

ADAPTABILITY TEST OF DRY FARMING TILLAGE TECHNIQUE IN NORTHERN CHINA AND STUDY OF KEY TECHNIQUES

中国北方旱作农业耕作技术适应性试验与关键技术研究

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ABSTRACT

Based on the problem of insufficient coordination of integrated machinery and technique configuration in the exploration of dry farming regions, a method of two-period comparative test was carried out in Shanxi Province, China. Zones of the effects of different treatments on straw coverage, soil moisture, emergence rate, seedling condition, yield, and benefit were monitored and analysed. The result was that the coverage before sowing decreased to below 55% after surface harrowing or rotary tillage in autumn by using dry farming technology in Northern China. The average number of emerging seedlings through surface tillage was larger than that without surface tillage by 1.7 plants/5 m; emergency rate was increased by 8.37%, and the increase in amplitude of grain yield reached 28% compared with that of traditional farming. Moreover, the input–output ratio reached 1:4.41. The experiments showed that the net income could reach RMB 1,251–1,401/hm², and compared with traditional farming, operating cost was lowered by 23.1%–28.8%, and benefit was elevated by 48.8% with prominent cost saving and benefit increase. The study results will facilitate the improvement of water-saving and production-increasing technologies in Northern China and play a critical role in the development of agricultural cultivation and steady growth of agricultural output in this region.

摘要

基于旱作区域的探索目前存在机艺融合配置不够协调的问题，本文在中国山西省进行了两期对比试验，在每种处理方法中监测和分析了不同的处理对秸秆覆盖率、土壤水分、出苗率、苗情和产量及效益的影响。试验结果是：利用北方旱作农机耕作技术，秋季浅耙或浅旋作业后使播前覆盖率降到 55% 以下；经表土耕作的出苗数比无表土耕作的平均数多 1.7 株/5m，出苗率提高 8.37%，粮食产量相比传统耕作增幅达 28%；投入产出比达到 1:4.41；试验表明纯收入可达 1251~1401 元/hm²，和传统作业比较，作业成本降低 23.1%~28.8%，效益提高 48.8%，节本增效尤为显著。本文研究结果将有力推动中国北方地区旱地节水增产技术的改进，进而对这一区域农业耕种发展和农产品产量稳定增长起到关键作用。

INTRODUCTION

Optimal development of dry land potential, scientific utilization of rain and heat resources, nutrient conversion of biological resources, and combined action on ecological environment are always the research focus of agricultural sustainable development worldwide. Since the 1930s, various countries have been exploring advanced technologies and effective patterns of agricultural production on dry lands and seeking for critical technologies, which improve the ecological environment and strengthen land productivity. The north of Kunlun Mountains, Qinling Mountains, and Huaihe River in China are mostly arid, semiarid, semi-humid, and drought-prone regions, including 966 counties and prefecture-level cities in 17 provinces, cities, and districts such as Inner Mongolia, Shanxi, and Shaanxi (Shangyu et al., 2019). Most of these regions have annual precipitation of 300–500 mm, where the gross amount of water resources accounts for less than 20% across China, and cultivated lands are averagely 5,580 m³/hm² in area. The land area in dry farming regions in Northern China occupies 56.0% throughout China, and the cultivated area is approximately 50,451,000 hm², accounting for 55.4% of the total cultivated land area in China (Yanqing and Bo, 2019). In recent years, the agricultural research focus in Northern China has always been on expansion and extension

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of irrigation techniques, whereas the improvement of agricultural production-increasing techniques in dry farming is relatively ignored. In comparison with irrigation farming, the water-use efficiency and yield of dry farming can be more easily affected by climate changes (Yi *et al.*, 2010, Shuang *et al.*, 2015). In arid and semi-arid regions, such as America and Australia, extensive attention has been paid to the improvement of dry farming tillage techniques (Andrew *et al.*, 2016). Therefore, this problem should become a focus in Northern China.

The key to dry farming tillage technique lies in “surface mulching, minimum and no-tillage, and combined operation” (Tiago *et al.*, 2018), where water storage, preservation of soil moisture, and soil fertilization are achieved by centring on “surface mulching, minimal tillage, and no-tillage” and using “combined operation” as the means (Neal *et al.*, 2017). The key technique of minimal tillage is sub-soiling while the soil layer is not ploughed (Yinzhu *et al.*, 2017). Hence, this technique has good water storage and moisture preservation effects. No-tillage (hard stubble) sowing is a straw stubble mulched ground and stubble sowing technique (Yan *et al.*, 2018). Under the technical requirements, tillage adaptability problems still exist in dry farming regions of Northern China (Meng *et al.*, 2011), which are manifested by the following: emergence and preservation of seedlings are difficult because of thick soil mulch; applying farmyard manures is difficult because soil is not ploughed in tillage, and irrigation is not good for water-saving and high crop yield. In recent years, our research group implemented adaptability test and key techniques for dry farming tillage in Pingding County and Tunliu County in Northern China in two periods. The study results show that increasing surface tillage and reducing surface mulching rate can remarkably solve the above-mentioned critical problems.

The theory of integrated machinery and technique configuration are combined, and Pingding County and Tunliu County test sites in China were used as examples. A direct injection-type rainfall simulator was used to perform five different tillage treatments in the test plots and investigate their effects on runoff and infiltration. Through two-period tests, the causes for low production-increasing amplitude in dry farming are found out, and the paths to increase crop yield and economic benefits are sought through dry farming tillage test and studying of key techniques in the second period.

MATERIALS AND METHODS

Profile of the study area

The first-period test was implemented in Pingding County, Shanxi Province, China, which was located at northern latitude of 37°39'30"–38°07'30" with altitude of 800–1,000 m, low temperature (annual average temperature, 10.9°C), annual frost-free season of 210 days, annual average precipitation of 508.6 mm, annual evaporation capacity of 1,202 mm and 7–15 days with above grade 6 wind in spring, and severe spring drought. The cropping system was one-season corn plantation each year. The main test site for dry farming corn tillage was 3.3 hm² in area. Corn was planted in successive years, and the demonstration area was 200 hm².

The second-period dry farming tillage test was set in Tunliu County, Shanxi Province, China. As a semi-arid region, Tunliu County had annual frost-free season of 160 days, annual precipitation of 540 mm, annual evaporation capacity of 1,710.9 mm, annual average air temperature of 10°C, and annual sunshine duration of 2,504.1 h. The plantation system was one-season corn plantation each year, and this county had the same natural climatic characteristics as Pingding County.

Test materials

A 4JQ-150-type straw shredding and returning machine produced in Zhaoxian County in Hebei Province, 1S-3-type subsoiler produced by Shanxi rotary tiller plant (Fig. 1a), 2BMF-4-type no-tillage fertilizer-seeder (disk opener; Fig. 1b) produced in Xinjiang County, Shanxi Province, and Dongfanghong SK600G tractor (power machine) were used in the first-period test.



a) 1S-3-type subsoiler



b) 2BMF-4-type no-tillage fertilizer-seeder

Fig. 1 - Materials of the first-period test

The 4JQ-150-type straw shredding and returning machine produced in Shijiazhuang, Hebei Province, was used in the second-period test. A 1GQN-200-type rotary tiller produced by Shanxi rotary tiller plant was used for surface rotary tillage (Fig.2a). A 2BJY-3-type hard stubble planter produced in Xinjiang County, Shanxi Province, was used for seed sowing (Fig.2b), and the Dongfanghong SK600G tractor was used as the power machine.

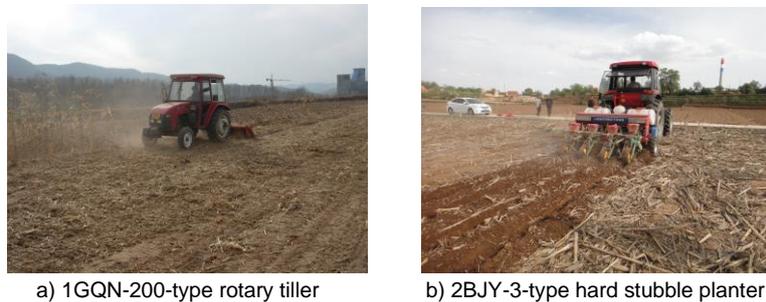


Fig. 2 - Materials of the second-period test

Test design

Five treatments were designed in the first-period test; each treatment was repeated three times. Fifteen plots were planned, and the area of each plot was 0.22 hm². The treatments were as follows: no-tillage with straw shredding mulch, no-tillage with complete straw overwhelming mulch, no-tillage with whole maize straw cover, sub-soiling with straw crushing mulch, and traditional mouldboard plough.

The process of this test was as follows: straw treatment after harvest in autumn no-tillage or sub-soiling fallow in winter no-tillage plus fertilization and seed sowing-field management (thinning, topdressing, and weeding) (Changmin *et al.*, 2013).

The second-period test site for dry farming corn tillage in Northern China was 3.3 hm² in area. Corn was planted in successive years, and the demonstration area was 33.3 hm². On the basis of the real cropping pattern in Tunliu County, nine tests were designed, where five treatments were used (each treatment was repeated three times) to explore key technical problems in dry farming tillage in Northern China, each treatment area was 0.33 hm². The treatments were as follows: deep ploughing after straws were taken out of field (abbreviated as traditional tillage); crushing and returning to field, no-tillage, and direct sowing in the following year (abbreviated as straw crushing plus no-tillage); surface harrowing after crushing and returning to field (abbreviated as straw crushing plus surface harrowing); surface rotary tillage after crushing and returning to field (abbreviated as straw crushing plus surface rotary tillage); and surface harrowing after crushing and returning to field and surface rotary tillage and sowing in the following year (abbreviated as straw crushing plus harrowing and rotary tillage). The preceding crop of the test plot was corn, and the average yield in the first 3 years was 6,075 kg/hm². The seeds were all Tunliu No. 1 corn in the tests, and manures were uniformly phosphorus nitrate and fertilizers for corn. The application amount of seed manure was 360 kg/hm². Nitrogen phosphorus potassium mixed fertilizer was used for topdressing with an application amount of 330 kg/hm². Seed sowing was implemented on April 15, and plant number per hm² was 65,250.

The process of this test was as follows: corn harvesting → straw crushing → no-tillage or sub-soiling for above 30 cm/surface rotary tillage or surface harrowing for 5–10 cm → fallow in winter → surface rotary tillage (when necessary) → fertilizer application and sowing → field management (thinning, weeding, and topdressing).

RESULTS

The first-period test results indicated that northern dry farming tillage had comprehensive benefits of soil and water conservation, soil fertilization, production and income increase, and Eco-environmental improvement, but the production-increasing amplitude was low because of the following reasons: poor sowing quality, straws covered on the surface were swept by wind into piles in the wintering period, which affected the operation of planters. As the latitude was partially northern, after the surface was covered by straws, ground temperature was low before sowing. Consequently, seed germination was slow, and seedlings emerged late. Furthermore, the probability of soil bacteria invasion could be easily increased.

Water and soil conservation test

The direct injection-type rainfall simulator was used to perform five different tillage treatments in the test plot and investigate their effects on runoff and infiltration. The results showed that under artificial rainfall simulation (Fig.3) with intensity of 80 mm/h, runoff started appearing at 39 min in sub-soiling no-tillage treatment with coverage (percentage of straw mulching part in unit cultivated area) of 70%, and runoff started appearing at 33 min in the no-tillage treatment with coverage of 80%, lagging behind bare tillage by 29 min and 23 min, respectively. In 15 min since runoff started appearing in the no-tillage and sub-soiling plug tillage treatment of dry farming, the average runoff intensity was 0.11 mm/min, being 61% of runoff intensity (0.18 mm/min) in traditional tillage. In 30 min since runoff started appearing, the average runoff intensity was 0.21 mm/min, being 51.2% of runoff intensity (0.41 mm/min) in traditional tillage. At 21 h of rainfall simulation, soil moisture content and volume weight within 0–100 cm soil layer were measured. Rainfall infiltration amount and soil water retention capacity in traditional tillage treatment were 38.9 and 270.9 mm, respectively, whereas those in dry farming tillage were 57.2 and 301.20 mm, respectively, which were higher by 47% and 11.1%, respectively.



Fig. 3 - Pictures of direct injection-type rainfall simulator

Soil moisture content test before sowing

The water and soil conservation test was carried out to investigate the protective effect of dry farming tillage technique on water and soil in Northern China, and the soil moisture content test before sowing aimed to study water storage capacity of the technique. Soil samples were sampled from the test plots once in April every year with sampling depth of 0–20 cm. Five sampling points were collected from diagonal cross in each plot of 1 m² to achieve positioned sampling and dynamic study. First, 15 soil samples of the same mass in the same plot were blended as one analytical soil sample, and then five analytical soil samples were obtained from 15 test plots.

As shown in Fig.4, in comparison with traditional tillage, soil moisture contents under different forms of northern dry farming tillage were elevated to different degrees, where the increased amplitude under straw crushing plus sub-soiling was the maximum (by 1.51 percentages), indicating that moisture storage capacity of soil was strengthened.

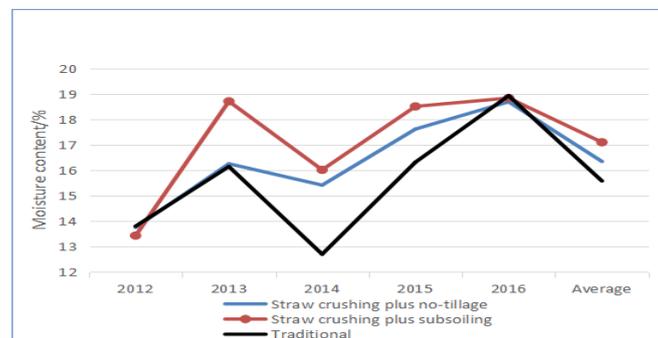


Fig. 4 - Comparison chart of soil moisture contents at 0–20 cm plough layer before sowing under different corn treatments

Soil fertility test

According to the treatments of soil samples, the annual average increase rate of organic content in soil under northern dry farming tillage was 0.046%, which was higher than that (0.0295) under traditional tillage by 35.74%, and the increase rates of hydrolysis nitrogen, rapidly available phosphorus, and rapidly available potassium were 6.55%, 16.4%, and 10.17%, respectively.

Crop yield test

Crop yield test was performed in the form of single threshing and single harvesting in the same plot. Five-year yields under different tillage patterns were shown in Table 1. In comparison with traditional tillage, northern dry farming tillage showed a certain production-increasing ability, where the yields under straw crushing plus no-tillage and straw crushing plus sub-soiling were increased by 14.94% and 13.90%, respectively.

Table 1

Yields under different corn treatments

Item	Treatment mode	Year					
		2012	2013	2014	2015	2016	Average
Yield/t·hm ²	Straw crushing plus no-tillage	3.091	8.032	5.090	5.753	4.416	5.2764
	Straw crushing plus sub-soiling	3.202	8.801	4.812	4.782	4.545	5.2284
	No-tillage with complete straw overwhelming mulch	3.188	8.032	5.419	4.354	4.851	5.1688
	Whole maize straw plus no-tillage	2.970	7.260	4.320	3.530		4.5200
	Traditional	2.602	6.665	4.416	4.903	4.366	4.5904

According to the analysis of the first-period dry farming tillage test, the second-period dry farming tillage test started with improving sowing quality. Improvements were made for the no-tillage planter, and combination-type depth-limiting round cutter plus inter-row weed pressing wheel-coordinated anti-blocking device was designed to improve the passing ability of the machine under high straw mulching rate. Different from the traditional tillage technique, northern dry farming tillage was demonstrated by two aspects (Teodor, 2014): crop straw stubble mulched the ground surface; no-tillage. These aspects were the primary factors influencing sowing quality and lowering ground temperature, and straw mulching was the main factor. This idea provided a path for the second-period dry farming tillage test.

Straw mulching rate

Steel tape was used to measure surface straw mulching rate. Within 10 m, every 10 cm was obtained as a measuring point (a total of 100 measuring points). The measuring tape was straightened to form 45° angle with the planting direction and randomly placed on the ground. The number of measuring points with straws beneath was counted, and the value was divided by 100 to obtain the mulching rate. The test was performed five times at left and right 45° angles, and the average value was obtained. The change results of the surface straw mulching rate before and after mechanical operation, such as surface rotary tillage and surface harrowing sowing, were presented in Table 2.

As shown in Table 2, the straw mulching rate decreased after different operations, and the declining process was divided into three phases: the straw mulching rate could be reduced by 23%–27% after surface harrowing or surface rotary tillage in autumn; during the fallow period in winter, the straw mulching rate could be lowered by 15%–20% because of air drying and decomposition of straws by natural environment; the straw mulching rate could be lowered by 22% or so before or after sowing. The test indicated that the before-sowing mulching rate decreased to below 55% by increasing surface harrowing or surface rotary tillage in autumn with natural treatment in winter. Consequently, no-tillage sowing and other planters could achieve smooth operation. After sowing, above 30% mulching rate could be kept, and water and soil conservation requirements could be achieved. Moreover, conditions were created for accelerating the recovery of ground temperature. Notably, rotary tillage in straw crushing, autumn harrowing, and spring rotary tillage was an operation designed to elevate ground temperature and guarantee sowing at the right time under special circumstances of low temperature and good soil moisture status in spring (Ling and Lixue, 2013).

Table 2

Surface straw mulching rates before and after different operations

Treatment	After harvesting (October)	Surface harrowing or surface rotary tillage (October)	Surface rotary tillage (April)	Before or after sowing (April)	
Straw crushing plus no-tillage	95.8	Winter fallow		79.3	45.6
Straw crushing plus surface harrowing	95.2	71.8	Winter fallow	55.8	32.3
Straw crushing plus surface rotary tillage	95.8	68.5	Winter fallow	53.5	30.9
Straw crushing, autumn harrowing plus spring rotary tillage	96.1	74.2	53.6	52.9	30.2
Traditional tillage	0			0	0

Soil moisture

The sampling and treatment methods in the soil moisture test were the same as that in the “soil moisture content test before sowing.” The soil moisture test suggested that the smaller the soil treated, the higher the mulching rate and the better the water storage and conservation effect of soil. The treatment results were shown in Table 3.

Table 3

Comparison table of soil moisture content tests

Treatment	2017-02-23				2018-03-20			
	5	10	20	30	5	10	20	30
Soil depth/cm	5	10	20	30	5	10	20	30
Straw crushing plus no-tillage	13.6	18.3	20.5	17.9	12.1	19.8	21.7	21.3
Straw crushing plus surface tillage	12.4	18.1	20.2	19.2	13.3	22.0	22.2	21.5
Straw crushing plus surface rotary tillage	10.3	19.7	19.1	17.3	13.8	23.2	22.6	21.3
Straw crushing, autumn harrowing plus spring rotary tillage	5.2	18.2	20.1	19.1	3.1	15.6	19.2	19.7
Traditional tillage	6.8	13.3	19.6	19.4	5.3	14.3	16.7	17.3

Emergence rate and seedling conditions

Emergence rate and seedling conditions were determined at 34 days after sowing. Seedlings within 5 m in one row of each segment were treated. A total of five segments were found, and the average emergence rate was obtained. A spot test of leaf number, plant height, and rootlet number of three seedlings was conducted. The average values of the above-mentioned factors in five segments were obtained to confirm seedling conditions, and the results were shown in Table 4. Averagely 22.0 plants/5 m were treated through the three treatment patterns with surface tillage. The number was higher than that without surface tillage by 1.7 plants/5 m. The seedling emergence rate was elevated by 8.37%. The growth conditions of seedlings were identical, and the seedling conditions under straw crushing plus surface rotary tillage were the best, indicating that surface tillage could not only improve sowing quality but also increase emergence rate and ensure complete and strong seedlings.

Determination results of seedling conditions

Table 4

Treatment	Seedling number	Leaf number	Elevation/cm	Rootlet number
Straw crushing plus no-tillage	20.3	7	33.1	10
Straw crushing plus surface harrowing	21.9	7	32.8	10
Straw crushing plus surface rotary tillage	22.3	7	35.1	10
Straw crushing, autumn harrowing plus spring rotary tillage	21.7	7	31.8	10
Traditional tillage	16.6	5	31.4	10

Yield and benefit

The test method of yield and benefit was identical with the “test of crop yield”. Taking the year of 2018 as an example, the yield and benefit were calculated when the market price of corn was 2 yuan/kg, the test results were shown in Table 5.

Table 5

Input–output test results under different treatments

Treatment	Input/yuan-hm ²					Output		Input–output ratio	Net income /t-hm ²
	Total	Seed	Fertilizer	Pesticide	Operation	Yield/t-h m ²	Output value/yuan-hm ²		
Straw crushing plus no-tillage	4,020	360	1,800	300	1,560	8.871	17,742	1:4.41	13,722
Straw crushing plus surface harrowing	4,320	360	1,800	300	1,860	8.8695	17,739	1:4.11	13,419
Straw crushing plus surface rotary tillage	4,320	360	1,800	300	1,860	9.185	18,370	1:4.25	14,050
Straw crushing, autumn harrowing plus spring rotary tillage	4,470	360	1,800	300	2,010	9.684	19,368	1:4.33	14,898
Traditional tillage	4,770	360	1,800		2,610	7.5705	15,141	1:3.17	10,671

In the northern dry farming tillage plus surface tillage, crop yield was additionally elevated, where the yield under straw crushing and spring harrowing plus autumn rotary tillage pattern was the highest, reaching 9.684 t/hm², which was higher than that (7.5705 t/hm²) under the traditional tillage by 2.1135 t; therefore, the increase in amplitude reached 28%, exceeding 14.94% of that in Pingding test plot (Table 5). The yield under straw crushing plus surface harrowing pattern was the lowest, being 8.8695 t/hm², which was higher than that (7.5705 t/hm²) under traditional tillage pattern by 1.299 t; therefore, the increase amplitude was 17.1%, exceeding 13.9% of that in the Pingding test plot. The input–output ratio reached 1:4.41, which was increased by a large margin in comparison with that (1:3.17) under traditional tillage pattern. Through agricultural process improvement in dry farming tillage, mechanized operation techniques were matched, thereby achieving full machine-technique integration (10). Although the mechanized operation cost was enlarged by 150–300 yuan, as the yield was increased by 0.7755 t/hm², being equivalent to income increase by 1,551 yuan/hm², after the added operating cost was deducted, the net income was 1,251–1,401 yuan/hm². In comparison with the traditional operation, the operating cost was lowered by 23.1%–28.8%, and the benefit was increased by 48.8% with remarkable cost-saving and benefit increase effects (Fig.5).

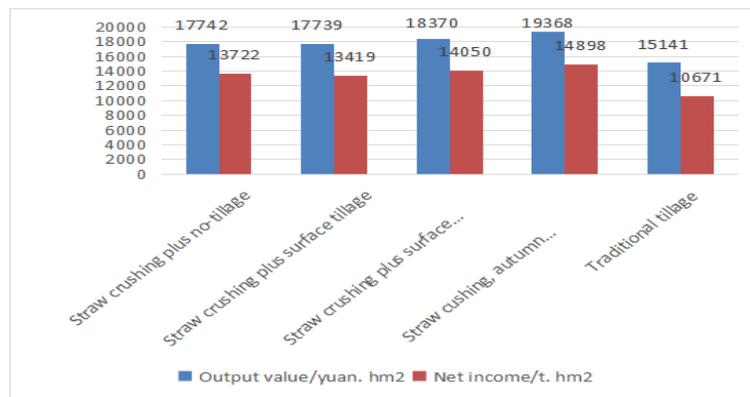


Fig. 5 - Income increase under different treatments

CONCLUSIONS

The technique was verified through two-period comparative tests in Shanxi Province, China, to confirm that northern dry farming tillage technique could boost efficient agricultural development in dry farming regions. Moreover, the two-period test data suggested that keeping a certain straw mulching, the northern dry farming tillage technique appropriately added surface tillage, which could elevate crop yield and increase farmer's income. The concrete conclusions were as follows:

1. Without soil tilling, the northern dry farming tillage technique uses crop straw stubble mulching to strengthen water-retaining and holding capacity of soil. Thus, the full advantages of autumn rains are obtained in spring. Spring drought is resisted in advance in winter, and the economic efficiency is evident.

2. The northern dry farming tillage technique can be popularized only after the adaptability test when applied to different regions. Under years of accumulation of straws and maximum straw quantity in good harvest year in northern latitude regions, surface harrowing or surface rotary tillage and other surface soil operations can be conducted to reduce straw mulching rate, accelerate straw decomposition in the fallow period, elevate before-sowing ground temperature, and strengthen dry farming technique. Although a certain operating cost will be added, in comparison with substantial production increase, the economic input–output ratio is continuously feasible.

3. The northern dry farming tillage technique, which consists of three elements—straw mulching, surface tillage and minimal tillage, and hard stubble sowing—creates good vegetation for bare field in the fallow period using organic resources of crops, and this technique can protect farmland surface soil from frequent erosion of dry and hot wind in winter and spring and radically solve straw burning problem with prominent ecological benefits.

4. The northern dry farming tillage technique has a positive promoting effect on elevating crop yield and increasing farmer's income. The popularization of this technique has three advantages: high reliability, high economic benefit, adaptable conditions. Therefore, active popularization and transformation of this technique have become a key technical measure used to lower cost, improve efficiency, and increase both yield and income in dry farming regions in Northern China.

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