi Metode, Procedurile experimentale pot fi scrise împreună, încorporând figurile şi tabelele; (3) Rezultatele şi Concluziile pot fi combinate într-o singură secţiune.

3. SINTEZELE

Sintezele, comentariile şi perspectivele acoperind subiecte de interes din domeniu sunt încurajate şi acceptate spre publicare. Sintezele trebuie să fie concise şi nu mai mari 8 pagini. Toate celelalte condiţii sunt similare cu cele de la articolele normale (obişnuite), enumerate mai sus.

Edited by: INMA Bucharest
6 Ion Ionescu de la Brad Blvd., sect. 1, Bucharest, ROMANIA
Tel: +4021.269.32.60; Fax: +4021.269.32.73
http://www.inmateh.eu