A MECHANIZED TECHNIQUE OF ECOLOGICAL SOIL PLANTING FOR THE ANNUAL DOUBLE CROPPING OF WHEAT AND MAIZE WITH A FIVE-YEAR CYCLE
/
适合小麦玉米一年两熟五年一周期的机械化生态沃土种植技术研究

Ph.D. Guohai Zhang, Prof. Ruicheng Du, Prof. Ph.D. Peisong Diao, Prof. Ph.D. Duanyang Geng
School of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo / China
Tel: +86 533 2789896; Email: guohz@163.com

Abstract: *An ecological soil planting method was proposed for the annual double cropping of wheat and maize with a five-year cycle. This method is suitable for Huang-Huai-Hai Region and aims to address the problems of reduced crop yield and soil crust as a result of soil and water loss, deteriorated land fertility, and protective tillage in intensive cultivation. Moreover, the planting specifications of the annual double-cropping rotation patterns of wheat and maize were unified, and the key agricultural equipment was designed for full mechanization. Research results on the test demonstration base showed that the return of straw to the field and scientific fertilization can limit the emissions of harmful gas and the use of fertilizer. Furthermore, these steps can enhance ecological agricultural production. The return of straw to the field and suitable cultivation can increase the content of organic matters in soil, improve the aggregate structure, and enhance soil fertility. Finally, the implementation of the ecological fertile soil planting technique can overcome the disadvantages of intensive cultivation and protective tillage, thereby facilitating stable and high crop yield.*

Keywords: *Intensive cultivation; protective tillage; planting specification; Agricultural mechanization*

摘要: *提出了一种合适小麦玉米一年两熟的五年一周期的生态土壤种植方法。本方法适合黄淮海地区，目的是解决精耕细作存在的水土流失、土地肥力减退和保护性耕作导致的农作物减产、土壤板结等问题。统一了小麦玉米一年两熟种植模式的种植规格，设计了全程机械化的关键农业装备。通过在试验示范基地的研究表明：秸秆还田及科学施肥，能够减少有害气体的排放和化肥的使用量，实现生态化农业生产；秸秆还田及适量耕作，可以增加土壤有机质含量、改善土壤团粒结构，提高土地肥力；生态沃土种植技术的实施，可以克服精耕细作和保护性耕作的缺点，实现农作物的稳产高产。*

关键词: *精耕细作, 保护性耕作, 种植规格, 农业机械化*

INTRODUCTION

The population of China comprises 18.84% of the world population. However, its arable land constitutes only 8.7% of that of the world. As a result, the development pattern of high agricultural yield involves a gradual increase in labor input-intensive cultivation. Intensive cultivation is essentially for a comprehensive technological system of traditional agriculture. In line with this knowledge, a series of studies has been conducted on intensive cultivation technology and its development. The results indicate that although intensive cultivation improves crop yield and solves the employment problem, it also induces soil erosion, environmental degradation, and other problems [1], [3], [5-7], [12], [20]. This process can also significantly reduce the earthworm population[6-7], as well as affect organic matter content, enzyme activities, microbial quantity, the abundance of fungal mycelium, the functional diversity of microbes, the abundance of bacterial species, and other soil properties[3],[7]. The increase in cropping intensity eliminated the self-protection function and activity of soil. In addition, straw burning enhanced atmospheric pollution.

Strong black storms hit the western US and the former Soviet Union in the 20th century. Many experiments have been conducted on sandstorm treatment, and they confirmed that protective tillage is the most successful suppression method [10]. Research on this method

引言

中国人口数量为世界人口总数的 18.84%，而耕地面积只有世界耕地面积的 8.7%，因此逐渐形成了通过增加劳动力投入换取农业高产量的发展模式——精耕细作。精耕细作是对中国传统农业精华的一种概括，是传统农业的一个综合技术体系。围绕精耕细作技术及其发展进行了一系列的研究，结果表明精耕细作虽然提高了农产品的产量，解决了劳动力就业问题，但同时带来了水土流失、环境恶化等问题 [1], [3], [5-7], [12], [20]。精耕细作能大幅减少蚯蚓种群[6-7]，影响有机质含量、酶活性、微生物量、真菌菌丝体丰富度、微生物功能多样性、细菌物种丰富度等土壤性质[3],[7]。耕作强度增大使得土壤失去了自我保护功能，土壤慢慢失去活性，同时秸秆焚烧加重了大气污染。

美国西部和前苏联曾在二十世纪发生了巨大的黑色风暴，针对治理沙尘暴进行了大量的实验研究，证明保护性耕作方法是最成功的抑制方法[10]。保护性耕作研究主要集中在对土壤性质的影响[2], [11], [13-17], [21-24], 土壤

mainly focused on its influence on soil properties[2], [11], [13-17], [21-24], the composition of soil species [4], and the microbial quantity and fungi abundance in soil [19], [25]. Protective tillage can limit soil erosion and water loss [8], increase the contents of organic matters in soil, improve soil structure, control soil loss, reduce wind and water erosion, and shorten tillage times. In addition, straw residue cover can limit dust hazard. Thus, its implementation can prevent the loss of dust, water, and soil in farmlands. It can also store and preserve water, promote the productivity of fertilized land, save costs, increase efficiency, reduce emissions from straw burning and greenhouse gas, and enhance the sustainable development of agriculture. However, many researchers believe that simple protective tillage is not conducive to high yield given that the overuse of chemical fertilizers, pesticides, and other chemicals has generated ecological issues and problems with soil crust.

Based on a survey of the annual double-cropping patterns of wheat and maize in the Huang-Huai-Hai Region and on the advantages of intensive cultivation and protective tillage following years of field experiment research, a new method of ecological soil planting is proposed in the current study for these patterns. This mechanized ecological soil planting technique is investigated by determining the representative dry area, well irrigation area, and saline land. The results suggest that scientific and reasonable soil cultivation can enhance ecological agricultural production, soil structure, and the contents of organic matters in soil to ensure the stable and high yield of grain, as well as to realize the sustainable development of agriculture.

MATERIAL AND METHOD

Description of the Mechanized Ecological Soil Planting Technique

The so-called ecological soil planting technique guides scientific development. It focuses on the stable and sustainable development of agriculture in the long term, as well as on ecological agriculture construction and soil fertility cultivation. Crops are planted using ecological and mechanized techniques and methods. Furthermore, straw is treated scientifically to increase the contents of organic matters in soil, to improve soil structure, and to reduce the use of chemical fertilizers, pesticides, and other chemicals. Ultimately, it achieves the purpose of ecology, which is to facilitate high-quality, low-consumption, and high-efficiency agricultural production.

Key Techniques of Mechanized Ecological Soil Planting

Scientific Tillage Method

Tillage method is a general term for all techniques and measures that recirculate several crop systems in a region, including planting, soil tillage, fertilization, and weed control methods. The ecological soil planting technique is an establishment of the ecological soil tillage method, which combines tillage and protection with the ecological planting method. Agricultural machinery and agronomy are integrated as well.

Soil Tillage Method

The ecological soil tillage method with a five-year cycle (ploughing in the first year, digging the soil in the

物种组成的影响[4]、土壤微生物量和菌类丰富度的影响[19], [25] 等几个方面。保护性耕作，可以减少侵蚀和水土流失[8]，增加土壤有机质，改善土壤结构，控制水土流失，减少风蚀和水蚀，减少土壤耕作次数，秸秆残茬覆盖可以减轻粉尘危害。实施保护性耕作具有防治农田扬尘和水土流失、蓄水保墒、培肥地力、节本增效、减少秸秆焚烧和温室气体排放、促进农业可持续发展等作用，但许多人认为单纯的保护性耕作不利于高产，由于化肥、农药等化学物品的过度使用，带来了一系列生态和土壤板结等问题。

在对黄淮海地区小麦玉米一年两熟种植模式调研基础上，综合精耕细作和保护性耕作的优点，经过多年田间试验研究，提出了适合黄淮海地区小麦玉米一年两熟种植模式的一种新的生态型土壤耕作方法——机械化生态沃土种植技术。对机械化生态沃土种植技术进行了研究，选取具有代表性的旱作区、井灌区和盐碱地块，对该技术进行了实验研究，结果表明通过科学合理的土壤耕作，可以实现农业生产生态化，可以改善土壤结构，增加土壤有机质含量，从而保证粮食的稳产高产，实现农业的可持续发展。

材料与方法

机械化生态沃土种植技术的含义

所谓机械化生态沃土种植技术，是以科学发展观为指导，着眼于农业长期稳定可持续发展，将建立生态型农业和土地肥力培育作为两大重要目标，用生态型机械化技术和方法耕作，配合秸秆科学处理以不断增加土壤有机质含量、改善土壤结构，逐步减少化肥、农药等化学物质的使用，最终达到农业生产生态、优质、低耗、高效的目的。

机械化生态沃土种植关键技术

科学耕作方法

耕作方法是一个地区循环种植几种作物系统采取的全部农田技术措施的统称。它主要包括种植方法、土壤耕作方法、施肥和杂草防除方法等。生态沃土种植技术建立了耕作与保护并重的生态型土壤耕作方法、农机农艺融合的生态型种植方法。

土壤耕作方法

建立“一耕三四松，二五间隔停”的五年一周期生态

third and fourth years, and no ploughing or digging in the second and fifth years) was developed to emphasize both soil tillage and protection equally. Thus, the tillage and protective measures complement each other.

Ploughing in the first year: Ploughing can improve soil structure, the capacity of water storage and preservation, and crop root growth and nutrient absorption. It can also adjust nutrient distribution, loosen the organic matters accumulated on the soil surface, continuously improve the fertility of the tilth layer of soil, enhance the soil ecosystem, and promote the balance of the biological population in soil. Finally, it buries weed seeds, pathogen spores, and pest eggs deep into the soil to inhibit diseases and pests.

Digging deeply into the soil in the third and fourth years: This process mainly protects the soil surface and its dynamic configuration. Its main role is to break the plough pan to help the roots of crops adhere to the soil, to improve water storage and preservation capabilities, to enhance soil porosity, to improve air and water operation in soil, to generate conditions for the decomposition of organic matters by soil microorganisms, and to promote soil fertility and nutrient absorption.

No ploughing or digging in the second and fifth years: Over-tillage has many disadvantages, and the most serious is water and soil loss. No ploughing after tillage and complete digging is conducive to shortening the times of mechanized farming and to protecting the soil surface.

型土壤耕作方法，使土壤耕作与保护并重、耕作措施与保护措施相辅相成。

“一耕”是指在耕作周期第一年进行翻耕。翻耕可以改善土壤结构，增强蓄水保墒能力，利于作物根系发育和营养吸收；调整养分分布，将土壤表层积累的有机质翻入深层，持续提高耕层土壤肥力；改善土壤生态，利于土壤生物种群平衡，并将杂草种子、病菌孢子、害虫卵块等埋入深层，抑制病虫害发生。

“三四松”是指在耕作周期第三、四年间隔深松。采用间隔深松主要是考虑土壤表层保护和动力配置。深松的主要作用是打破犁底层，利于作物根系深扎，提高蓄水保墒能力，提高土壤孔隙度，改善土壤内部气、水运行状态，创造土壤微生物分解有机质的条件，利于土地肥力发挥和作物营养吸收。

“二五间隔停”是在耕作周期第二年和第五年既不耕也不松。过度耕作有很多弊端，最严重的是造成水土流失。在耕后的一年和完成全面深松后的一年不进行耕、松作业，有利于减少机器进地次数、保护土壤表层。

Planting Specification

The unification of planting specifications is the premise of the scientific design of mechanized agronomy. Planting specification mainly includes row width, line quantity and spacing, as well as the strip width and line spacing of deep digging. The parameters are agricultural machinery, agronomy, and irrigation methods. For convenient machine configuration, planting specifications must be unified, such as line spacing and row width. To adapt to the annual double-cropping patterns of wheat and maize in the well irrigation area of the Huang-Huai-Hai Region, a planting specification is designed as shown in Fig.1.

种植规格

统一种植规格是科学设计机械化农艺的前提，种植规格主要包括畦宽、行数、行距、苗带宽、深松行距等参数。这些参数既有农机的也有农艺的，甚至与灌溉方式紧密相关。为了便于机器配套，应当尽量统一，比如统一行距、统一畦宽等。为适应黄淮海井灌区小麦玉米一年两熟种植模式，设计了如图 1 所示的种植规格。

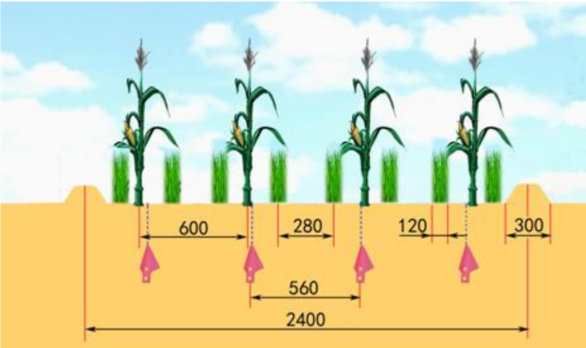


Fig. 1 - Planting Specification in the Well Irrigation Area (Unit: mm)

Key Agricultural Equipment

The mechanized ecological soil planting technique emphasizes the heavy integration of agricultural machinery and agronomy, enhances standardized planting procedures, and regards high efficiency, low consumption, and low investment as the goals of the system configuration and of machine operation. The tillage and planting requirements of this technique are presented in Table 1.

关键农业装备

机械化生态沃土种植技术，强调农机农艺深度融合，推行规格化种植，把高效、低耗、低投入作为机器系统配置和运行的目标。生态沃土种植技术的耕作及种植要求如表 1 所示。

Table 1

Requirements of the Mechanized Agronomic System

Item Name	Requirements of Agronomy
Ploughing depth (mm)	200～250
Digging depth (mm)	230～300
Wheat planting depth (mm)	30～50
Fertilization depth for wheat planting (mm)	80～100
Interval width between wheat seeds and fertilizer(mm)	50～60
Suppression strength for wheat sowing (N/cm^2)	20～30
Maize planting depth (mm)	30～40
Fertilization depth for maize sowing (mm)	100～120
Interval width between maize seeds and fertilizer (mm)	60～80
Suppression strength for maize sowing (N/cm2)	20～50
Cutting length of maize straw (mm)	<100

Given the annual double-cropping patterns of wheat and maize, the key agricultural equipment and techniques include:

小麦玉米一年两熟种植模式下，涉及的关键农业装备及关键技术主要有：

Fig. 2 - Sowing by Wheat Deep Digging and Fertilization Seeder and Seedlings

Wheat Seeder

The deep-digging wheat seeder performs six processes, namely, deep digging, rotary tilling, fertilizing, sowing, covering, and suppressing. Two rows of deep digging spades are staggered to prevent grass entangling and plugging effectively and to enhance the stability of deep digging [18] On October 12, 2012, the Shandong Agricultural Machinery Test Evaluation Station assessed the performance of the deep-digging wheat seeder. The main parameters are displayed in Table 2.

小麦播种机

小麦深松播种机由深松、旋耕、施肥、播种、覆土和镇压 6 部分组成，深松铲前后两排交错排列，有效避免了铲间缠草、堵塞问题，提高了深松的稳定性[18]。2012 年 10 月 12 日山东省农业机械试验鉴定站对小麦深松施肥播种机进行了性能检测，主要参数如表 2 所示。

Table 2

Performance Parameters of Wheat Deep Digging Fertilization Seeder

Performance Index	Parameter	Performance Index	Parameter
Supporting Dynamics (kW)	⩾73.5	Fertilization spacing qualified rate (%)	⩾98
Number of sowing Lines	8	Sowing rate error (%)	±0.4
Productivity (hm2/h)	⩾0.8	Linking spacing qualified rate (%)	⩾90
Sowing depth qualified rate (%)	⩾80	Digging depth (cm)	⩾30
Sowing uniformity variation coefficient (%)	⩽45	Digging depth stability (%)	⩾85

The wide strip sowing technique can improve the effective tillage of seeds and assist in ventilation, lighting, and crop growth. Wheat seeds are distributed in the field uniformly, and yield increases by 6% to 8% in comparison with that obtained with conventional sowing.

采用宽苗带播种技术，可提高种子有效分蘖、有利于通风、采光和作物生长，小麦种子在田间分布更加均匀，比常规播种增产 6％至 8%。

(a) 2BYMZ-8 monomer copying maize seeder

(b) Strip grooming device

Fig. 3 - Maize Seeder and Its Strip Grooming Device

Maize Seeder and Dynamic Anti-plugging Device

The strip grooming device depicted in Fig. 3(b) is adopted to solve the plugging problem of the furrow opener on the no-tillage maize seeder when straw coverage is large (more than 0.6 kg/m2) or when straws are long (more than 22 cm) and scattered unevenly. This device exhibits the functions of dynamic anti-plugging and stubble ploughing. The number of the rotating knives is similar to that of furrow openers. In this device, a group of rotating knives is placed in front of the pillar of each furrow opener. Each group of rotating knives contains two rotating knives that are installed symmetrically at 180° [26].

The strip grooming device not only clears straw residues but also breaks the dry and hard soil layer on the surface, thus generating a good seeding bed and increasing the seedling rate by 2.5%. The monomer copying technique reduces the leakage sowing rate caused by uneven ground and enhances the consistency of seedlings.

Maize Straw Returning Machine

Given that the spacing of maize does not match the wheel tread of the harvester, the maize straws may be crushed during harvest. This phenomenon strongly affects the returning quality. To solve this problem, the technique employed by the crushing machine is improved by installing a stubble digging device in front of the machine (as exhibited in Fig. 4). This device digs maize straws up from the surface of the ground slowly and returns them to the straw returning machine. The straw returning machine crushes the straws rapidly to prevent its blade from hitting the earth, to reduce dynamic consumption, and to slow the onset of blade wear. Thus, the problem wherein maize straws cannot be returned to the field as a result of wheel rolling is solved.

玉米播种机及动力防堵装置

针对玉米免耕播种机在秸秆覆盖量较大（大于0.6kg/m2）或秸秆长度较长（大于 22cm）和秸秆抛撒不均匀时，开沟器易被堵塞的技术难题，采用图 3(b)所示的苗带清整装置。该装置具有动力防堵和灭茬功能，旋刀组数与种肥开沟器数量相同，每个种肥开沟器的立柱前端均设有一组旋刀，每组旋刀包括呈 180º 对称安装的两把旋刀[26]。

苗带清整装置既清理了苗带的秸秆残茬，又破除地表干硬土层，营造良好种床，提高发苗率 2.5%。采用的单体仿形技术，减少了因地面不平导致的漏播率，提高了出苗的一致性。

玉米秸秆还田机

由于玉米行距与收获机轮距不匹配，在收获的时候玉米秸秆可能被压倒，严重影响还田质量，为此，对粉碎还田机进行了技术改进，在还田机前方安装挖茬机构（如图 4 所示）。挖茬机构以较低的速度将玉米秸秆贴地表挖起，向后抛向还田机，还田机以较高的速度将玉米秸秆打碎还田，防止还田机刀片打土，减小动力消耗，减缓刀片磨损，解决了因车轮碾压引起的部分秸秆无法还田的问题。

Fig. 4 - Stubble Digging, Crushing and Returning Machine

The comprehensive crushing and returning of maize straws and roots after harvest not only limits the dynamic harvest but also gathers the remaining ears in the harvesting process to reduce harvest loss and the cleaning of emerging wheat seedlings.

在玉米收获后对秸秆和根系进行一次综合性粉碎还田处理，这样不仅减少了收获过程的动力消耗，而且能够使收获过程出现的果穗遗落损失得到及时捡拾，降低了果穗的收获损失，减少了小麦出苗后的玉米苗清理问题。

RESULT ANALYSIS

结果分析

The representative dry area, well irrigation area, and saline land were selected as per the proposed mechanized ecological soil planting technique to determine the test demonstration bases (as indicated in Table 3).

根据提出和设计的机械化生态沃土种植技术，选取旱作区、井灌区、盐碱地等较为典型的地域建设试验示范基地（如表 3 所示）。

Table 3

Test Demonstration Bases

Serial No.	Item Name	Cooperation Unit	Construction Time
1	Dry Area Test Demonstration Base	Longyi Village in Zichuan District, Zibo	2011
2	Well Irrigation Area Test Demonstration Base	Donglai Agricultural Machinery Cooperative in Changshan Town, Zhouping County, Bingzhou	2012
3	Saline Land Test Demonstration Park	Jin Fu Xiang Peasant Planting Cooperative in Mingji Village, Lijin County, Dongying	2012
4	Well Irrigation Area Test Demonstration Base	Fujia Village, Zhangdian, Zibo	2005

The protective tillage system has been implemented in test demonstration base no. 4 since 2005. The mechanized planting technique has been adopted since 2011. After 10 years of returning straw to the field and of scientific and reasonable soil tillage, significant effects have been observed.

在 4 号试验示范基地上，从 2005 年开始实施保护性耕作制度，从 2011 年开始采用机械化种植技术进行土壤耕作，经过长达近 10 年的秸秆还田及科学合理的土地翻耕，取得了较为明显的效果。

Ecological Production Mode

生产方式生态化

In the case in which all straws were returned to the field, 11 t/hm2 to 15 t/hm2 of maize straws were recovered annually. The amount of wheat straws returned ranged from 7.5 t/hm2 to 9 t/hm2. The concentrations of gas emissions reduced directly by straw returning per hm2 are displayed in Table 4 based on the data reported in the literature [9].

秸秆全部还田情况下，每年还田的玉米秸秆为 11～15t/hm^2 ,小麦秸秆为 7.5～9 t/hm^2。根据文献[9]所提供的数据，采用秸秆还田每公顷直接减少的气体排出量如表 4 所示。

Table 4

Directly Reduced Gas Emissions per hm^2 (unit:kg)

Chemical Name	Quality
CO	2413.45～3150.3
CO_2	26598.15～34722
NO	15.07～19.5
NO_2	6.75～8.67
NO_x	21.92～28.32

The return of straw to the field can reduce air pollution and prevent damage to the soil structure as a result of straw burning. It can also improve the efficiency of fertilizer use and reduce usage by 40%. Root stubble crushing loosens and stirs the topsoil, thereby changing the physical and chemical properties of the soil and destroying the parasitic environment of insects and other pests on the surface. This process inhibits the onset of plant diseases and pest invasion.

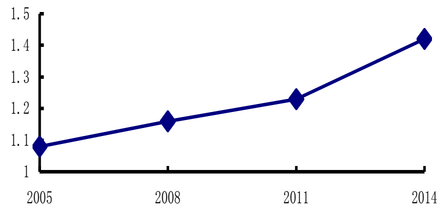
秸秆还田可以减少大气污染，并且可以避免因秸秆焚烧而带来的土壤结构破坏问题。合理施肥，提高了化肥的使用效率,可以减少 40%的化肥使用量。由于根茬粉碎疏松和搅动表土，能改变土壤的理化性能，破坏表层害虫及其他地下害虫的寄生环境，故能抑制病虫害的发生。

Organic Soil Fertilization

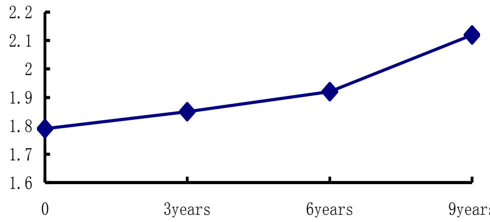
The scientific processing of crop straws increases the content of organic matters in soil consistently every year, improves the aggregate structure of soil, enhances soil permeability, balances soil microorganisms, and improves the microenvironment of the field, thus realizing stable and high yields. The changes in the contents of organic matters, the increment of water content, and the volume-to-weight ratio reduction in the soil of test demonstration base no. 4 are shown in Fig. 5.

培肥地力有机化

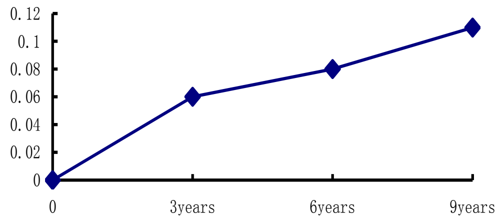
通过科学处理作物秸秆，逐年稳步增加土壤有机质含量，改善土壤团粒结构，增加种床土壤透气性，平衡土壤微生物，改善农田微环境，实现稳产高产。在 4 号实验示范基地，其土壤有机质含量、土壤含水量增量和土壤容重比下降量变化如图 5 所示。



a) The Content of Organic Matters in Soil (%)



b) Water Content Increment in Soil (%)



c) The Volume-to-weight Ratio Reduction of Soil

Fig. 5 - Influence of the return of straw to the field on soil

Since 2011, soil tillage has strictly accorded with the requirements of the ecological soil planting project, thereby steadily increasing the yields of wheat and corn. Scientific fertilization limits the use of fertilizer and fundamentally weakens the adverse influence of fertilizer production and use on soil and ecology. The yields of wheat and corn, as well as the amount of fertilizer used in test demonstration base no. 4, are depicted in Fig. 6(Note: The crops in Shandong were frozen because of the low temperature, snow, and rain in the spring of 2013). Late in May, rare rainstorms and strong winds resulted in a severe loss of wheat. Moreover, droughts in the late summer and early autumn affected sowing. In the middle of September, Luzhong experienced hail, which intensified the disaster and reduced yield.

从 2011 年以来，严格按照生态沃土种植工程要求，进行土地的耕作，小麦玉米产量得到了稳步提高，通过科学施肥，减少了化肥的用量，从根本上减少化肥生产和使用对土壤和生态的不利影响。4 号试验示范基地小麦玉米产量及化肥使用量如图 6 所示（说明：山东省 2013 年春季低温雨雪使农作物受冻，5 月下旬罕见的大风暴雨气候导致小麦倒付严重，夏末秋初少雨干旱影响秋播，9 月中旬鲁中遭受风雹袭击令灾害严重，导致粮食减产）。

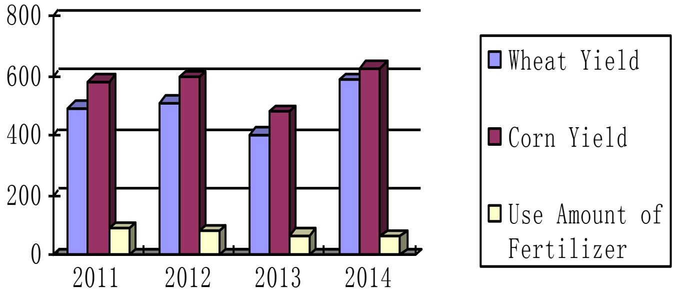


Fig. 6 - Yields of wheat and corn and the amount of fertilizer used (unit: kg/mu)

CONCLUSIONS

Based on the analysis of the two typical planting patterns of intensive cultivation and protective tillage and according to several years of testing and research, a mechanized ecological soil planting technique was proposed for the annual double cropping of wheat and

结论

在分析精耕细作和保护性耕作两种经典种植模式基础上，根据多年的试验研究，提出了一种适合黄淮海地区小

maize. This method is suitable for the Huang-Huai-Hai Region. The characteristics of the planting technique were explained, and the planting specification was designed. This specification was appropriate for the ecological soil tillage method employed in the mechanized ecological soil planting technique and for the combination of agricultural machinery and agronomy. The corresponding key agronomic equipment was designed to mechanize the operation of the annual double cropping of wheat and maize fully. The proposed technique was applied, and the results showed that it reduced the emissions of polluted gases and the amount of fertilizer used through scientific fertilization to establish the ecological production mode. In addition, it increased the contents of organic matters in soil, improved the microenvironment of farmland, and enhanced the organic fertilization through the return of straw to the field and through suitable soil tillage. Thus, the implementation of this tillage method ensured stable and high crop yields, as well as the sustainable development of agricultural production.

ACKNOWLEDGEMENT

This research was supported by the Young Teachers Program of Shandong University of Technology and the Maize Industry Innovation Team Program of Shandong Modern Agricultural Industrial Technique System (SDAIT-01-022-10).

REFERENCES

[1]. Adepetu J. A., Corey R. B., (1997) - *Changes in N and P availability and P fractions in soil from Nigeria under intensive cultivation,* Plant and Soil, vol. 46, pp. 309-316;

[2]. Afzalinia S., Zabihi J., (2014) - *Soil compaction variation during corn growing season under conservation tillage,* Soil and Tillage Research, vol. 137, pp. 1-6;

[3]. Bonanomia G., D'Ascolic R., Antignania V., et al. (2011) - *Assessing soil quality under intensive cultivation and tree orchards in Southern Italy,* Applied Soil Ecology, vol. 47, no.3, pp. 184–194;

[4]. Boscutti F., Sigura M., et al. (2015) - *Conservation Tillage Affects Species Composition But Not Species Diversity: A Comparative Study in Northern Italy,* Environmental Management, vol.55, no.2, pp.443-452;

[5]. Coote D. R., Ramsey. J. F. (1983) - *Quantification of the effects of over 35 years of intensive cultivation on four soils,* Canadian journal of soil science, vol. 63, no.1, pp. 1-14;

[6]. Curry P.J., Byrne D., Schmidt O., (2002) - *Intensive cultivation can drastically reduce earthworm populations in arable land,* European Journal of Soil Biology, vol. 38, no.2, pp. 127−130;

[7]. Fraser P.M., Haynes R.J., Williams P.H., (1994) - *Effects of pasture improvement and intensive cultivation on microbial biomass, enzyme activities, and composition and size of earthworm populations,* Biology and Fertility of Soils, vol. 17, no.3, pp. 185-190;

[8]. Gebhardt R. M., Daniel C. T., Schweizer E., Allmaras R., (1985) - *Conservation Tillage,* Science, vol. 230, no.4726, pp. 625-630;

[9]. Hefeng Zhang, Xingnan Ye, Tiantao Cheng, et al. (2008) - *Emission simulation of gaseous pollutants and GIS analysis from agricultural crop residue combustion in China,* The 26th CCS Congress, Division of

麦玉米一年两熟种植模式的机械化生态沃土种植技术，阐述了该种植技术的内涵特点。提出了适合机械化生态沃土种植技术的生态型土壤耕作方法和农机农艺融合的种植规格，设计了适合该种植技术的关键农艺装备，实现了小麦玉米一年两熟全程机械化作业，并对提出的机械化生态沃土种植技术进行了试验示范。结果表明，机械化生态沃土种植技术通过秸秆还田减少污染气体的排放，通过科学施肥减少化肥使用量，建立了生态化的生产方式；通过秸秆还田和适当土壤耕作，提高了土壤有机质含量，改善了农田微环境，实现了有机化地力培育；通过该耕作方法的实施，保证了农作物产量稳产丰产和农业生产可持续发展。

致谢

本研究得到山东理工大学青年教师支持计划和山东省现代农业产业技术体系玉米产业创新团队项目（SDAIT-01-022-10）的资助。

参考文献

[1]. Adepetu J. A., Corey R. B. (1997) - *精细耕作对尼日利亚伊沃土壤中 N 和 P 的利用率和 P 分数的改变,* 植物和土壤, 第 46 卷, 309-316;

[2]. Afzalinia S., Zabihi J. (2014) －*保护性耕作下在玉米生长期土壤板结变化研究,* 土壤耕作研究, 第 137 卷, 1-6;

[3]. Bonanomia G., D'Ascolic R., Antignania V.等. (

[7]. Fraser P.M., 2011) - *意大利南部精耕细作和树果园土壤质量评估,* 应用土壤生态学, 第 47 卷, 第 3 期, 184－194;

[4]. Boscutti F., Sigura M. 等. (2015) - *保护性耕作对物种组成, 非物种多样性的影响:在意大利北部的比较研究,* 环境管理, 第 55 卷, 第 2 期, 443-452;

[5]. Coote D. R., Ramsey. J. F. (1983) - *对超过 35 年的精耕细作四个土壤的量化影响,* 加拿大土壤杂志, 第 63 卷, 第 1 期, 1-14;

[6]. Curry P.J., Byrne D., Schmidt O. (2002) - *精耕细作可以大大减少耕地蚯蚓群体,* 欧洲土壤生物学报, 第 38 卷, 第 2 期, 127−130;

Haynes R.J., Williams P.H. (1994) - *草场改良和精耕细作对微生物量、酶活性及组成和蚯蚓种群数量的影响,* 土壤肥力生物学, 第 17 卷, 第 3 期, 185-190;

[8]. Gebhardt R. M., Daniel C. T., Schweizer E., Allmaras R. (1985) - *保护性耕作.* 科学, 第 230 卷, 第 4726 期, 625-630;

Environmental Chemistry, July, Tianjin, China.
[10]. Huanwen Gao, Wenying Li, Hongwen Li. (2003) - *Conservation tillage technology with Chinese characteristrics,* Transactions of the CSAE, vol. 19, no. 3, pp. 1-4;
[11]. Jiantao Du, WenQing He, Vinary Nangia, et al. (2008) - *Effects of conservation tillage on soil water content in northern arid regions of China,* Transactions of the CSAE, vol. 24, no. 11, pp. 25-29;
[12]. Ketcheson J. W., (1980) - *Long-range effects of intensive cultivation and monoculture on the quality of southern Ontario soils,* Canadian journal of soil science, vol. 60, no.3, pp. 403-410;
[13]. Ketema H., Yimer F., (2014) - *Soil property variation under agroforestry based conservation tillage and maize based conventional tillage in Southern Ethiopia,* Soil & Tillage Research, vol. 141, pp. 25–31;
[14]. Lal R., Kimble J.M., (1997) - *Conservation tillage for carbon sequestration,* Nutrient Cycling in Agroecosystems, vol. 49, no.1-3, pp. 243–253;
[15]. Lixue Wang, Xi Jiang, et al. (2014) - *Effects of conservation tillage on soil water erosion and soil compaction degree,* Journal of Irrigation and Drainage, vol. 33, no. 2, pp. 83-85;
[16]. López-Garrido R., Madejón E., Moreno F., and Murillo J. M., (2014) - *Conservation tillage influence on carbon dynamics under Mediterranean conditions*, Pedosphere, vol. 24, no. 1, pp. 65–75;
[17]. Page K., Dang Y., Dalal R., (2013) - *Impacts of conservation tillage on soil quality, including soil-borne crop diseases, with a focus on semi-arid grain cropping systems,* Australasian Plant Pathology, vol. 42, no.3, pp. 363–377;
[18]. Peisong Diao, Ruicheng Du, Fuhui Li, et al. (2013) – *Development of Wheat Subsoiling and No-tillage Fertilization Planter,* Journal of Agricultural Mechanization Research, no. 11, pp. 103-106;[16]
[19]. Plaza C, Courtier-Murias D, et al. (2013) - *Physical, chemical, and biochemical mechanisms of soil organic matter stabilization under conservation tillage systems: A central role for microbes and microbial by-products in C sequestration,* Soil Biology & Biochemistry, vol. 57, pp. 124-134;
[20]. Saini G. R., Grant W. J., (1980) - *Long-term effects of intensive cultivation on soil quality in the potato-growing areas of New Brunswick (Canada) and Maine (U.S.A.),* Canadian journal of soil science, vol. 60, pp. 421-428;
[21] Shenzhong Tian, Zengjia Li, et al. (2008) - *Effects of conservation tillage on different soil nutrient forms*, Journal of Qingdao Agricultural University (Natural Science), vol. 25, no.3, pp. 171-176;
[22]. Van Wie J. B., Adama J.C., Ullman J.L., (2013) - *Conservation tillage in dryland agriculture impacts watershed hydrology,* Journal of Hydrology, vol. 483, pp. 26-38;
[23] Yan Wang, Xiaobin Wang, et al. (2008) - *Conservation tillage and its effect on soil organic carbon,* Chinese Journal of Eco-Agriculture, vol. 16. no. 3, pp. 766-771;
[24]. Yilai Lou, Minggang Xu, et al. (2012) - *Stratification of soil organic C, N and C: N ratio as affected by conservation tillage in two maize fields of China*, Catena, vol. 95, pp. 124–130.

[9]. 张鹤丰, 叶兴南, 成天涛, 等. (2008) - *中国地区农作物秸秆燃烧排放大气污染物模拟及 GIS 分析* [C], 中国化学会第 26 届学术年会环境化学分会, 7 月, 天津, 中国.
[10]. 高焕文, 李问盈, 李洪文. (2003) - *中国特色保护性耕作技术*, 农业工程学报, 第 19 卷, 第 3 期, 1-4;
[11]. 杜建涛, 何文清, Vinay Nangia, 等. (2008) - *北方旱区保护性耕作对农田土壤水分的影响,* 农业工程学报, 第 24 卷, 第 11 期, 25-29;
[12]. Ketcheson J. W. (1980) - *精耕细作和单一作物种植对安大略省南部地区土壤质量的长期影响,* 加拿大土壤杂志, 第 60 卷, 第 3 期, 403-410;
[13]. Ketema H., Yimer F. (2014) - *埃塞俄比亚南部农林业和玉米保护性耕作下土壤性质的变化,* 土壤耕作研究, 第 141 卷, 25﹣31;
[14]. Lal R., Kimble J.M. (1997) - *保护性耕作下碳封存,* 农业生态系统养分循环, 第 49 卷, 第 1-3 期, 243﹣253;
[15]. 王丽学, 姜熙, 等. (2014) - *保护性耕作对农田土壤水蚀及土壤紧实度的影响,* 灌溉排水学报, 第 33 卷, 第 2 期, 83-85;
[16]. López-Garrido R., Madejón E., Moreno F., and Murillo J. M. (2014) - *地中海条件下保护性耕作对碳动态的影响,* 土壤圈, 第 24 卷, 第 1 期, 65﹣75;
[17]. Page K., Dang Y., Dalal R. (2013) - *聚焦于半干旱粮食种植系统的统保护性耕作对包括土传病害的土壤质量的影响,* 澳大利亚植物病理学, 第 42 卷, 第 3 期， 363﹣377;
[18]. 刁培松, 杜瑞成, 李复辉, 等. (2013) ﹣ *小麦深松免耕施肥播种机的研制,* 农机化研究, 第 11 期, 103-106;
[19]. Plaza C, Courtier-Murias D, 等. (2013) - *保护性耕作体系下土壤有机质物理、化学、生化稳定机制：副产品微生物碳吸收的核心作用,* 土壤生物与生物化学, 第 57 卷, 124-134;
[20]. Saini G. R., Grant W. J. (1980) - *精耕细作在新不伦瑞克省（加拿大）和缅因州（美国）马铃薯种植区土壤质量的长期影响,* 加拿大土壤杂志, 第 60 卷, 421-428;
[21]. 田慎重, 李增嘉, 等. (2008) - *保护性耕作对农田土壤不同养分形态的影响,* 青岛农业大学学报(自然科学版), 第 25 卷, 第 3 期, 171-176;
[22] Van Wie J. B., Adama J.C., Ullman J.L. (2013) - *旱作农业区保护性耕作对流域水文的影响,* 水文学报, 第 483 卷, 26-38;
[23]. 王 燕, 王小彬, 等. (2008) - *保护性耕作及其对土壤有机碳的影响,* 中国生态农业学报, 第 16 卷, 第 3 期, 766-771;
[24]. Yilai Lou, Minggang Xu, 等. (2012) - *在中国两个保护性耕作玉米地分层土壤有机碳, N 和 C:N 比,* 连锁; 土壤科学-水文学-地貌学杂志, 第 95 卷, 124﹣130;

[25] Yun Wang, Zengjia Li, et al. (2007) - *Effects of conservation tillage on soil microbial biomass and activity,* Acta Ecologica Sinica, vol. 27, no. 8, pp. 3384-3390;
[26]. Zidong Yang, Ningning Liu, Duayang Geng, et al. (2013) - *Design and Experiment on Type 2BYM-12 Folding and Dynamic Anti-blocking No-till Planter,* Transactions of the CSAM, vol. 44, supplement 1, pp. 46-50.

[25]. 王芸, 李增嘉, 等. (2007) - *保护性耕作对土壤微生物量及活性的影响,* 生态学报, 第 27 卷, 第 8 期, 3384-3390;
[26]. 杨自栋, 刘宁宁, 耿端阳, 等. (2013) - *2BYM-12 型折叠式动力防堵免耕播种机设计与试验,* 农业机械学报, 第 44 卷, 增刊 1, 46-50.