CPWF Project Report

Conservation agriculture for the dry-land areas of the Yellow River Basin: Increasing the productivity, sustainability, equity and water use efficiency of dry-land agriculture, while protecting downstream water users

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Program Preface

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

Soil erosion is a major problem in the Yellow River Basin: the river is one of the most sediment-laden in the world. Although there is a rainfall gradient from 750 mm in southern Shandong, to 200mm per year in northern Ningxia, most of the rainfed cropping area is in regions with more than 400 mm per year – it is here that the project concentrated.

Conservation agriculture (featuring reduced or zero tillage, mulch retention, crop rotations and cover crops) offers a possible solution to problems of soil erosion and low crop productivity. Conservation agriculture (CA) systems typically result in increased crop water availability and agroecosystem productivity, reduced soil erosion, increased soil organic matter and nutrient availability, reduced labor and fuel use and increased biological control of pests. Most of the recent advances in conservation agriculture in China have been in irrigated areas, from which technologies and approaches were adapted for this project.

The project goal was to improve the incomes and livelihoods of smallholder farm families in the rainfed cropping areas of Henan, Inner Mongolia, Ningxia and Shandong (Shanxi was added later) while simultaneously improving soil quality and reducing land degradation and soil erosion that threaten system sustainability. Specific objectives included fostering farm family adoption of conservation agriculture practices through participatory research, farmer experimentation and farmer-to-farmer interaction and extension; assessing the (biophysical, social and economic) consequences of conservation agriculture adoption; encouraging a policy environment that does not discriminate against conservation agriculture; and strengthening the capacity of local partners. Project partners include two international Centers (CIMMYT and IWMI), Provincial and County NARES, and Universities. Project beneficiaries were expected to include farm families; downstream water users; researchers and extension workers; and future generations.

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PROJECT HIGHLIGHTS

It is sometimes forgotten how strongly climate affects cropping system and their potential for improvement, and consequent environmental impacts and poverty reduction. The project characterized 6 first-level cropping systems and 15 second-level sub-cropping systems in the Yellow River Basin (YRB). Related to climate, water scarcity is a key determinant of crop productivity. In the YRB rainfall decreases from the north to the south, and from the northwest to the southeast. The growth of population and industry placed heavy demands on water in the YRB which led to crisis during the 1990s.

Conservation agriculture (featuring reduced or zero tillage, mulch retention, crop rotations and cover crops) offers a possible solution. Conservation agriculture (CA) systems typically result in increased crop water availability and agroecosystem productivity, reduced soil erosion, increased soil organic matter and nutrient availability, reduced labor and fuel use and increased biological control of pests. Building on experienced in irrigated areas of China and international experience, the project adapted CA for rainfed areas of the YRB.

Project scientists distinguished Full CA (or Real CA) and Partial CA (or Nominal CA) technology packages. Full CA is characterized by adopting both no till (or reduced till) technology with residue retention, and is consistent with the internationally recognized three principles of CA definition. In contrast, Partial CA is characterized by either no till (or reduced till) technology or residue retention technology. Appropriate is crucial to effective CA and the project supported the development and improvement of no-till seeders and other machinery in all Provinces. For example, the 2BM-5X NT seeder is now successful for direct seeding wheat, maize, minor grain crops on wheat, rice or maize residue fields due to a special knife opener introduced by the project.

Project scientists showed that CA techniques increased soil moisture (beneficial for crop growth) across a range of environments. CA also reduced maximum soil temperature, with variable effects on crop establishment and growth depending on environment. However, residue retention reduced maize yields because of the lower soil temperatures under the residues. This was especially marked in relatively cold Ningxia Province.

Although in the trials CA generally had positive effects on yields, survey results of farmers who have adopted CA report no significant effects of CA on yields. As in other countries, farmers perceive the reduction in production costs from the reduction or elimination of tillage as a major advantage. The project surveys found that adoption of CA technologies significantly reduced farm household poverty by 5 percent.

CA contributes to increasing water use efficiency through reduction in soil evaporation and consequently higher soil moisture available to the crop. The project survey found that 71% of villages reported an improvement of their environment following the adoption of CA; and some farmers had observed an increase in water use efficiency.

More than 5000 farmers took part in project training courses or field days at the CA demonstrations. Our research results show that Partial CA technology begun to be adopted in the YRB since the early 1980s, but rapid development commenced during the 1990s, and picked up especially since the 2000. In contrast to Partial CA technology, Full CA technology began to be adopted during the late 1990s. Overall, the adoption rates of CA technology (either for partial or full CA technology) are still very low. The adoption rate for Partial CA technology (especially for residue retention) is relatively high. However, the Full (or real) CA (combining reduced till and residue retention together) is limited.

Policy and socio-economic factors are important drivers of wider adoption of CA technology. Results show that policy intervention (such as machinery subsidy policy and policy of forbidding burning residue) can play some role in promoting the adoption of CA technology. The project has had some success in influencing policy; for example, a no-till seeder has been put into the list of Agricultural Machinery Purchase Allowance of 40% of purchase price. More than 85 sets of the seeder have been produced and used to no-till plant more than 700 ha in YRB region.

The capacity of National, Provincial and County research and extension organizations has been built. Also 4 PhD candidates and 33 Master students have worked on project data. With the implementation of this project, 5 patents relative to CA have been registered. Five international papers and 50 national papers have been published. Two CA techniques got provincial prizes. At same time, the participants from the project organizations won 5 national CA project and 10 provincial CA projects. Senior project scientists took part in high-level policy dialogues at national and provincial levels, and project results were utilized to reorient the five-year plan, including “CA blueprints” in national & provincial plans. This is a very important impact in the light of the survey results which showed that resource endowment positively affected CA adoption, and that this could be offset by subsidies on the CA components that increased initial investment – especially no-till machinery.

Executive summary

Issue

The Yellow River Basin (YRB) is characterized by very high population density and extensive poverty. Soil erosion is also a major problem in the Basin: the river is one of the most sediment laden in the world. Many regions of the YRB are relatively dry and there are large areas of rainfed cropping. Hydrology is a key issue: there was a crisis of water availability and river flow in the 1990s because of the rapidly growing demand from agriculture, domestic and industrial uses. Conservation agriculture (featuring reduced or zero tillage, mulch retention, crop rotations and cover crops) offers a possible solution to these issues. Conservation agriculture systems typically result in increased crop water availability and agroecosystem productivity, reduced soil erosion, increased soil organic matter and nutrient availability, reduced labor and fuel use and increased biological control of pests. Most of the recent advances in conservation agriculture in China have been in irrigated areas, from which technologies and approaches were adapted for this project.

Objectives

The project goal was to improve the incomes and livelihoods of smallholder farm families in the rainfed cropping areas of Henan, Inner Mongolia, Ningxia and Shandong (Shanxi was added later) while simultaneously improving soil quality and reducing land degradation and soil erosion that threaten system sustainability. Specific objectives include fostering farm family adoption of conservation agriculture practices through participatory research, farmer experimentation and farmer-to-farmer interaction and extension; assessing the (biophysical, social and economic) consequences of conservation agriculture adoption; encouraging a policy environment that does not discriminate against conservation agriculture; and strengthening the capacity of local partners. Project partners include two international Centers (CIMMYT and IWMI), Provincial and County NARES, and Universities. Project beneficiaries were expected to include farm families; downstream water users; researchers and extension workers; and future generations.

Methods

The project brought together scientists, extension workers and policy makers from National, Provincial and County organizations along with scientists from CIMMYT and IWMI to conduct research, extend results to, train and foster adoption of CA among farmers. Experimental sites were identified in five pilot Counties and characterized in terms of soils, climate and cropping history. These provided the platform for the 4-year trials of CA techniques especially tillage and residue management with wheat, maize and cash crops. Minimum data sets of agronomic and soil data were systematically collected at all sites. The results of the experiments were the basis for the establishment of participatory on-farm demonstrations and farmer training in all the Counties. The experimental data were an input to crop modeling of CA technologies using the DSSAT model. Farm household group and individual interview surveys were conducted in 2005 and 2008. Again, participatory research methods were applied to the testing and adaptation of farm equipment especially no-till planters for CA. Impact pathways were identified. Students benefited from supervised analysis and interpretation of project data. Study tours to observe CA in the field and participate in conferences were organized for the project scientists. Policy discussions were arranged at various levels to foster appropriate policy adjustments to support CA adoption,

Research findings

The field experiments were a rich source of data on CA for different cropping systems, soils and climates. Climate affects cropping system and their potential for improvement, and consequent environmental impacts and poverty reduction. The project assembled and analysed detailed meteorological data for the YRB. Rainfall decreases from the north to the south, and from the northwest to the southeast. The growth of population and industry placed heavy demands on water in the YRB which led to crisis during the 1990s, providing an underlying rationale for water-efficient methods such as CA. The project characterized the six first-level cropping systems and 15 second-level sub-cropping systems in the Yellow River Basin (YRB) – see more detail below. Related to climate, water scarcity is a key determinant of crop productivity; but the project experiments showed that low soil temperatures were a binding constraint on crop establishment in the north.

Conservation agriculture (featuring reduced or zero tillage, mulch retention, crop rotations and cover crops) offers a possible solution. The project showed that CA techniques affect soil moisture (affecting hydrology and crop growth) and temperature (affecting crop establishment and growth) – see details below -- in general strongly. Consequently, it increased agroecosystem productivity (in a majority of experiments). While crop yields were increased significantly, the water and nutrient use efficiency increased by more than 20% for wheat and maize. However, low spring soil temperatures were aggravated by surface residue in the north (Ningxia) and the Full CA (no-tillage with full residue retention) delayed summer crop (maize) establishment, and for this reason farmers preferred plastic to mulch. Specific details are described below.

The project supported the development and improvement of no-till seeders and other machinery in all Provinces. For example, the 2BM-5X NT seeder is successful for direct seeding wheat, maize, minor grain crops into fields covered with wheat, rice or maize residues due to a special knife opener. As well as developing equipment for medium sized tractors, the project experimented with some two-wheel tractor equipment. Moreover, the project facilitated the import of three advanced no-till planters (“Happy Seeders”) from India to Ningxia Province which have been successfully put to work.

Policy and socio-economic factors are important drivers of wider adoption of CA technology. Results show that policy intervention (such as machinery subsidy policy and policy of forbidding burning residue) can play some role in promoting the adoption of CA technology. The project has had some success in influencing policy; for example, a no-till seeder has been put into the list of Agricultural Machinery Purchase Allowance of 40% of purchase price. More than 85 sets of the seeder have been produced and used to plant without tillage on more than 700 ha in YRB the region.

The capacity of National, Provincial and County research and extension organizations has been built. Also 4 PDFs, 8 PhD candidates and 17 Master students have worked on project data. Five international papers and 50 national papers have been published. Two CA techniques got provincial prizes.

Outcomes

More than 5000 farmers took part in project training courses or field days at the CA demonstrations. Our research results show that Partial CA technology begun to be adopted in the YRB since the early 1980s, but rapid development commenced during the 1990s, and picked up especially since the 2000. In contrast to Partial CA technology, Full CA technology began to be adopted during the late 1990s. Overall, the adoption rates of CA technology (either for partial or full CA technology) are still very low. The adoption rate for Partial CA technology (especially for residue retention) is relatively high. However, the Full (or real) CA (combining reduced till and residue retention together) is limited.

With the implementation of this project, 5 patents relative to CA have been registered. At same time, the participants from the project organizations won 5 national CA project and 10 provincial CA projects. Senior project scientists took part in high-level policy dialogues at national and provincial levels, and project results were utilized to reorient the five-year plan, including “CA blueprints” in national & provincial plans.

Impacts

As well as increasing productivity, CA also reduces soil erosion from wind and water. As in other countries, farmers perceive the reduction in production costs from the reduction or elimination of tillage as a major advantage. For example, CA can reduce the cost of machine service fees, reduce fuel input from 25 to 40 percent, and reduce labor input. The farm surveys found huge reductions in labour use with CA – up to 80% reduction in the maize crop. Similarly, CA increases farmer income, and the project surveys found that adoption of CA technologies can significantly reduce farm household poverty by 5 percent.

In relation to environmental impacts, CA contributes to increasing water use efficiency, increasing soil moisture and reducing soil evaporation by about 30 percent. Finally, CA reduces runoff of surface water by about 60 percent. The project survey found that 71% of villages reported an improvement of their environment following the adoption of CA; and some farmers had observed an increase in water use efficiency.

Survey results showed that farm family resource endowment was positively linked to CA adoption, and that the initial cost of switching to CA can be a limitation to adoption. In this regards the efforts of project personnel to have one of the no-till seeders developed in the project included in the Agricultural Machinery Purchase Allowance, which will result in an effective 40% subsidy on this equipment is a clear project impact, and will no doubt result in more CA adoption.

1 INTRODUCTION

The rainfed agricultural areas of the provinces of Ningxia, Inner Mongolia, Henan and Shandong share many similarities despite the many differences in climatic factors, cropping patterns, infrastructure, and income levels that also characterize these regions. While part of the targeted region is situated on the highly erodible Loess Plateau, others are on sedimentary deposits. Rainfall varies from approximately 750 mm per year in southeastern Shandong to 200 mm in northern Ningxia. Most of the rainfed agricultural areas are found in zones that receive at least 400 mm of annual rainfall. However, rainfall use efficiency is generally quite low throughout the region. The reasons for poor efficiency vary somewhat with soil type: in the loess areas it is largely due to high evaporation rates from the soil, whereas in the areas of alluvial deposits, low soil water infiltration rates are a major limiting factor, leading also to significant water run-off and soil erosion.

Soil erosion has long been recognized as a severe problem in the Yellow River basin. The Yellow River is the most sediment-laden river in the world with most of the sediment originating in the thick loess deposits of Shaanxi and Shanxi Provinces, outside the geographic scope of this project. Nevertheless, soil erosion, both by wind and water, in the basin as a whole removes the most fertile topsoil and compound water and air pollution problems. These processes are particularly marked in the drier and more sloping lands associated with rainfed agriculture.

Dryland area accounts for almost 6.6 million hectares or approximately 57% of the cultivated land in the Yellow River Basin (YRB), although definitions of “dryland” in China also include areas that have some supplemental irrigation. Using the official poverty definition of per capita income less than US$625 a year, the average incidence of poverty in the YRB overall has been estimated at 11.8%. While official data on poverty incidence in the rainfed areas alone does not exist, research findings suggest an incidence at least 5% higher than the basin average (CCAP unpublished, 2003). Not only are off-farm income opportunities frequently not available to agricultural households in many of the YRB rainfed areas, but crop diversification opportunities are largely limited by agro ecological conditions. Agriculture is generally the predominant source of income for households in this region, and, therefore, successful means of increasing agricultural system productivity and water use efficiency of agriculture will contribute to the improvement of farmer livelihoods.

Crop residues cover on the soil surface has numerous advantages: surface soil structure, and therefore water infiltration rate, is maintained and evaporation reduced; drought is mitigated; soil biological activity is increased as there is a permanent substrate for soil fauna and flora; biological pest control is enhanced; and soil organic matter, the motor behind soil physical, chemical and biological fertility, gradually increases over time (e.g. Six *et al*., 2002). Surface residues also efficiently reduce soil erosion, both by wind, due to the protective cover and wind impedance, and by water, due to the improved infiltration rate and reductions in water run-off velocity. Moreover, the reduction in soil tillage associated with residue retention (optimally zero tillage), reduces labor inputs, benefiting especially women and children, and creates the potential for more diversification possibilities in the farm enterprise.

The adoption of conservation agriculture brings benefits not only to the farm family in terms of increased livelihoods, reduced risk, reduced labor requirements and the possibility of the diversification, but also to other members of society. Downstream water users benefit from decreased sediment load in waterways, and more even stream flow when fed by a greater proportion of ground-water and less surface run-off. City dwellers benefit from decreased wind erosion: dust clouds from the more arid western regions have become an important problem in China, reaching as far east as Beijing. Increases in soil organic matter, attributable to the omission of tillage, surface residue retention and increased biological activity, imply the sequestration of carbon in the soil, and a reduction in carbon dioxide emissions. A 60-70% reduction in fuel use for crop production, in areas with mechanized traction, further reduces greenhouse gas emission. As agriculture accounts for 20-25% of the worlds CO2 emissions, conservation agriculture can play an important role in the mitigation of global warming.

Zero tillage agriculture has already proved viable and profitable to farmers in Shanxi, Hebei, Sichuan and parts of Inner Mongolia, especially in fully or partially irrigated areas. There is little published information from these projects, but correspondence with some of the researchers involved has revealed benefits in water use efficiency, weed control and, in many instances, in crop productivity (J. Tullberg, C. Chang – personal communication).

The principles of conservation agriculture, comprising reduced or zero tillage, residue retention and crop rotation, have extremely wide applicability and have been adopted on more than 70 million hectares worldwide. They are used in areas with as low as 200 mm of annual precipitation and with as much as 2500 mm per year; on soils with up to 85% clay and on soils with more than 90% sand. However, even though the principles are widely adapted, the specific techniques and technologies required to apply them are very site specific: some farmers in Brazil even change their management practices between different adjacent fields.

The project aimed to extend the use of conservation agriculture to pilot areas in the rainfed cropping areas of the Yellow River basin. The project will promote the development of innovation networks focusing on the efforts and experiences of innovative farmers, farmer experimentation with the proposed technologies, and farmer-to-farmer extension and dissemination. In this way the project proposes to initiate a process of spontaneous adoption, as has happened in regions of small farmers in Brazil, India, Pakistan and Ghana. As conservation agriculture involves a complete change in the agricultural system, and a change away from the paradigm of the plough and aggressive tillage, it is the initial adoption that may be slow and difficult. Once a few innovative farmers have adopted the system, the evident benefits have led to an explosion of adoption in other small-farm areas: in the Indo-Gangetic Plains less than 100 ha in 1997 had grown to 500, 000 ha of zero-tillage wheat in 2003. The expected widespread adoption of conservation agriculture in the rainfed areas of the YRB, in all probability after the end of the project, will attain the project goal of increasing farm family livelihoods through improved productivity, profitability and sustainability of agriculture in these areas, while at the same time reducing the downstream effects of soil degradation, especially soil erosion.

The project focused on the areas of five Provinces targeted by the Water and Food Challenge Program that receive, on average, more than 400 mm per year of rainfall. Although conservation agriculture may well prove successful in the drier areas, the project team felt that it will be more advantageous to first adapt conservation agriculture to the "wetter" areas, and, once adoption has begun, then concentrate on extending it to the drier areas. The project established sites with two pilot communities in each of the four Provinces (Henan, Shandong, Ningxia and Inner Mongolia), plus additional sites in Shanxi Province. All provinces have rainfed agricultural areas with more than 400 mm/yr rainfall. Aided by Geographic Information Systems and Participatory Rural Appraisal techniques, the project located the eight communities that represented a gradient in rainfall from the nearly 700 mm of Henan to the 400 mm/year areas of southern Inner Mongolia and Ningxia.

2 OBJECTIVES

2.1 Project Goal

Contribute to poverty alleviation by improving the livelihoods, system productivity and the sustainability of agricultural production in the poorer rainfed areas of the Yellow river basin. Through the development and dissemination of conservation agriculture management systems to increase rainfall use efficiency, crop and labor productivity, and reduce soil erosion.

2.2 Specific objectives

(1) Foster farm family adoption of conservation agriculture practices based on zero tillage, direct seeding, residue retention and crop rotation in four villages of the Yellow River basin, representing a rainfall gradient.

(2) Assess the consequences of the adoption of conservation agriculture practices on system productivity, income, livelihoods, equity, resource quality, water use, and soil erosion at the field, watershed and river basin levels.

(3) Encourage the development of a policy environment that does not discriminate against conservation agriculture practices and of input, equipment and rental markets needed to make conservation agriculture practices generally accessible.

(4) Strengthen the capacity of local partners to conduct collaborative research and development on conservation agriculture in a partnership mode with multiple stakeholders.

3 PROJECT METHODS, RESULTS, DISCUSSION AND CONCLUSIONS FOR EACH OF THE OBJECTIVES.

This main body of the report begins with an overview of the farming systems of the YRB in the next section, followed by a brief profile of the selected Counties which implemented the research and demonstrations.

The farming systems of the Yellow River Basin

Because of the spatial and temporal differences in climate, soil type and physiography in the YRB, crops grown and their management vary between regions. In Shandong and Henan, double cropping (two crops per year) of winter wheat and maize is the common practice. Livestock is mainly pigs, poultry and cattle, and farmers earn off-farm income through providing labour to other farms. In Inner Mongolia, Ningxia and Shanxi, the main crops are millet and wheat with one crop per year, and the principal livestock are cattle, sheep, pigs and poultry (Figure 1).

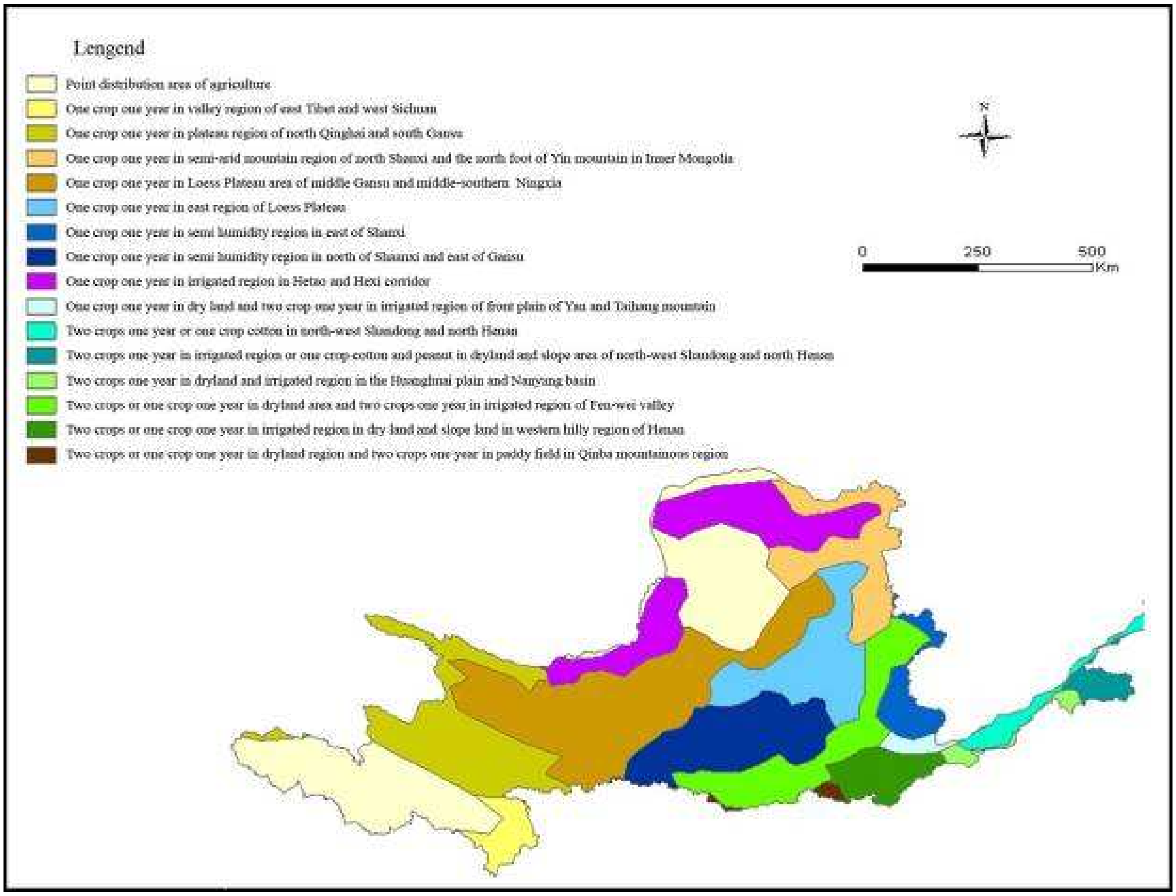


Figure1. Map of cropping systems in the Yellow River Basin

Introduction to the pilot counties

The core of the project was based on the field experiments, learning sites and demonstrations in four provinces.

According to specific rainfall, geographical feature and dryland faming systems, four counties in four provinces were selected for pilot research and learning sites. They are: Zhangqiu County, Shandong Province; Mengjin County, Henan Province; Pengyang County, Ningxia Province and Qingshuihe County, Inner Mongolia. In addition, a supplementary experiment site was identified in Shouyang County, Shanxi Province, in which the annual rainfall is intermediate between the humid and dry pilot sites of the four target counties (Figure 2).

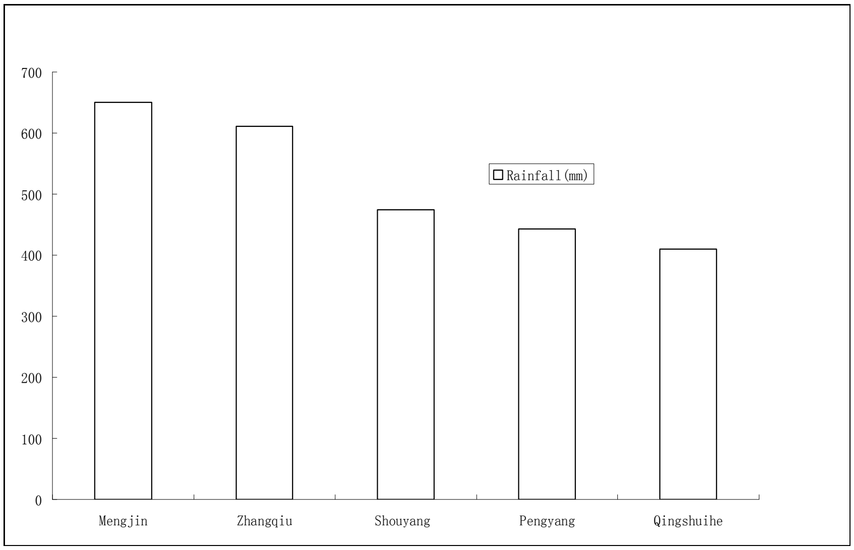


Figure2. The annual rainfall amount in the pilot sites and supplementary site

Each pilot county was selected through in-depth discussion during the inception workshop. The principal relevant characteristics of the Counties are shown in Table 1 and the location of each shown in Figure 3.

Table 1. Principal characteristics of the Counties in which project activities were located.

Province	**Shandong**	**Henan**	**Inner Mongolia**	**Ningxia**	**Shanxi**
County	Zhangqiu	Mengjin	Qingshuihe	Pengyang	Shouyang
Longitude	117°10 -117°35 E	112º12 - 112º49 E	112º21 - 112º07 E	106º41 - 106º46 E	112º46 - 113º26 E
Latitude	36°25 -37°09 N	34º43 - 34º57 N	39º35 - 40º11 N	35º51 - 35º55N	37º32 - 38º6 N
Annual ave. temp °C	12.9	13.7	7.1	7.6	8.1
Annual rainfall (mm)	611	650	410	450	474
Cumulative temp > 10°C (deg days-1)	4,900-5,000	4,523	2,200-3,200	2,350	2,900~3,000
Annual ave. frost-free days	192	235	110-160	150	130
Main problems	Drought, hail, dry-hot desiccating winds and frost	Hilly region, drought, soil erosion	Hilly region, drought	Drought	Drought, and low temperature in easrly spring
Main crops	Winter wheat, maize, cotton	Wheat, corn, sweet potato, mung bean, millet	Maize, potato, millet, glutinous millet, oak, buckwheat, bene (flax), sunflower	Winter wheat, maize, buckwheat, potatoes, flax	Maize, millet, potato
Livestock numbers @	280,000	65,500	435,000	495,000	156,000
Ave. maize yield (kg ha-1) approx.	7,500	7,000	4,500	5,250	5,300
Ave. wheat yield (kg ha-1) approx.	4,500	4,000		1,600	
Research site location	Wangguang village	Songzhuang village and Yaowa village	Potouyao village	Wengou village, Gushign township, Zhongzhuang village, Baiang township	Zongai village
Notes	More than 60% rainfed			Drought frequency is 60% to 80%.	

[@] Livestock numbers include only cattle, sheep and horses. They do not include pigs and chickens.

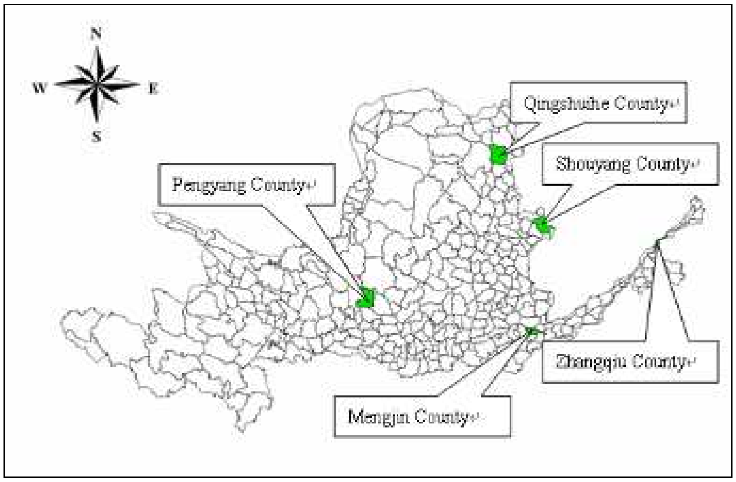


Figure3. The location of pilot counties in the Yellow River Basin

3.1 Foster farm family adoption of conservation agriculture practices based on zero tillage, direct seeding, residue retention and crop rotation in four villages of the Yellow River basin, representing a rainfall gradient.

3.1.1 Methods

Data collection and investigation of CA

After inception, scientists from CAAS, CAU, CAS and Henan, Shandong, Inner Mongolia as well as Ningxia carried out the primary data collection. The data set included the daily temperature, humidity, rainfall, crop species, yield, crop plantation structure, and current status of CA application, especially for the 4 pilot counties. At the end of 2005, experts from CIMMYT, CCAP and CAAS carried out the social and economic investigation in YRB, which data-set include cultivated land, irrigated land, and the sowing area of major crops, crop yield, agricultural production inputs, farmer income, livestock population and other socio-economic relevant data. International and domestic conservation agriculture literature was also reviewed, especially for the target 4 provinces.

In the 5 pilot sites, field trials were designed and planned to last 4 years. The trials are described briefly in the following sections which present the main findings for each location.

Management of no-tillage conditions.

In Shandong, conservation agriculture (CA) based practices have been widely adopted for maize planting in recent years. Maize generally follows wheat, which is harvested using combine harvesters and all the straw left covering the soil. After that, the direct seeding of maize with seed drills is conducted without tillage and with residue retention (Figure 4). Therefore in the following experiments we superimposed the tilled check plot on these fields, and the CA treatments followed on from the previous untilled system and the results reflect effects of no-tillage for longer than the establishment of the trials.

Figure 4. Zero till maize direct seeded into wheat mulch. This is a common farmer practice in Shandong.

In the first season we compared soil conditions in the no tillage plots with the conventionally tilled checks that had been superimposed on the no-till fields. No significant differences in soil porosity and soil bulk density were observed in conservation and conventional tillage conditions.

The plant nitrogen content was determined at late growth stages of maize. Also, no significant difference in nitrogen content was found, with plant nitrogen content (0.48% to 0.49%). Likewise, previous no tillage exerts little effect on maize developments and yield component formation.

CA modeling-DSSAT Model

The project endeavoured to validate and use the DSSAT model for the conditions of the project sites. We used the beta version of the new DSSAT-CSM which has been updated with algorithms with handle effects of tillage and residue management on the cropping system. The new DSSAT (version 4.5) cropping system model (CSM) has a modular structure to allow easy replacement or addition of modules. However, the model needed some major modifications to incorporate the treatments used in China, and this was not completed during the project. The following are some of the issues encountered.

For few soil properties we used the values suggested by the model because they were not available from the field trials. The model can handle all tillage and residue management operations performed during the field trials. Use of plastic covers is common in China but the DSSAT model does not have a routine for handling plastic mulch. The team tried to modify soil properties such that they mimicked the conditions created by plastic mulch but we have found no reference in the literature to similar adjustments to the model and so are still not confident of the adjustments that we have made to the model. The model is also not capable of simulating the effects of standing stubble. The Inner Mongolia site has two treatments in which they leave standing stubble of two different heights. We are incorporating the effects of standing stubble by simulating the residue into soil rather than leaving on the surface. This way we can simulate the effect of roots of standing stubble and we are testing different amounts of residue until we get a good match with the field trial data. To help us neutralize the effects of variables other than residue cover and tillage, we first calibrate the model for conventional tillage so that everything except residue cover and conservation tillage operations is accounted for in the model. We then used this model and modify it to calibrate for conservation agriculture treatments. We agree however that this method is very questionable and until we are able to modify the model adequately we will not present the results.

3.1.2 Results, discussion and conclusions

In this section the principal results are presented for the major challenges under Objective 1 for each County. Most experimental data are documented in other reports and papers; only a few illustrative or key data are presented here.

Zhangqiu County, Shandong

Expt 1. Comparison of Soil Properties and Physiological Traits in Winter Wheat under Conservation Agriculture (No Tillage) and Conventional Tillage

A field experiment with three replications was carried out at the experiment station at Zhangqiu in 2005/2006 to compare three varieties commonly grown in Shandong - Jimai 20, Yannong 19, and Yannong 24 – under CA conditions. Jimai 40 was also seeded under conventional land preparation for comparison. The objective of the trial was to see which of the varieties performed best under CA; to evaluate the effects of CA on the performance of Jimai 40; and to collect data for the validation of the DSSAT model. The trial was fertilized at planting with 100 kg N ha^{-1} applied as urea and 120 kg P_2O_5 ha^{-1} applied as triple superphosphate and top-dressed with 100 kg N ha^{-1} as urea at the booting stage.

Soil bulk density and soil porosity.

After one year of applying the treatments soil bulk density was higher, and soil porosity lower, in the Jimai 20 plots with conservation tillage compared to the conventionally tilled plots (Table 2). We are unable to explain why the bulk density of the soil under Yannong 19 was so much lower than the other two varieties, especially in the 0-20 soil layer.

Table 2. Soil bulk density and soil porosity in different planting systems after one season of treatments. Zhangqiu County, Shandong March, 2006.

Planting method	Variety	Soil porosity (%)		Soil bulk density (g cm^{-3})	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm
No tillage	Yannong 19	54.94	49.78	1.19	1.33
	Yannong 24	49.29	47.71	1.34	1.39
	Jimai 20	49.61	45.48	1.34	1.45
Conventional tillage	Jimai 20	55.62	52.60	1.18	1.26
PF		*	*	*	*
LSD (5%)		5.47	6.84	0.14	0.17
CV%		6.45	6.20	7.10	5.99

Soil moisture content.

The soil moisture content under CA was lower than that under conventional tillage system. As the wheat grew, the moisture in no-tilled soil showed a lower water loss and higher rainfall water retention. This suggests that the water evaporation rate is lower under no tillage and residue retention conditions.

Soil temperature.

Between March 30 and May 18, 2006, average soil temperature at 10 cm below the soil surface was 2.0ºC lower in the CA plots than in conventional tillage plots, whereas at 20 cm, the difference was less – the soil under conservation tillage was only 0.6ºC cooler.

Soil organic matter content.

After only one year, and despite the very high variability, the organic matter content was significantly greater in the CA system at 0-20 cm soil depth, while at 20-40 cm soil depth no significant differences were observed (Table 3). The variations in organic matter content are partially attributed to residue retention under the CA system. There were no significant differences in total nitrogen contents, but alkali-hydrolyzable nitrogen was significantly higher in CA plots at 0-20 cm soil depth, while at 20-40 cm soil depth there were no significant differences (Table 3).

Table 3. Soil organic matter and nitrogen contents in the two tillage systems. Zhangqiu County, Shandong 2006.

Planting method	Soil depth (cm)	Organic matter content	Total nitrogen(g kg^{-1} soil)	Alkali-hydrolyzable nitrogen (mg kg^{-1} soil)
No tillage	0-20	1.38	0.13	2.38
	20-40	0.56	0.06	0.88
Conventional tillage	0-20	1.01	0.12	1.74
	20-40	0.51	0.05	0.96
LSD (5%)		0.18	0.17	0.26
CV%		48	45	40

Wheat population dynamics.

There were no differences in establishment between tillage treatments, and plant population was similar across treatments. However, tiller numbers per plant and tillers m^{-2} were significantly higher under CA: there were 70% more tillers m^{-2} under CA. So we conclude that the tillering in early winter and early spring is promoted under CA practices, even though germination and plant establishment is not affected.

Leaf area index (LAI).

Wheat LAI was measured on twenty plants per plot with a LICOR LI-3000A area meter. Results showed that in variety Jimai 20 (grown under both conventional tillage and CA) LAI under CA conditions was consistently higher than in conventional tillage system, and increased more rapidly as plants grew during the March 20 to May 18 period. At peak LAI (18-27 April) the crop under CA had a LAI of 2.3 whereas under conventional tillage it was only 1.5.

Relative chlorophyll content

There were no significant differences between treatments in relative leaf chlorophyll content (expressed as SPAD value)

Dry matter accumulation.

The crop was sampled to measure total above-ground dry matter at four times during the season from March 20 to April 28. Aboveground biomass was determined on twenty plants per plot after oven drying at 60°C to a constant weight. In Jimai 20 there were no differences between the tillage treatments at the first three samplings, but at the last sampling date, TDM was 10% higher in the CA treatment.

Grain yield and yield components.

Yield was measured at maturity by hand harvesting the middle 20 rows of each plot on June 7, 2006. The harvested plants were mechanically threshed and the grain was allowed to air-dry to 13% moisture. The number of heads per square meter and the number of kernels per head were determined from the harvested plant samples. Kernel weight was determined by taking the average weight of 1000 kernels taken randomly from seeds harvested within each plot.

As shown in Table 4, the yield of wheat Jimai 20 increased by 20% under no-tillage conditions, due to the significantly higher spike numbers and grain numbers per spike – offset to some degree by lower kernel weights as would be expected. Under conservation o-tillage practice, the maximum yield was obtained in variety Yannong 19, followed by Yannong 24 and Jimai 20. The two Yanong varieties appear to be well adapted to no-tillage, rainfed conditions.

Table 4 Grain yield and yield components under different tillage systems

Planting method	Variety	Spikes m^{-2}	Grains per spike	1000 kernel weight (g)	Yield (kg ha^{-1})
No tillage	Yannong 19	468	26.8	35.2	4416
	Yannong 24	442	27.4	36.0	4355
	Jimai 20	434	26.6	34.6	3995
Conventional tillage	Jimai 20	391	24.2	35.3	3339
LSD (5%)		32	2.10	0.95	462
CV%		12.27	5.37	1.63	12.28

Conclusions

In the conservation tillage system, soil alkali hydolyzable nitrogen and organic matter were higher than in the conventionally tilled treatment, presumably due to the effects of residue retention. Yield of Jimai 20 was considerably (20%) higher in the conservation tillage treatment, and the other two varieties appear well adapted to conservation tillage conditions.

Expt 2. Selection of Wheat Varieties with High Drought-resistance and Water Use Efficiency under CA Conditions

To select wheat varieties having high water utilization efficiency under CA conditions, 16 varieties (Yan Blue 6439, Luohan 6, Aikang 58, Shimai 12, Shijiazhuang 8, Shimai 15, Linfeng 3, Linfeng 51329, Yannong 21, Kenong 9204, Lainong L155, and Lainong 0301) obtained from Shandong, Henan, Shijiazhuang, Ningxia and other provinces were planted using no tillage. The trial was established with three replications and a plot size of16 m^2.

Measurement of photosynthetic rate (Pn), leaf area index (LAI) and dry matter accumulation (DMA)

Leaf Pn were measured with a portable photosynthesis system (LI-6200, Li-Cor, USA) at midday. Thirty newly and fully expanded leaves per plot were selected for the measurements. Wheat LAI was measured with a LICOR LI-3000A area meter. Wheat dry matter accumulation (DMA) of aboveground parts of plants was determined after oven drying at 60°C to a constant weight. Twenty wheat plants per plot were sampled for each measurement.

In all the 16 genotypes of wheat, photosynthetic rate was steady prior to flowering, and then decreased gradually. Before flowering, higher photosynthetic rates were observed in Yan Blu 6439, Luohan 6, Lainong 0301 and Linhan 51329, while after flowering, higher photosynthetic rate was observed in Lainong L155, Luohan 12 and Aikang 58. However, photosynthetic rate was not correlated in this study with grain yield.

Measurement of normalized difference vegetative index (NDVI)

The normalized difference vegetative index (NDVI) has been correlated with physiological plant parameters and used to evaluate plant growth (Govaerts et al., 2007). At 145-146 DAT for autumn application or 30 DAT for spring application, canopy reflectance was measured using a GreenSeeker Hand-held optical sensor (NTech Industries, Inc., Ukiah, CA, USA). The sensor unit has self-contained illumination in both red and near infrared bands and measures reflectance in the red and near infrared (NIR) regions of the electromagnetic spectrum. This reflectance is used by the sensor to compute NDVI according to the formula NDVI = (NIR-R)/(NIR+R), where NIR is the reflectance of emitted NIR radiation returned from the sensed area, and R is the reflectance of emitted visible red radiation returned from the sensed area. Measurements were taken around mid-day (between 10:00 h and 14:00 h). The sensor was held parallel to the soil, about 50 cm above the crop canopy. In measuring a plot, the trigger was kept down for 4-5 seconds so that 12 single counts were collected. The NDVI values of these counts were then averaged to obtain a mean value for each plot.

Figure 5 shows that Shimai 15 and Shijiazhuang 8 have the highest NDVI, Kenong 9204 has the lowest. The NDVI values are very consistent with their grain yield, suggesting that NDVI is significantly correlated with the grain yield and water use efficiency in wheat.

Results showed that NDVI values of different wheat genotypes differed significantly at different development stages. Value of wheat NDVI expressed a positive correlation with drought yield index at heading stage. Varieties that had higher NDVI values at heading had better drought yield indices. Under the experimental conditions, Shimai 15, Shijiazhuang 8 and Yan Blu6439 have higher drought yield index than others.

Leaf area index of different genotypes of wheat

The maximum LAI in all the wheat genotypes was observed at flowering, followed by a gradual decrease after flowering. During the period from heading to flowering, Shijiazhuang 8, Shimai 15 and Shimai 12 developed higher LAI than the other 13 varieties. The LAI is highly concordant with the grain yield, which suggests that the LAI during the period from heading to flowering can be used as an important indicator of water use efficiency and yield formation under CA conditions in dry-land.

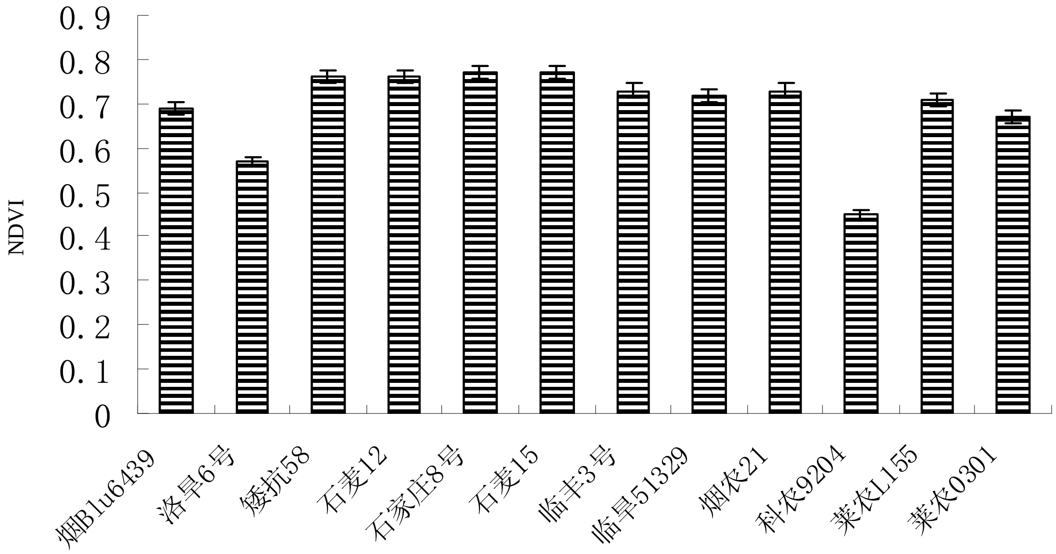


Figure 5. NDVI of different genotypes of wheat under CA conditions

SPAD values

Generally speaking, flag leaf SPAD values in all wheat genotypes increased during the early stages of wheat growth, and then decreased at later stages. The maximum flag leaf SPAD value was found at flowering or early grain filling. During grain filling Shimai 15 had the highest leaf chlorophyll concentrations – significantly higher than all the other varieties except Yannong 21, Kenong 9204 and Shijiazhuang 8.

Expt. 3. Effects of Different Planting Methods on Soil Moisture and Soil Microbial Activity

Field experiments were conducted in the 2007/2008 crop season at trial fields of the Shandong Academy of Agricultural Sciences (36'42" N, 117' 04" E). The CA technologies were first adopted in 2004 with wheat/maize rotation system. The soil of the site is a loam, containing 1.22% of organic matter, 13.45 mg kg^{-1} rapidly available phosphorous, 138.3 mg kg^{-1} of rapidly available potassium, and 66.9 mg kg^{-1} of rapidly available nitrogen. The winter wheat variety Jimai 22 was used for experiment.

The experiment was laid out in a randomized complete block design with a split plot arrangement. Three treatments - no-tillage with straw cover (NS), tillage plus straw cover (TS), and conventional tillage without straw retention (CT) - were replicated four times on experimental plots 2.8 m wide by 10 m long.

For determination of soil moisture, samples were taken from to 0-10 and 10-20 cm horizons. Three soil samples were taken from each plot using steel tubes (5 cm × 10 cm). Soil moisture was measured by the oven-drying method. The samples were weighed wet, dried in a ventilated oven at 105°C for 48 h, and weighed again to determine soil water content. The air-dried soil samples were used to determine the contents of nitrogen and organic matter contents.

Subsurface soil temperature (5 cm depth) was measured from seeding to the first node stage at 7:00, 13:00 and 19:00 h daily, using mercury-in-glass thermometers with bent stems. The thermometers were sunk into the inter-row ground to the depths of 5 cm.

Soil respiration measurement was performed based on carbon dioxide analyses using an ADC 2250 differential infrared CO_2 gas analyzer (ADC BioScientific Ltd). Shoots were removed by clipping at soil level before measuring soil respiration. Measurements were made by sealing the lid onto the collar and continuously circulating air from the chamber through the ADC 2250 CO_2 analyzer and back into the chamber through the perforated air-dispersion ring on the underside of the lid. The sampling pump had a flow rate of 1 L min^{-1}, with the CO_2 concentration obtained within 30 s to an accuracy of 1%.

Soil moisture

As can be seen from Table 5, the soil moisture increased as the soil depth increased. Treatment effects were not consistent. Generally speaking, the 0-20 cm soil moisture under NS conditions tended to have higher moisture content than the CT treatment, but this positive difference was only significant in the March 14, April 14 and May 14 sampling dates. In the early May sampling, there was significantly more soil moisture in the CT plots than in the NS plots in the 0-20 cm layer. The reasons for this are not known.

Table 5. Difference in soil moisture (%) for the different planting methods

Soil depth (cm)	Planting method	Date				
		14 March	31 March	14 April	8 May	14 May
0-20	CT	14.66	15.26	10.88	15.87	12.56
	TS	15.71	15.36	12.26	14.95	13.92
	NS	16.36	15.41	13.08	13.67	14.02
20-40	CT	17.38	16.92	14.96	16.75	13.63
	TS	16.09	15.71	14.97	12.96	12.93
	NS	17.26	16.06	15.63	17.78	14.72
40-60	CT	18.12	17.22	16.71	19.8	15.55
	TS	18.05	17.59	18.00	14.48	14.76
	NS	16.57	17.77	16.88	18.79	16.15
LSD (5%)		0.64	0.94	1.13	1.09	0.87
CV%		6.79	6.18	15.78	14.54	8.20

Soil temperature

The soil temperature at 5 cm under NS conditions was significantly lower than that under TS and CT conditions (results not shown here). The lower soil temperature under no tillage conditions may be attributed to weak light penetration to soil with higher compaction and residue retention. The reduced absorptions of radiant energy will result in the lower temperature.

Soil respiration

Under NS conditions, the soil respiration was lower than that under TS and CT conditions, indicating that the release of CO_2 from soil respiration decreased due to the no-tillage and straw cover.

Soil microorganisms

A large number of colonies of soil microorganisms were observed on the culture medium. The soil microorganisms, including bacterium, yeast, actinomycetes, and mould, varied with different planting methods. There were a great number of actinomycetes in the soil under NS conditions, while mould abounded in the soil under TS conditions (Table 6). Under CT conditions, only bacterium and yeast were observed in the soil. The species were determined using biochemical reaction approach after isolation and purification of microorganisms. The main species of bacteria are bacillus (Bacteriaceae), Vibrio (Vibrionaceae), staph (Micrococcaceae).

Table 6. Numbers of soil microorganisms (10^5 μl^{-1}) under different tillage treatments. Shandong Academy of Agricultural Sciences, 2008.

Planting methods	Soil depth (cm)		
	0-20	20-40	40-60
CT	1.32	1.54	1.20
TS	1.83	1.57	1.32
NS	2.03	1.46	1.44

The microorganisms were higher in the 0-20 cm horizon under NS and TS conditions, and decreased as the soil depth increased, while under CT conditions there was little difference between counts at different depths. The data presented here indicate that straw cover could promote reproduction of microorganisms. No tillage had higher numbers than the tilled treatment with residues, but results could not be analysed statistically.

Expt 5. Effects of Different Planting Methods on Wheat Physiology and Ecology in Dry-land

Field experiments were conducted in the 2007/2008 crop season at Liujiachedao village, Changyi city, and the trial fields of the Shandong Academy of Agricultural Sciences. The soil contains 1.13% of organic matter, 29.1 mg kg^{-1} available phosphorous, 188.6 mg kg^{-1} of available potassium and 52.3 mg kg^{-1} of available nitrogen. The winter wheat varieties Yangnong 19 was used for experiment.

Two treatments, no-tillage (CT) plus straw cover and conventional tillage (CT), were designed. Wheat was planted on 25 September, 2007 at a planting rate of 13 kg mu^{-1}. The trials were fertilized with 37.5 ton ha^{-1} organic fertilizer (manure), 105 kg N ha^{-1} applied as urea, 130 kg P ha^{-1} applied as triple super phosphate and 105 kg K_2O ha^{-1} as basal fertilizer at planting and 105 kg N ha^{-1} top-dressed as urea at the booting stage.

For determination of soil moisture, samples were taken from every 10 cm of the top 20 cm depth in planting zone. Three soil samples were taken from each plot using steel tubes (5 cm × 10 cm). Soil moisture was measured by the oven-drying method. The samples were weighed wet, dried in a fan-aided oven set at 105°C for 48 h, and weighed again to determine soil water content. The air-dried soil samples were used to determinate the contents of nitrogen and organic matter contents.

Wheat LAI was measured with a LICOR LI-3000A area meter. Wheat DMA of aboveground parts of plants was determined after oven drying at 60°C to a constant weight. Twenty wheat plants per plot were sampled for each measurement.

Soil moisture content

During the period of plant growth and development, the average soil moisture content at all soil depths was slightly, but not significantly, higher in NT planting over CT planting (Table 7).

Table 7. Soil moisture content for the different planting methods

Planting method	*Soil depth (cm)*	*18 April*	*17 April*	*30 April*	*13 May*	*20 May*	*27 May*	Average
NT	0-20	16.36	15.26	12.26	12.02	15.87	14.02	14.30
	20-40	17.26	16.06	15.63	12.79	17.78	14.72	15.71
	40-60	18.05	17.77	16.88	14.43	18.79	16.15	17.01
CT	0-20	15.51	15.41	10.88	11.58	13.67	13.92	13.50
	20-40	17.38	16.12	14.96	12.43	16.75	13.63	15.21
	40-60	18.12	17.22	16.71	14.08	16.88	15.55	16.59
LSD (5%)	Same depth	0.72	0.37	2.42	0.95	1.27	0.84	1.27
CV%		5.91	6.11	18.87	8.83	10.56	6.84	8.69

Tiller development

There was no difference in plant population between NT and CT conditions. The number of tillers per plant under NT conditions was 1.3 more than that under CT conditions (5.5 vs 4.2). However, this did not result in more spikes, and there were more spikes m-2 in the CT treatment than in the NT treatment in contrast to Expt. 1 above where there were more spikes in the NT treatment than in the CT treatment. .The results indicate that that NT planting favors the tillering due to the slower drop of temperature in the fall and early winter. While at greening-up stage of wheat, the soil temperature was lower in NT planting than in CT planting due to the residue retention. As a result, the total number of spikes per ha and percentage of ear-bearing tillers were lower under NT conditions, than that under CT conditions.

Leaf area index (LAI) in winter wheat under different planting methods

From the grain-filling stage on, the leaf area index (LAI) in wheat under NT conditions was lower than under CT conditions, probably due to the smaller area of the flag leaves and second leaves from the top. However, the LAI decreased more slowly in no-tillage planting than in CT planting after the mid grain-filling stage. These data indicate that under NT planting conditions, the air circulation and light transmission were improved, light reception was increased, leaf senescence was delayed, and the photosynthetic duration for functional leaves was extended.

Photosynthetic rate and dry matter accumulation.

The photosynthetic rate of flag leaves in winter wheat was higher in NT planting than in CT planting during the period from flowering stage to late grain-filling stage.

At early stages of plant growth, no significant difference in dry matter accumulation was observed between NT and CT planting conditions. While after the flowering stage, the dry matter accumulation differed significantly between NT planting and CT planting. These results suggest that the efficiency of assimilation in winter wheat in NT planting is higher than in CT planting. The higher assimilation efficiency in NT planting favors the transfer of organics from vegetative organs to grains, increasing crop yield.

At the mid grain-filling stage, no significant difference in the dry weight ratio of spike and total plant was observed between NT planting and CT planting, while as the plant grew, the dry weight ratio of spike and total plant was significantly higher in NT planting over CT planting. During the whole grain-filling stage, the proportion of functional leaves in the entire plant was higher in NT planting than CT planting, indicating that the NT planting could delay the leaf senescence and keep the canopy photosynthesis higher. At early grain-filling stage, the dry weight ratio of straw and whole plant was slight higher in NT planting than in CT planting, contributing the higher lodging-resistance in wheat under NT planting conditions. Whereas at mid and late grain-filling stages, the ratio was lower in wheat in NT planting than in CT planting, which may be due to the more effective transfer of dry matter from stem to grains in NT planting.

Although the spike number per unit area was lower, the grains per spike and 1000-kernel weight were significantly higher in NT planting than in CT planting. Ultimately, the grain yield for NT planting was increased by 8.21% as compared to CT planting (Table 8).

Table 8. Effect of different planting methods on grain yield and yield components in winter wheat

Planting method	Spikes (million ha^{-1})	Grains per spike	1000-kernel weight (g)	Grain yield (t ha^{-1})
NT	6.01	30.8	40.9	7.56
CT	6.98	25.2	39.7	6.99
LSD (5%)	0.34	3.6	5.6	0.76
CV%	10.6	14.1	2.0	5.5

The research has indicated that the area of flag leaves and second leaves are considerably lower in NT planting than in CT planting, which can improve light transmission in the canopy and air circulation, promoting the border effect and delaying the leaf senescence. Both the individual and population structures of wheat are better in NT planting in dry land. These advantages have effectively increased the grain yield of winter wheat.

Conclusions

The results of this research demonstrate that no-tillage planting is very suitable for winter wheat production in dry land.

Investigations on the Practices and Economical Benefits of Conservation Agriculture in Shandong Province

Analysis of the production costs of CA cf conventional system

Based on a long-term trial conducted at Weibei farm (yield results not reported here), production costs were calculated for the conventional and conservation agriculture systems. In the case of Conservation agriculture with wheat/maize rotation, production costs were 11,325 yuan RMB ha^{-1}. In the case of Conventional intensive cultivation, also with wheat/maize rotation, the production cost was 13,290 yuan RMB ha^{-1}. In the case of Conventional roto-tillage planting, the production cost amounted to 12,705 yuan RMB ha^{-1}.

According to the estimation of crop yield in 2007, the average wheat yield of CA plots in six demonstration counties including Changyi, Zhangqiu, and Gaoqing was 6735 kg ha^{-1} with the highest yield of 7677 kg ha^{-1}. The average yield with CA was 8 percent higher than that of conventional planting. In hill and dry-lands, grain yield of wheat grown under CA conditions was 4455 kg with the highest yield of 5775 kg ha^{-1}, 23 percent higher than yields with conventional tillage. In the fields of Innovation and Demonstration Projects managed by Shandong Agricultural Machinery, the grain yield reached to 9215 kg ha^{-1}, 13.7% higher than conventional planting. In dry-lands of Boshan, wheat grain output was 6576 kg ha^{-1}, 35% higher than conventional planting. Corn mechanical direct sowing can give good plant density, efficient application of fertilizers, good air and light penetration and thriving development, and can avoid damage of the wheat and corn when seeding corn or when harvesting wheat. The corn yield can increase by about 5%.

During the past years, the wheat planted using CA technology cropped better than that using conventional planting. The grain yields have significantly increased. This may be attributed to the following: 1) The seeding-machine newly-purchased in 2006 works well and gives good seed placement and seed-soil contact; 2) improved soil moisture because the soil is not disturbed and exposed to the atmosphere, and because residue cover inhibits soil moisture evaporation and increases the ability of the soil to retain water. A measurement made in 14 April, 2007 in dry-lands of Wangguang village in Zhangqiu showed that the water volume that the 0-20 cm topsoil can hold increased by 6.7% after adoption of CA technology.

There were more ineffective tillers due to the higher temperature under conventional planting conditions, thus wasting much water and fertilizers. While in fields planted using CA technology with residue retention, the lower soil temperature, slower soil moisture evaporation and deeply applied fertilizers promote the seedling and root growth and productive tiller development. A survey of experimental plots in Zhangqiu showed that the wheat planted using CA technology developed 3-5 more tillers per plant than that using conventional planting technology. Results showed that 1-2 more effective tillers developed in wheat planted using CA technology and nearly no excess growth occurred. Whereas the secondary roots in conventional planted wheat developed poorly due to high soil moisture evaporation during the long turn-around period in corn/wheat rotation planting system, thus leading to the deficiency of water and fertilizers and then affecting the wheat yields.

The slower rise of soil temperature due to the stalk covering and higher soil moisture in spring gave a slightly later development of seedlings, and so the wheat escaped the freezing damage by the late spring cold that occurred in 16 March, 2007.

The germination of weed seeds is light-dependent. Under CA conditions the stalk covering can effectively block the post-germination growth of weeds. Based on our investigations we have found that the weed numbers in the fields planted using CA technology are less than half those in the fields planted using conventional planting.

The soil fertility in fields planted using CA technology is gradually increasing year by year due to the residue retention. In Changyi, Zhangqiu and other counties, the soil fertility in fields planted using CA technology for 2-3 years has significantly enhanced, giving better harvests.

The wide row spacing alternating with narrow spacing in wheat fields planted using no-till seeder could improve the air and light penetration into the canopy and favor the development of border row superiority. Additionally, the lower soil temperature and higher soil moisture under CA conditions could prevent senescence, and thus increasing the grains per spike and 1000-kernel weight.

Wheat planted using CA technology can develop reasonable crop structure and better air and light availability, with decreased plant height and improved growth. Seeds sown with the wide row spacing are uniformly distributed and develop vigorous roots, more effective tillers, and robust and lodging-resistant seedlings. Lodging occurred frequently in conventionally planted wheat, while this was rarely seen in CA-planted wheat.

Incomes of farmers and holders of agricultural machinery

The production cost can be cut down by 100 yuan when using CA technology and increase income from grain output by 90 yuan, thus giving an additional 190 yuan of net income. The farmers' income increased by 79.61 million yuan in Shandong after the adoption of CA technology in 419 000 plots in 2006. If the area could increase to 30 million mu (2 million ha), the farmers' income should have increased by 5.7×10^9 yuan.

Sun Deguang, the owner of the rotary no-till seeder, sowed more than 500 mu of crop in 2005, about 1000 mu in the fall of 2006, having recovered his costs in these two years. According to a survey that each of eight owners of no-till seeders in Changyi planted 700-1000 mu of crop in 2006. Though subsidized and lower rates for seeding requested by the governments, one of the owners could still earn more than 20 RMB yuan from seeding of one mu of wheat, and the average annual incomes for the equipment owners could reach 12,000 yuan. The net income of all machine owners in Shandong totaled 8.38 million yuan in one year.

Soil fertility

The soil fertility and nutrient components have significantly been improved in CA planting system. The soil organic matter content has increased by 0.05% due to residue retention in double-cropped systems. The soil under CA conditions has a good infiltration of rainfall due to the continuous pore system, and has higher drought-resistance due to large soil moisture storage and residue retention.

Environmental protection and resource-saving

Under CA conditions, residue retention and stalk covering favor soil conservation, increase soil organic matter, improve aggregate structure of soil and decrease the finely ground particles of soil that are easily eroded by wind. CA can save fuel by 2.47 liter per mu compared to conventional planting. If the adoption of CA technology could increase up to 2 million ha, 74,100 ton of diesel oil would be saved. During one wheat/corn rotation period, 60 m^3 of water would be saved per mu. The irrational extraction of groundwater has greatly diminished.

Conclusions and recommendations

The adoption of CA technology can significantly reduce the production cost and resource inputs. The CA technology is not only adapted to hill and dry-lands but to irrigable lands with high yields as well. Conservation agriculture is a highly efficient management system. Conservation agriculture favors the construction of resource-saving society.

Low operating efficiency of corn combine and high charges for harvest considerably increase the production cost. The development of corn combine should be strengthened. The size of current no-till planter used for irrigable lands is the same as used for dry-lands. The row spacing created by the planter is too wide for the dry-land wheat to cover the ridge, causing the waste of light and energy and higher water evaporation rate from soils. No-till planter with variable row spacing should be developed to meet the agriculture needs of lands with different water availability and soil fertilities. Installation of equipment for residue cutting on wheat combines should be encouraged to enhance the quality of corn direct seeding. The time is ripe for comprehensive extension of the CA technology in Shandong. Local governments at all levels the executive branch of agriculture machinery should give more policy support, publicity and promotional events, intensify the efforts on market guides and popularize the revolutionary technology as soon as possible.

Mengjin County, Henan

Sub-soiling, straw cover, reduced tillage and zero tillage were chosen as the main research and demonstration thrusts. The goal was to find a set of best and easy techniques for the farmers: the techniques should be easy to operate, save water, move less soil and be suitable for the local area.

Expt 1

Research of different CA techniques in Songzhuang

We chose Yaowa village for demonstration and established a demonstration field (learning site) of about 20 Chinese mu (more than 1 ha). The treatments were: zero-tillage (with zero till seeder made by "Nonghaha"); furrow planting which is widely accepted by the local farmers; and permanent bed-planting. The year of 2007 was a very dry year in the history of Luoyang area. The total rainfall was only 370.2mm, 62% of the average precipitation. The rainfall in Aug-Sep was only 59.2mm, 33% compare to the normal year. The climate was also dry in 2008, e.g., the rainfall between Feb-Mar was only 11.3mm, or 19% of the normal rainfall. Wheat developed only 2-3 tillers (usually 6-7 tillers) and the yield decreased to 60%-80% of the average wheat yield.

Yield

In 2006, all the cover treatments, including plastic cover and straw cover, improved wheat yield (Table 9). The reason is these treatments improve the ear number m^{-2} and the grains/ ear. The plastic cover can improve the yielding by 10.4% compare to the CK. The straw cover also can improve 3.9% yielding compare to the check.

In 2007, there were few significant differences in yield between treatments (Table 10). However, the treatment with plastic mulch did yield significantly less than the highest yielding treatment – bed planting with straw cover - as early season temperatures were high so that the wheat under plastic cover grew very fast and consumed too much water in the early stages and did not have enough water for grain filling.

The beginning of the 2008 season was dry and there was significant moisture stress in all treatments. Wheat yields were very low this season (Table 11) because of this stress and the resultant low spike numbers and grain numbers per spike.

Table 9. Wheat yield and yield components under different cover treatments, 2006.

Treatment	Grain Yield (kg ha^{-1})	Increase over CK %	1000 grains weight (g)	Grains/ spike	Spikes m^{-2}
CK	5110	-	33.1	32.2	536
PC	5640	10.4	33.3	34.2	564
FP	5300	3.8	33.9	34.5	742
BP	5150	0.9	33.1	34.8	670
BC	5260	3.0	34.2	34.6	675
SC	5310	3.9	32.6	34.0	829
PF	**		**	**	**
LSD (5%)	229		0.6	0.6	56
CV%	2.4		1.8	2.8	16.3

Treatment key: CK: Check; PC: plastic mulch; FP: furrow planting; BP: bed planting; BC: bed planting and straw cover; SC: straw cover.

Table 10. Wheat yield and yield components under different cover treatments, 2007.

Treatment	Mean Yield kg/ha	Increase over CK (%)	1000 kernel wt (g)	Grains/ spike	Spikes/m2
CK	3,163		22.2	35.6	466
PC	3,126	-1.2	21.3	34.2	466
FP	3,324	5.1	23.3	35.8	484
BC	3,513	11.1	25.9	36.6	535
SC	3,289	4.0	23.0	35.2	514
PF	*		**	NS	**
LSD (5%)	384		1.3	2.5	24
CV%	4.7		7.4	2.5	6.2

Treatment key: CK: Check; PC: plastic mulch; FP: furrow planting; BC: bed planting and straw cover; SC: straw cover.

Table 11. Wheat yield and yield components under different cover treatments, 2008.

Treatment	Mean Yield (kg/ha)	Increase%	1000 grain weight (g)	Gains/Ear	Ears/m^2
CK	911	0	44.2	12.6	246
SB	1284	41	45.6	16.5	240
PC	1383	52	45.1	16.7	228
FP	941	3	36.7	13.6	239
BC	1674	84	49.7	15.6	245
SC	1523	67	46.5	16.3	239
PF	***		**	**	NS
LSD (5%)	287		1.8	1.8	18
CV%	24.0		9.7	11.2	2.7

Treatment key: CK: Check; PC: plastic mulch; FP: furrow planting; SB: straw replaced after tillage; BC: bed planting and straw cover; SC: straw cover.

In maize in 2006 (Table 12), all of the treatments except the plastic mulch yielded significantly more than the check, with the furrow planted treatment giving the highest yield as a result of having significantly more cobs/ha than all the other treatments. In 2007 (Table 13) all the cover treatments were significantly higher yielding than the check. The bed-planting treatment with straw cover, which improved yield by 26.4% and the plastic cover which improved yield by 24.2% yielded significantly more than the furrow planting and straw cover treatments which significantly more than the check with increases of 17.8% and 17.6% respectively over the check. The 2008 season was very dry and there was not enough moisture for a maize crop.

Table 12. Maize yield and yield components under different cover treatments, 2006.

Treatment	Yield (kg/ha)	Increase over CK %	1000 grain wt (g)	Grains /cob	Cobs/ha
CK	3,823		221	413	31,875
PC	4,042	5.7	217	436	31,249
FP	4,690	22.7	224	474	32,709
BP	4,344	13.6	234	442	31,041
BC	4,359	14.0	226	447	31,666
SC	4,348	13.7	222	428	31,666
PF	**		NS	*	**
LSD (5%)	370		24	42	584
CV%	3.9		2.6	4.7	1.8

Treatment key: CK: Check; PC: plastic mulch; FP: furrow planting; BP: bed planting; BC: bed planting and straw cover; SC: straw cover.

Table 13. Maize yield and yield components under different cover treatments, 2007

Treatment	Mean Yield (kg/ha)	Increase over CK (%)	1000 kernel wt. (g)	Grains/cob	Cobs/ha
CK	3,900	-	160.1	508	50,907
PC	4,845	24.2	179.6	547	52,500
FP	4,594	17.8	192.7	542	45,000
BC	4,930	26.4	210.9	510	56,718
SC	4,585	17.6	175.3	508	56,718
PF	**		**	*	**
LSD (5%)	246		21.1	27	4,540
CV%	8.9		10.4	3.8	9.3

Treatment key: CK: Check; PC: plastic mulch; FP: furrow planting; BC: bed planting and straw cover; SC: straw cover.

Expt 2. Comparison of different CA technologies under a double-crop maize-wheat system – Luoyang Village, Zhangqui County.

A trial comparing five six tillage systems in a maize-wheat double-crop system was initiated in Luoyang Village in 2006. The trial, arranged in a randomized block design with three replications compared a) Maize (zero till) +Wheat (sub-soiled); b) Maize (zero till) +Wheat (zero till); c) Maize(sub-soiled)+Wheat(sub-soiled); d) Maize (sub-soiled) +

Wheat(zero till) e) Maize (zero till) + Wheat (sub-soiled) with residues replaced after sub-soiling and f) the check treatment with both maize and wheat conventionally tilled.

Yield

In year 2006, sub-soiled and zero till both improved wheat yields: the best system was the Maize (Zero till)-Wheat (Zero till) which gave 6.5% higher wheat yield than the conventionally tilled check. The Maize (Sub-soiled) - Wheat (sub-soiled) treatment improved wheat yield by 5.2%, and Maize (sub-soiled) – Wheat (zero till) improved wheat yield by 5.1%.

Maize (sub-soiled)-Wheat (zero till) gave the highest maize yields compared to the other treatments. Maize yield in this treatment was 23.54% higher than the Check, whereas in the Maize (zero till)-Wheat (zero till) maize yields were 14.97% higher than those in the Check.

In 2007, there were no significant differences in wheat yields between tillage treatments (Table 14). The 1000 grain weight, ear numbers and numbers of grains per ear were all significantly higher in all the sub-soiled and zero tillage treatments compared to the check.

Table 14. Wheat yield of different CA technologies in a double-crop system (2007)

Treatment	Grain Yield kg ha^{-1}	Increase %	1000 Grains weight (g)	Grains/ear	Ears/m^{-2}
MzWs	3300	4.3	23.4	36.8	584
MzWz	3320	4.8	24.4	35.4	540
MsWs	3440	8.8	25.1	38.9	570
MsWz	3340	5.6	24.7	39.2	552
SB	3270	3.4	23.0	34.9	486
CK	3160	-	22.2	35.6	467
PF	NS		**	**	***
LSD (5%)	361		0.8	1.1	24
CV%	6.0		4.6	5.0	8.8

Treatment key: MzWs: Maize (zero till) +Wheat (sub-soiled); MzWz: Maize (zero till) +Wheat (zero till); MsWs: Maize (sub-soiled)+Wheat(sub-soiled); MsWz: Maize (sub-soiled) + Wheat(zero till) SB: straw replaced after tillage

Maize yields in 2007 were, however, significantly greater in all the no-till and sub-soiled treatments than in the check (Table 15). Highest yields were obtained when both crops were sown without tillage (11.4% higher than the check) and when both crops were sub-soiled (10.8% greater than the check). Yield increases arose from a combination of increased ear numbers and grains per ear.

The wheat season in 2008 was particularly dry and yields were low as a result of the moisture stress (Table 16). Under these conditions the effect of the no-till and sub-soiling treatments on crop yield were huge: the yield of wheat in the double no-till system (MzWz) was almost double that of the check, and the lowest yielding alternative tillage treatment – where straw was replaced after sub-soiling prior to the wheat crop – was 44% higher than the check, and all the no-till and sub-soiled treatments yielded significantly more than the check. These yield increases were largely due to a combination of increased grain numbers per spike and heavier grains, suggesting benefits in soil moisture both before and after flowering in the no-till and sub-soiled treatments.

Table 15. Maize yield of different CA technologies in a double-crop system (2007)

Treatment	Grain Yield kg ha^{-1}	Increase %	1000 grains weight	Grains/ear	Ears ha^{-1}
CK	3900	-	160.1	508.4	50,907
MzWs	4180	7.2	164.3	497.0	58,595
MzWz	4340	11.4	168.5	538.6	53,907
MsWs	4320	10.8	168.9	542.3	52,970
MsWz	4070	4.4	163.3	522.0	58,125
PF	***		NS	*	**
LSD (5%)	137		12.1	30.9	1,535
CV%	1.8		2.2	3.7	6.1

For treatment descriptions see Table 14.

Table 16. Wheat yield of different CA technologies in a double-crop system (2008)

Treatment	Grain Yield kg ha^{-1}	Increase %	1000 gains weight	Gains/Ear	Ears m^{-2}
MzWs	1580	73	46.	17.9	245
MzWz	1820	99	47.9	18.3	257
MsWs	1700	87	47.5	17.4	263
MsWz	1710	88	47.6	17.7	258
SB	1280	41	45.6	16.5	240
CK	910		44.2	12.6	246
PF	***		*	**	0
LSD (5%)	104		2.3	2.6	16
CV%	8.5		3.1	12.6	3.6

For treatment descriptions see Table 14.

Soil water content

The soil moisture in the various treatments during the 2007 and 2008 wheat season are shown in Figures 6 and 7 respectively. It is evident from these two figures the difference in total soil moisture in the top two meters of soil during most of the early part of the season in 2007. In 2008, soil moisture increased towards the end of the season as the crop was so poor it did not extract all of the moisture available from some late rains.

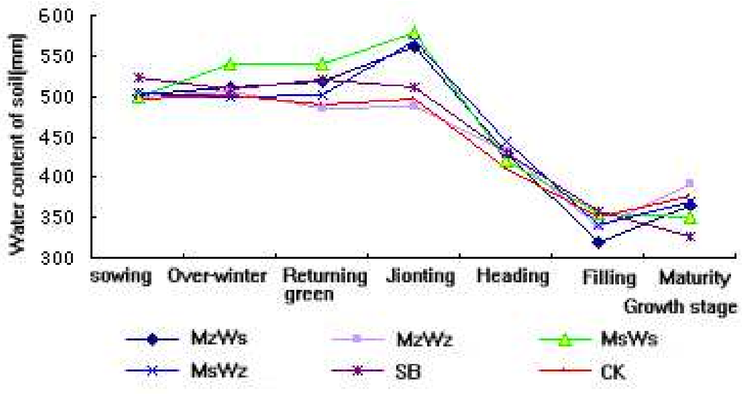
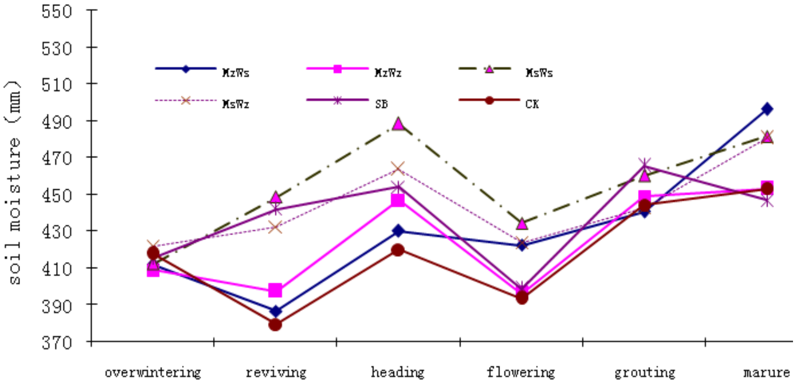


Figure 6. The dynamic changes of 0-200cm soil water content (2007)



The dynamic changes of 0-200cm soil water content (2008)

Figure 7. The dynamic changes of 0-200cm soil water content (2008)

In 2008, the soil moisture content of all 4 kinds of conservation tillage and the straw stalk tillage were higher than the Check, although there were changes between treatments at the different crop stages.

Expt 3. **The effects of different CA techniques on wheat**

This experiment was conducted in 2006 in Songzhuang village. There were five treatments in a randomized block design with three replications: Reduced tillage (one crop a year, wheat), zero tillage (one crop a year, wheat), sub-soiling (one crop a year, wheat), two crops a year, Conventional tillage.

Yield

In 2006, none of the treatments yielded significantly differently to the check. However, the treatment with wheat in a system with two crops per year yielded the least, and this was significantly less than the treatment with wheat after sub-soiling (Table 17).

Table 17. The wheat yielding under different CA treatments (2006)

Treatment	Grain Yield kg ha^{-1}	Increase Over CK (%)
R	5,166	-0.1
Z	5,217	0.9
DC	4,926	-4.8
S	5,445	5.3
CK	5,172	
PF	*	
LSD (5%)	312	
CV%	3.5	

R: reduced tillage (one crop a year, wheat) Z: zero tillage (one crop a year, wheat) S: sub-soiling (one crop a year, wheat) DC: two crops a year (wheat-maize) C: conventional tillage.

Expt 4. **Research results from the Yaowa village site**

The rainfall of Luoyang area usually is enough for one crop a year but not enough for two crops a year (as can be seen in Table 17). In recent years, more and more farmers choose the wheat-maize rotation instead of only planting wheat in a growing season, but the proportion of maize suffering from drought in the early summer is very high, so the farmers in this area have an aphorism "you can plant maize but you should not hope for any harvest". We hoped to find another crop for this area to decrease the risk of planting maize. There were some good choices for this area such as millet and sesame. Soybean isn't the best one for this area, but we think the soybean needs less field work than other crops and it is also easier to harvest by machine.

Yield

We used furrow-planting, zero tillage and bed-planting in farmers' fields for the second year in 2006 following wheat, maize and soybean planted in the field last year. Data on yield and yield components are shown in Tables 18 and 19 for the 2006 and 2007 seasons respectively. In 2006, furrow-planting produced the highest yield in a double-crop system, bed-planting was second, and the lowest was zero-tillage. However, in 2007, the ranking of yields was reversed, with zero tillage resulting in the highest yields – significantly more than both the furrow planting and the wheat on beds. However, the seeding mechanism of the seeder used for the raised bed system did not work properly, resulting in lower plant stands and fewer spikes per unit area.

The highest wheat yield was produced in the one-crop system, significantly higher than conventional wheat after maize, suggesting that stored moisture in the soil profile at the start of the wheat season is very important. However, in the 2007 season (Table19) the wheat sown with zero tillage in a double crop system did not yield significantly less than the single crop wheat in a conventionally tilled system.

Table 18. Wheat yielding under different tillage methods in Yaowa village (2006)

Tillage method	Grain Yield kg ha^{-1}	Yield components		
		Ears m^{-2}	Grains/ear	1000 grains weight(g)
Zero-tillage	5285	552	29.7	37.68
Bed-planting	5699	560	29.6	37.68
Furrow-planting	6000	486	33.6	38.74
PF	*	*	*	
LSD (5%)	696	48	3.94	1.82
CV%	6.35	7.60	7.37	1.61

Table 19. Wheat yielding under different tillage methods in Yaowa village (2007)

Tillage method	Grain Yield kg ha^{-1}	Yield components		
		Ears m^{-2}	Grains/ear	1000 grains weight(g)
Zero-tillage	4017	559	30.3	32.6
Bed-planting	2591	487	29.1	30.4
Furrow-planting	3127	545	28.1	28.6
Wheat-maize	2742	528	28.3	26.4
Wheat(one crop)	4473	655	26.7	30.7
PF	**	**	NS	**
LSD (5%)	734	40	3.4	2.0
CV%	24.2	11.2	4.7	7.9

In 2008, wheat plants only had 2-3 tillers, instead of the 6-7 tillers in normal years. Yields this year decreased by 60-80% due to drought. Total rainfall was only 370.2 mm – only 62% of the precipitation in a normal year. Rainfall during Aug-Sept was only 59.2 mm, 33% of that in a normal year. Even so the wheat crop as a single crop appeared to have sufficient moisture stored in the soil to be able to give a yield similar to the previous seasons (Table 20), and significantly more than all the double-crop treatments.

Table20. Wheat yield components under different treatments (2008)

Treatments	Grains/ Ear	Ears m^{-2}	1000 grains weight (g)	Grain Yield (kg ha^{-1})
Two crop	31.2	261	40.9	2476
Bed-planting	33.2	241	42.7	2861
Furrow-planting	33.1	246	41.7	2349
Reduced tillage	32.1	265	41.6	2697
One crop	30.8	471	39.5	4490
PF	NS	**	**	**
LSD (5%)	4.2	22.0	1.1	213
CV%	3.4	33.0	2.9	29.3

Shouyang County, Shanxi

The trial in Shouyang County compared a conventionally tilled check (CK) (All residue removed, plowing in autumn, harrowing in spring); a conventionally tilled treatment with all residues returned (ASRT) (All residue plowed in to 0~20 cm in autumn, seeding and fertilizing in spring in one pass); no tillage with mulch (NTSM)(No tillage, all residue remain on soil surface); a roto-tilled treatment with 2/3 residues removed (RRT) (About 1/3 straw chopped and rotary plowed into 0~15 cm layer); and a no till treatment with all residues removed (NTWS – treatment started in 2008). The maize genotype used in this trial was Qiangsheng 31, bred by Shanxi Academy of Agricultural Sciences in 2002 and examined and approved by National Authorities in 2003 (No. 2003043).

Soil moisture was measured gravimetrically at ten day intervals from planting to harvest .in the 0~20cm, 20~40cm, 40~60cm, 60~80cm, 80~100cm, 100~120cm, 120~140cm, 140~160cm, 160~180cm, 180~200cm layers.

Soil temperature was measured by a probe (HIOKI, Japan) and an electric resistance-probe (IEDA) at 8~9 am and 14~15 pm on certain days. Soil temperature was measured each day from planting to seedling and every 2 days from seedling to end of May, every 3 days in June and every 7 days in July.

Soil microorganism: Soil sampling was carried out in October 2007 (after harvesting maize). Soil samples from each plot were composed from ten sub-samples which were taken with a probe (5 cm diameter core) and divided into layers of 0-5cm, 5-10cm, 10-20cm, and 20-30 cm. After carefully removing the surface organic materials and fine roots, each mixed soil sample was divided into two parts. One part of the soil sample was air-dried for the estimation of soil chemical properties and the other part was sieved through a 2 mm wide screen and adjusted to 50% of its water holding capacity and then incubated at 25^{o}C for 2 weeks to permit uniform rewetting and to stabilize the microbial activity after the initial disturbances. Microbial biomass C and biomass N were estimated by fumigation–extraction. Soil enzyme activities (dehydrogenase, β-glucosidase, alkaline phosphatase, and urease) were determined by the method of Wu et al.

The soil moisture results showed that July to August is a high consumption period for moisture stored in the soil, because the crop has high water requirement and evaporation due to the high temperatures during this period. There are differences in soil moisture at different stages of crop growth. The steady period of moisture is the first, from seeding to emergence, when the crop requires less water, and differences in soil moisture depend mainly on the treatments. NTS and the control had the lowest soil moisture levels, whereas other treatments retained more water in soil and thus had higher moisture content. From early July to mid-August, water stored in soil dropped to the lowest level. From mid-August, soil moisture recovered since the temperature gradually falls, and the crop’s water requirement also decreases. In addition, soil moisture is supplemented by rainfall and the amount of stored soil water increases gradually. Although the soil moisture pattern is the same for all treatments, there are differences between the different treatments and ASRT and NTSM retain more water than the others. CK and NTS had the lowest soil moisture. No tillage and mulching improved and enhanced soil moisture.

Soil temperature has a large influence on maize germination, and CA and tillage can have major effects on surface soil temperature. Because the soil surface is covered with straw, it difficult for sunlight to reach the ground directly and soil temperature under CA is lower than under conventional tillage. The no tillage with mulch treatment reduced soil temperature by 1 to 2°C compared with conventional tillage. Under the no tillage treatment, soil moisture content is high and soil heat exchange is not good. The temperature effect is greatest at the soil surface but can be measured all the way down to 60cm.

Under the no tillage the soil temperature of the treatment with all straw mulch retained was rather low over the seeding period: around 8-13°C. Low temperature is always a key limiting factor. Diurnal variation in soil temperature in the 0-5 cm layer was affected by different treatments. For all the treatments, the highest diurnal variation in soil temperature occurred in the 0-5 cm layer, which can reach 10-20%. The variation coefficient of soil temperature decreased rapidly in the layers below 5 cm (Figure 8).

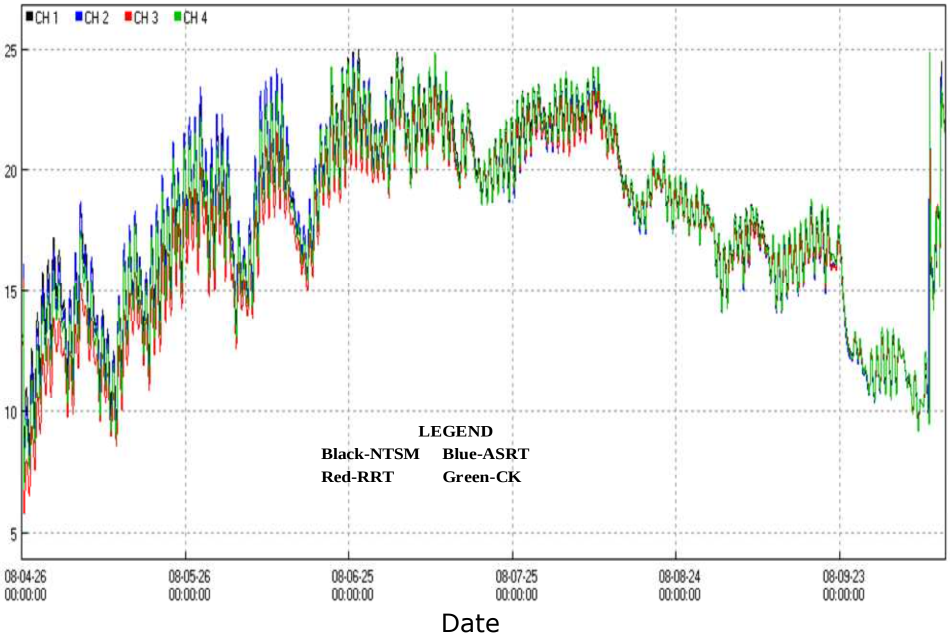


Figure 8. Soil temperatures with different tillage in the growth period

<u>Water infiltration.</u>

Soil water infiltration is the process of water entering the soil through all or part of the ground surface. The process is influenced by water supply and the soil capacity for water infiltration, which determines the quantity of water entering soil or lost by runoff. The capacity for soil water infiltration is related to soil texture, soil structure, ground gradient and water content of soil section pane. At the same time, the capacity for soil water infiltration in the field is related to the tillage method. The stabilized infiltration rate (26.4mm/h) with deep tillage (DT) was twice that with light tillage (LT), and 4.1 times more than with no tillage (6.4mm/h). When rainfall lasted 20 and 40 min, deep tillage increased infiltration by 21% and 28%, respectively, compared with light tillage, and increased by 31% and 33%, respectively, compared with no tillage. This typically signals serious soil degradation after several years of farming. Conservation agriculture with mulch cover promotes soil water infiltration and improves soil physical and chemical properties. However, the effect only becomes apparent after quite a long period. The results of our trial show that treatments including whole straw mulch, no tillage with mulch, shallow rotary tillage with mulch, and conventional tillage all affect soil infiltration rate. Initially, the infiltration rate under conventional tillage was the highest, and the rate under no tillage with mulch was the lowest. However, the differences in infiltration rate gradually decreased, which is consistent with the results reported by other researchers. This indicates that conservation agriculture technologies like zero and reduced tillage are useful for improving soil water infiltration.

Soil organic carbon, soil total N and soil total phosphorus

Tillage had large effects on soil chemical properties. Soil organic carbon (SOC) differed significantly ($P>0.05$) among tillage systems and soil depths. In the 0 to 5 cm layer, organic matter content increased with decreasing tillage intensity so that it was 43% greater with no tillage, compared to the average of the other tillage treatments. CK and RRT resulted in the lowest organic matter content throughout the 0-20 cm soil layer. Below the 0 to 5 cm layer, organic matter decreased under no tillage, but tended to remain constant in the other treatments. The CK and RRT treatments, compared to no-tillage, incorporate residues into a larger volume of soil and therefore increase the rate of organic matter decomposition and C mineralization (Salinas-Garcia et al., 2002), by increasing the contact between soil microorganisms and crop residues (Henriksen and Breland, 1999). Return of all the residues did not increase SOC throughout the 0-20 cm in all treatments. However, after four years, the effects were extended to the 20-40 cm depth, where ASRT had higher values than other treatments. Below 50 cm, ASRT and NTSM had higher SOC than RT and CK treatments (Table 21).

Table 21. . Spatial distribution of soil organic carbon under different tillage treatments (g kg-^{1}) after four years of treatments.

Treatment [#]	ASRT	NTSM	RRT	CK
0-5	11.1 b [@]	15.7 a	12.1 b	10.0 c
5-10	10.4 b	11.9 a	10.2 b	10.6 b
10-20	10.7 a	10.3 b	9.9 c	10.9 a
20-30	9.5 a	9.3 a	9.2 a	6.7 b
30-40	7.5 a	4.9 bc	4.6 c	5.7 b
40-50	4.1 a	3.3 b	4.2 a	4.3 a
50-60	3.1 a	2.5 a	1.5 b	1.6 b
60-70	2.3 a	2.0 a	1.5 b	1.4 b
70-80	1.7 a	1.8 a	1.6 a	1.2 b
80-90	1.7 a	1.8 a	1.3 b	1.1 b
90-100	1.5 a	1.4 a	1.0 b	0.8 b

[#] CK = conventionally tilled check; ASRT = conventionally tilled with all residues returned; NTSM = No tillage, all residue remain on soil surface; RRT = roto-tilled with 2/3 residues removed.

[@] Treatments that share the same letter within the same row (depth) are not significantly different ($P<0.05$).

Soil organic carbon stocks have been identified as a good indicator of carbon dynamics under different management systems (Farage et al. 2007). Unlike SOC concentrations, stocks account for changes in both SOC concentrations and bulk density. Comparison of horizon and cumulative carbon stocks among tillage systems showed significant ($P>0.05$) tillage effect. At 0–20 cm depth, NTSM had significantly ($P>0.05$) higher horizon stocks than other treatments. Similarly, horizon stocks were higher at 20-40cm under ASRT than other treatments. After 4 years, CT (55.4 Mg C/ha) and RT (56.4 Mg C/ha) had about 19.5% lower ($P>0.05$) cumulative carbon stocks at 0–100 cm than ASRT (65.9 Mg C/ha) and NTSM (67.8 Mg C/ha).These remarkable increases in carbon stocks indicate attainable carbon sequestration by converting from conventional tillage to straw return tillage and no tillage systems (Table 22).

Table 22. Spatial distribution and cumulative soil organic carbon stocks under different tillage treatments (Mg C ha^{-1}).

Treatment [#]	ASRT	NTSM	RRT	CK
0-10cm	10.2 c [@]	17.4 a	11.0 b	10.7 b
10-20cm	12.7 b	13.4 a	12.4 b	14.0 a
20-30cm	13.2 a	12.7 b	12.2 b	9.0 c
30-40cm	10.4 a	6.7 b	6.2 c	7.6 b
40-50cm	5.6 a	4.5 b	5.5 a	5.9 a
50-60cm	4.1 a	3.4 b	2.0 c	2.2 c
60-70cm	3.1 a	2.7 a	1.9 b	1.8 b
70-80cm	2.3 a	2.5 a	2.2 a	1.6 b
80-90cm	2.3 a	2.5 a	1.7 b	1.5 c
90-100cm	2.0 a	1.9 a	1.3 b	1.2 b
Cumulative stock	65.9 a	67.8 a	56.4 b	55.4 b

[#] See Table 21 for treatment descriptions.

[@] Treatments that share the same letter within the same row (depth) are not significantly different (P<0.05).

Aggregate-size and soil organic carbon in aggregates

Significant differences due to different tillage systems were observed in all aggregate size classes (>2, 0.25–2 and 0.053–0.25 mm), and in the silt + clay fraction (<0.053 mm). ASRT and NTSM soils had a higher proportion of macroaggregates than microaggregates. Within the macroaggregates of ASRT and NTSM, the 0.25-2 mm fractions were more abundant. RRT and CK significantly reduced macroaggregates in the surface layer (0-20 cm) (Table 23).

Table 23. Percentage of soil size classes under different tillage treatments (%)

Treatment	Macro-aggregate		Micro-aggregate	
	>2mm	0.25-2mm	0.053-0.25mm	<0.053mm
ASRT	23.0 a [@]	29.8 b	25.1 c	22.1 c
NTSM	19.7 b	31.4 a	28.9 b	20.0 d
RRT	14.6 c	29.6 b	26.2 c	29.5 a
CK	11.3 d	28.2 c	37.3 a	23.1 b

[@] Treatments that share the same letter within the aggregate size are not significantly different (P<0.05).

The effect of tillage systems on soil aggregate stability was evaluated by mean weight diameter (MWD) of aggregates. MWD was significantly (P>0.05) affected by tillage systems in the top 0–20 cm. Average MWD at 0–20cm depth decreased in the order: ASRT (0.84mm)>NTSM (0.80mm)>RRT (0.68mm)>CK (0.61mm) (Figure 9). The increasing trend (CK<RRT<NTSM<ASRT) at 0–20cm in MWD reflected the importance of increasing SOC in stabilization of soil aggregates. Poor aggregate stability under CT was related to the weakening of aggregates due to periodic perturbation of soil by tillage implements, exposing soil organic carbon to oxidation. Chivenge et al. (2007) observed that the destruction of aggregates during tillage operations was a major cause of soil structural breakdown under conventional tillage. Our findings support other studies which showed higher aggregate stability under RT and CK than ASRT and NTSM.

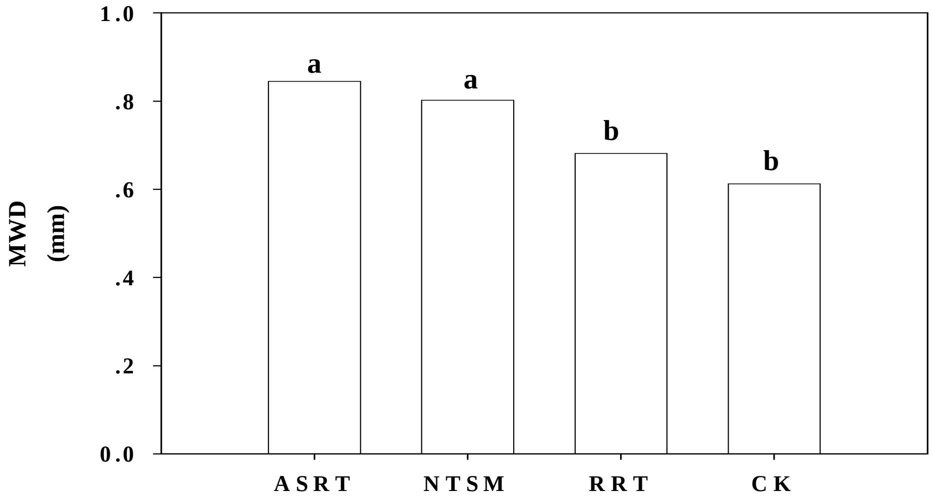


Figure 9. The mean weight diameter (MWD) of aggregates (mm)

Conservation agriculture is often a beneficial method for reducing C losses in agricultural soils. In general, trapping C in aggregates can slow mineralization and result in a net gain in soil C (Mikha and Rice, 2004). In a previous study (Zibilske and Bradford, 2003), significantly greater C mineralization, alkaline phosphatase activity, and O_2 uptake were found in the surface 20 cm of these tillage treatments, indicating enhanced microbiological activity. All aggregate size classes in soil managed with ASRT, NTSM and RRT concentrated more C than the CK treatment. The SOC was higher in the NTSM treatment followed by ASRT treatment. CA treatments were more effective in storing C: results indicate that increases in soil C occur with the use of CA. This accreted C should help stabilize the soil, leading to improved sustainability of the system (Table 24).

Table 24. Soil size classes in SOC under different tillage (g kg-1)

Treatment	Macro-aggregate		Micro-aggregate	
	>2mm	0.25-2mm	0.053-0.25mm	<0.053mm
ASRT	13.9 b [@]	13.0 b	10.0 a	10.0 ab
NTSM	16.8 a	15.2 a	9.8 a	10.9 a
RRT	13.2 c	13.3 b	9.6 b	9.3 b
CK	12.7 c	12.5 c	9.3 b	9.0 b

[@] Treatments that share the same letter within the aggregate size are not significantly different ($P<0.05$).

Soil microbial biomass carbon, microbial biomass nitrogen (MBN) and enzymatic activities

Microbial biomass C (MBC) and N (MBN) were significantly affected by soil depth and tillage system. MBC varied from 136 to 312 mg g-1 in the soil under ZT and from 120 to 166 mg g-1 under CK. MBN varied from 25 to 64 mg g-1 in the soil under ZT and from 26 to 47 mg g-1 under CK. In the 0-5cm and 5-10cm soil layers, MBC and MBN were significantly higher under ZT than CK. In the 0–5cm layer, microbial biomass C and N were, on average, 88% and 73% higher under ZT than under CK. Microbial biomass C and N decreased with soil depth, particularly under ZT. Soil subjected to ZT accumulated crop residues and organic C, which are substrates for soil microorganisms near the soil surface.

Since dehydrogenase activity is only present in viable cells, it is thought to reflect the total range of oxidative activity of soil microflora and consequently may be considered to be a good indicator of microbial activity (Nannipieri et al., 1990). Tillage system had significant effects on soil dehydrogenase activity. The dehydrogenase activity ranged from 5.2 to 44.8 mg TPF kg-1 24h-1 in the soil under ZT and from 13.8 to 36.8 TPF kg-1 24h-1 under CK (expressed as nmol reduced triphenyl formazan (TPF) g^{-1} dry weight soil). Zero tillage resulted in a significantly increase in dehydrogenase activity at the 0-5cm layer. In the 5-30 cm depth, there was no significant difference in dehydrogenase activity between treatments ZT and CK.

The phosphatases are a broad group of enzymes that hydrolyze esters and anhydrides of phosphoric acid. Long term tillage had a significant effect on alkaline phosphatase activity, particularly in the 0-5 and 5-10 cm soil depths, where ZT significantly improved alkaline phosphatase activity by at least 53.7% compared to CK as measured using p-nitrophenyl phosphate (PNP) as a substrate. In the 10-30cm depth, values for both treatments were similar, indicating that tillage effects on alkaline phosphatase activity were pronounced in the topsoil. Kremer and Li (2003) showed that phosphatase activity in soils under organic management was greater than under conventional management. The β-glucosidase activity varied from 185.6 to 352.9 mg PNP kg-1 h-1in the soil under ZT and from 106.6 to 257.0 mg PNP kg-1 h-1under CK. Averaged across the depths, β-glucosidase activity in soil under ZT was 46.7% higher than under CK. β-glucosidase, an enzyme already reported as an early indicator of changes in soil properties induced by tillage systems, catalyses the hydrolysis of various β-glucosides during the decomposition of organic materials. This fact could indeed explain the increase in β-glucosidase initially observed as a result of ZT with straw cover treatment.

After 4 years of experiments in Shouyang, the no tillage system and the conventional tillage system had different effects on soil chemical properties, microbial biomass and soil enzymatic activities in this study. SOC, TN and TP in the topsoil (0-10) were greater under ZT than under CK. Zero tillage promoted surface accumulation of crop residues and was more effective in improving soil biochemical quality than conventional tillage system. The beneficial effects of conservation management on soil quality were more noticeable in the surface 0–10 cm than below. In addition, the microbial biomass and enzyme activity showed higher sensitivity to soil management practices than did chemical properties. These variables might be used as soil good quality indicators once their critical values have been determined for different conditions.

The effect of different tillage treatments on crop growth and yield

Through investigating the maize emergence rate under different tillage systems in 2007-2008, we found that with NTSM, the crop emerges later than with other treatments, because the soil is relatively compact under no tillage, soil moisture is relatively high, and soil thermal conductance is poor. When the ground temperature drops, this influences the rate of emergence. With RRT, the crop emerged fastest, showing that topsoil cultivation can improve the rate of emergence. The data also show that NTSM guaranteed the number of seedlings just after filling the gaps with seedlings.

Growth traits of maize under different tillage treatments

Ecophysiological features such as crop height, root length, leaf area index and biomass were measured. Maize height was measured on May 25, July 2, August 6 and October 7, 2008. The results show that maize under ASRT had the tallest plants, while under no till without straw mulching and no till with straw mulching maize produces relatively short plants: crop height is affected by the treatments. The results of variance analysis showed there are significant differences among ASRT, NTSM with RRT, and CK in the early stages, and also significant differences between ARST and NTSM, NTS, RRT and CK at harvest.

On May 26, July 2 and August 7, 2008, we measured root length, root numbers and biomass. The results showed variations at different growth stages under different treatments. In the early stage, maximum root length was 13.5 to 18.0 cm, about 9 roots per plant; after the intermediate period, maximum root length was about 25 cm, and roots per plant increased sharply with crop development. The variance analysis showed no significant differences between treatments. The situation for biomass is different: after the intermediate stage, there are some significant differences among the various treatments.

The leaf is a very important organ and plays a key role for crop growth. The leaf area index (LAI) reveals the status of a crop. The results indicated that LAI was affected by tillage treatments, and in the early growth stages, there were significant differences between ASRT, NTS, CK and NTSM, RRT. In July and August, the LAI of ASRT and CK were almost the same, and the LAI of NTSM, NTS, RRT were lower. This indicates that the CA treatment affects the LAI.

Yield and yield components of maize under different tillage treatments

Compared with CK, CA treatments influenced the harvest index and yield of maize in dryland areas (Table 25). In 2005 and 2007, ASRT, RRT and NTSM increased maize yield by 10 to 12%, compared with the control. However, in 2006, the situation was different, with the control showing the highest yield, and with RRT and NTSM both showing reductions by a relatively large margin. In 2008, ear diameter and length, and grain rows and grain number per row were affected by tillage. With the ASRT, RRT and control treatments, ear diameter and length were better than that of NTSM and NTS, and directly caused grain number per ear to increase.

Table 25. Maize yields under different tillage treatments from 2005 to 2007

	Thousand kernel weight (g)			Yield (t/ha)		
Treatment	2005	2006	2007	2005	2006	2007
ASRT	259	302	296	5.29	5.58	7.54
NTSM	247	250	291	5.17	4.62	7.15
RRT	234	267	284	4.65	4.90	6.99
CK	238	317	282	4.72	6.13	6.60
PF	**	**	**	NS	*	*
LSD (5%)	1.8	2.3	0.9	0.95	0.68	0.67
CV%	3.2	5.3	1.2	9.3	6.9	5.1

Economics analysis

Based on our investigation in the pilot site, CA tillage is associated with reduction of crop production inputs, such as labor and machine fees (Table 26). With CA, total inputs may decrease 15-20%. This is consistent with farmer perceptions of the advantages of CA component technologies which are primarily centered on saving labor.

Table 26. The input of different tillage for maize in Shouyang County (2008)

Treatment	Fertilizer (Yuan)	Machine (Yuan)	Seed (Yuan)	Pesticide (Yuan)	Labor (Yuan)	Total (Yuan)	Percent (%)
CK	1500	1125	412.5	150	1650	4838	
ASRT	1500	1125	412.5	150	1500	4688	96.9
NTSM	1500	300	412.5	150	1500	3863	79.8
RRT	1500	525	412.5	150	1500	4088	84.5
NTWS	1500	300	412.5	150	1650	4013	82.9

Qingshuihe County, Inner Mongolia

The research site is located in Potouyao village and the learning site in Xiaomiaozi town. Five crops (oat, soybean, millet, sticky millet and maize) were compared under five tillage and residue management treatments: no till with high stubble (15-20cm)(NH), no till with low stubble (5cm) (NL), no till with high stubble (15-20cm) + 30% residue (NHS), no till with low stubble (5cm) + 30% residue (NLS), conventional tillage (T). Plot size was 700m^2.

At sowing, soil surface temperature under conservation tillage was less affected by changes in ambient temperature because of crop stubble and straw mulch, but the exposed soil surface under conventional tillage was more sensitive. In the seedling stage soil temperature rose in all treatments, and conventional tillage had the highest surface soil temperature. At maturity when there are severe temperature changes, soil temperature was not influenced by ambient temperature in the CA treatments, while soil temperature under conventional tillage dropped markedly: at harvest soil temperature was significantly lower under conventional tillage than under the CA treatments.

Soil moisture

In the whole growth period, soil moisture content with CA treatments was higher than with conventional tillage. Soil moisture with high stubble and residue cover is the highest, then low stubble with residue cover, low stubble and high stubble; CA conserves more soil moisture, which benefits crop growth and development.

Soil infiltration

The infiltration rate of water into soil was significantly affected by treatments and appeared directly related to the amount of residues retained: high stubble with residues cover > low stubble with residues cover > high stubble > low stubble > conventional tillage.

SOM and N, P, K nutrients

CA leads to increases in soil organic matter content from year to year. After four years of CA, soil organic matter content in 0 ~ 20 cm of NHS was higher than CK by 0.12%, NLS by 0.09%, and NH and NL by 0.05%. CA improves soil structure, increases soil moisture, and accelerates mulch decomposition, so that the organic matter content on the soil surface increases significantly.

Continuous no-tillage and straw mulch resulted in total nitrogen content in soil increasing year by year. High stubble with residues cover, low stubble with residues cover, high stubble and low stubble treatments all had greater total nitrogen contents than conventional tillage in all years (2006-2008) showing that no-tillage and straw mulch can raise the soil total N contents significantly.

Different tillage methods affected soil total phosphorus content significantly. The total phosphorus content under conventional tillage was lower in 2006-2007 than in 2005 while in all other treatments the total phosphorus content showed a gradual upward trend. The trend of 2008 was the same as 2007.

As the time under CA increased, soil potassium showed a significant increasing trend. At harvest in the third year total soil potassium in the 0-20cm layer was significantly greater than levels at sowing time of the second year. The greatest increase was with high stubble with residue cover, followed by high stubble, low stubble with residues cover and low stubble.

Soil microbial biomass

Soil microbial biomass carbon, nitrogen and phosphorus changed with soil depth in all growth stages. In all treatments microbial C, N and P levels were highest in the sub-surface (10-20cm) layer followed by surface soil (0-10cm) – microbial C, N and P were lowest in the 20-40cm layer. When measured at three different times, the differences between treatments in levels of microbial C, N and P followed the same pattern: NHS> NLS> NH> NL> T. Within the same treatment, levels also varied over time within the season - grain filling period> seeding period> harvest period.

Water and soil erosion

The water and soil erosion quantity was different under different tillage treatments. For example, in 2006 the largest quantity of run-off and soil loss was from the conventional tillage treatments, and the lowest from the high stubble with residue cover treatment. The runoff and soil loss quantity from the conventional tillage treatment was respectively 3.08 times and 2.79 times that of the high stubble with residue cover. The runoff and soil loss from the high stubble treatment were 2.09 times and 1.05 times that of the high stubble with residue cover. The water and soil loss in 2004 and 2005 were similar to that of 2006. Therefore, it is clear that CA significantly reduces the soil and water loss compared with the conventional tillage, while the residue cover can significantly increase the soil and water erosion protection effects.

Crop yield

In 2006, the yield of the conventional tillage treatment was the highest in all crops, while the yield of the zero tillage treatment with residue cover was higher than that without cover. In corn, for example, the yield of the conventional treatment was 20.5% higher than that of the yield of the zero tillage with high stubble treatment with residues, and 92.4% higher than the high stubble treatment without residues (Table 27). The yield of the zero tillage with low stubble and residue cover was 60% higher than that of the treatment without residue cover. The yields of millet, soybean, oat and sticky millet (broomcorn millet – *Panicum miliaceum*) with conventional tillage were 13%, 28%, 12% and 10% higher, respectively, than that of the zero tillage with residue cover. It should be noted however that the land on which this trial was sited had been abandoned due to severe land degradation prior to the trial.

In the very dry year of 2007, yield was relatively lower than normal. The yield of the different treatments showed: zero-tillage and mulching>zero-tillage and no mulching>conventional tillage. In 2008, after four years of applying CA, crop yield shows increasing benefits: crop yield in NHS was 33%, 33%, 29%, 27% and 27% higher than the conventional tillage check in maize, oat, soybean, millet and sticky millet, respectively (Table 28); crop yield in NLS was 30%, 27%, 22%, 2q% and 17% higher than the check oat, maize, soybean, millet and sticky millet, respectively; NH increased yield by 10-20% and NL by 10-15% compared to that of traditional tillage. Yield was higher in 2008 mainly because of higher than normal rainfall.

Table 27. The impacts of the different tillage to the crop yields (kg/hm^2) in 2006

Treatment	Corn	Millet	Soybean	Oat	Sticky millet
Low stub	3263 E [@]	3257 E	827 E	1703E	1412 E
Low stub with cover	5228 C	4346 C	1013 C	1934C	1584 C
High stub with cover	6333 B	4478 B	1047 B	2021B	1647 B
High stub	3965 D	3761 D	855 D	1818D	1497 D
Conventional	7629 A	5081 A	1338 A	2253A	1820 A

[@] Treatments that share the same letter within the same species are not significantly different (P<0.01).

Table 28. Effect of different tillage treatments on crop yield in 2008

treatments	Grain Yield (kg/ha)				
	maize	millet	soybean	oat	Sticky millet
NL	5255 A [@]	1965 A	1882 A	2114 A	1814 A
NLS	5972 B	2164 B	2090 B	2339 B	1999 B
NHS	6066 B	2288 C	2211 C	2445 C	2160 C
NH	5475 C	2062 D	2010 D	2218 D	1869 D
T	4577 D	1795 E	1711 E	1844 E	1706 E

[@] Treatments that share the same letter within the species are not significantly different (P<0.01).

Pengyang County, Ningxia

Expt 1. **Winter Wheat Zero-tillage Trial**

A trial was initiated in Pengyang County in September 2006 comparing the conventional tillage practices for winter wheat with no-till treatments with either 15cm or 30cm stubble left standing in the field. The trial was organized in a randomized block with three replications.

The Analysis of Variance of the yield results in 2007 showed that there was significant difference between 30 cm stubble treatment and conventional tillage treatment. Keeping 30 cm and 15 cm stubbles increased yield by 16.2% and 12.9%, respectively, compared with traditional tillage (Table 29). However, 1n 2008 after three years of continuous wheat there were no significant differences between treatments (Table 30).

Table 29. Comparisons of winter wheat yield with different tillage treatments (2007)

Treatment	Average Yield t/ha
CK	0.91
15 cm straw	1.03
30 cm straw	1.06
PF	*
LSD (5%)	0.10
CV%	7.4

Table 30. Comparisons for Winter wheat yield different tillage treatment (2008)

Treatment	Average Yield t/ha
CK	1.18
15cm straw	1.14
30cm straw	1.05
PF	NS
LSD (5%)	0.18
CV%	7.6

Expt 2. **Plastic mulch and winter wheat trial**

In this randomized block trial with three replications established in 2006/2007, an increasingly common practice of laying a strip of white plastic mulch and planting wheat at the side of this strip was compared with winter wheat seeded without the plastic mulch. The results (Table 31) showed that winter wheat with plastic mulch yielded 79% more than in the check without plastic mulch. Analysis showed that net income from seeding of winter wheat with plastic mulch was 80% higher than in the check without mulch, showing that the plastic mulch resulted in greater water use efficiency, especially in a drought year.

Table 31. Winter wheat yield and yield components in winter wheat with and without plastic cover as a mulch.

Treatment	Spike length (cm)	Grains/spike	1000-grain weight (g)	Grain yield (t ha^{-1})
Check	5.4	22.4	32.8	1.98
Winter wheat + plastic mulch	6.2	26.6	38.1	3.54
PF	*	*	*	*
LSD (5%)	0.4	1.4	1.8	0.43
CV%	7.9	8.7	7.7	28.9

***Expt 3*.** **Conservation tillage trial with plastic mulch**

A winter wheat trial was conducted with no tillage and with plastic mulch in all treatments to compare the effect of stubble height on crop performance in situations with plastic mulch. The three treatments in the trial were with stubble cut at 5cm, 15 cm and 30 cm. Analysis showed that there were significant differences in yield and yield components between treatments, with taller stubble giving greater yields (Table 32). Keeping 30 cm and 15cm stubbles increase yield by 17% and 8%, respectively, compared to the 5cm stubble treatment: yield was directly related to the height of stubble or increase straw quantity.

Soil moisture response to stubble height with plastic mulch

Soil moisture contents (0—60cm) for the different treatments were measured over the period from October 2006 to June 2007. Soil moisture contents of the different treatments showed an increase in moisture content with increasing stubble height: 30cm and 15cm stubble increased soil moisture content by 16％ and 20％, respectively, compared to the 5cm stubble treatment.

Table 32. Comparisons of winter wheat yield and yield components in treatments with plastic mulch and different stubble heights.

Treatment	5cm straw	15cm straw	30cm straw	PF	LSD (5%)	CV%
Spike number m^{-2}	158	188	170	*	10	28.9
Plant height (cm)	43	48	47	NS	7	7.7
Spike length (cm)	5.7	5.8	5.6	*	0.16	5.3
Kernel number grains/spike	13.8	16.2	16.3	*	1.2	8.3
1000 kernel weight (g)	35.9	37.5	36.7	*	0.5	2.5
Stalk Yield t/ha	1.065	1.065	1.245	*	0.117	7.7
Root t /ha	0.620	0.800	0.737	*	0.083	12.6
Yield t/ha	0.750	0.810	0.885	*	0.058	7.1

The effect of stubble treatments on soil moisture could be seen in all soil layers down to 60 cm: in the 0—20cm layer soil moisture was increased by 26％and 31％, respectively in the 30cm and 15cm stubble treatments compared to the 5cm stubble; in the 20—40cm layer soil moisture was increased by 31％and 26％; and in the 40—60cm layer soil moisture was increased by 14％and 3％, respectively in the 30cm and 15cm stubble treatments compared to the 5cm stubble.

Soil temperature change in different winter wheat treatment

Analysis of the effects of the different stubble height treatments with plastic mulch on soil temperature showed that there was a significant difference between 15cm and 5cm stubble treatments, but that, inexplicably the treatment with the 30cm. stubble was intermediate (Table 33).

Table 33. Effect of stubble treatments on soil temperature – all treatments had plastic mulch.

Stubble height (cm)	Average Temperature ^{o}C
30cm	10.0
15cm	10.7
5cm	9.4
PF	*
LSD (5%)	1.061
CV%	6.321

Expt 4. Maize zero tillage trial

A trial on the effects of zero tillage on maize was conducted in 2006. The trial, in a randomized block design with three replications, consisted of the following treatments:

A. Conventionally tilled with maize straw incorporated to 5cm (CK):(tillage)
B. Direct seeding (no tillage) 1/2 of maize straw left in the field.
C. Direct seeding (no tillage) all maize straw left in the field.

Effect on yield and other characters

Table 34. Yield and yield components

Treatment	Weight of 100 kernel(g)	Kernels /ear	Calculated ear no. ha^{-1}	Yield (t/ha)	Increase over CK (±%)
CK	20.4	485	54,983	5.44	
1/2 maize straw	20.9	381	44,958	3.58	-34.2
All maize straw	22.4	419	48,372	4.54	-16.5
PF	NS			*	
LSD (5%)	3.3	10		0.68	
CV%	5.3	10.1		17.7	

Yield was reduced by residue retention due largely to a decrease in plant stand (Table34), although grain weight per ear was also somewhat reduced by residue retention. Thus the principal effect was the effect of the treatments on plant stand. There was, however, more soil moisture at seeding in the plots with residue cover (Table 35) and emergence rates were not different between treatments (Table 36). Soil moisture throughout the season was higher in the plots with residue cover than in the check (Figure 10). However, early growth was much slower in the treatments with straw cover (Table 37). Although the crops with straw cover had caught up to some degree with the check by tasselling, the effect of this reduced growth on ear numbers was already established.

Table 35. WUE comparison among treatments with different amounts of straw retention.

Treatment	CK.	1/2 maize straw	All maize straw
Water storage before seeding (mm)	319	357	335
Water storage after harvest (mm)	263	314	278
Precipitation in growing period (mm)	296	296	296
Water consumption (mm)	352	339	353
Yield(t/ha) #	5.44 c	3.58 c	4.54 b
Water use efficiency (kg/mm)	15.5	10.6	12.9
Percentage increase compared to check		-32	-17
Rainfall productive efficiency (kg/mm)	18.4	12.1	15.4
Percentage increase compared to check		-34	-17

Yield levels that do not share the same letter are significantly different ($P<0.05$)

Table 36. Maize seedling emergence rate in the differences treatments. May 4, 2006.

Treatment	% emergence
CK	94.7
1/2 maize straw	96.5
Whole maize straw	94.7
PF	NS

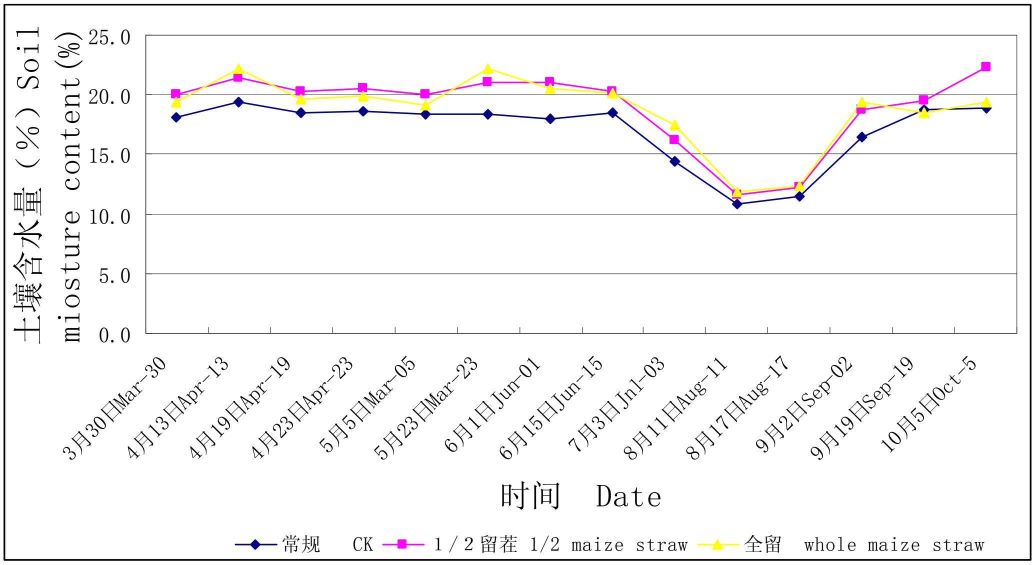


Figure 10. Seasonal change of soil water in the three treatments.

Table 37. Dry weight of above and below ground biomass over the season in the three treatments.

Treatment	Dry weight above ground (kg/ha)			Root dry weight(kg/ha)		
	CK	1/2 maize straw	All maize straw	CK	1/2 maize straw	All maize straw
Seedling stage	89	41	39	41	30	32
% increase vs. check		-55	-56		-26	-20
Jointing stage	2151	1319	534	360	248	122
% increase vs. check		-39	-75		-32	-66
Tasselling stage	11441	8792	10224	927	1061	1317
% increase vs. check		-23	-11		14	42
Harvest #	12056 a	9434 b	11760 ab	1647 b	1383 b	2466 a
% increase vs.check		-22	-2		-16	50

Yield levels that do not share the same letter are significantly different ($P<0.05$)

Effect of treatments on soil temperature

Average temperature of different soil layers was measured in different growth stages from 8:00 to 20:00. The soil temperature variation curves are shown in Figure 11 comparing soil temperature effects in the different treatments. Keeping residues on the soil surface reduced soil temperature, and temperature was reduced more with greater quantities of straw mulch. In the seedling stage 1/2 and full straw retention treatments reduced soil temperature by 17% and 26.2% respectively compared with control; while in the jointing stage soil temperatures were reduced by 8.2% and 13.8% by the 1/2 and full straw retention treatments respectively. Similarly at the heading stage soil temperatures of the 1/2 and full straw retention treatments reduced soil temperature by 9.2% and 13.1% respectively compared to the control, but at the harvest differences in soil temperature were smaller: 3.2% and 5.1% lower than the control in the 1/2 and full straw retention treatments respectively.

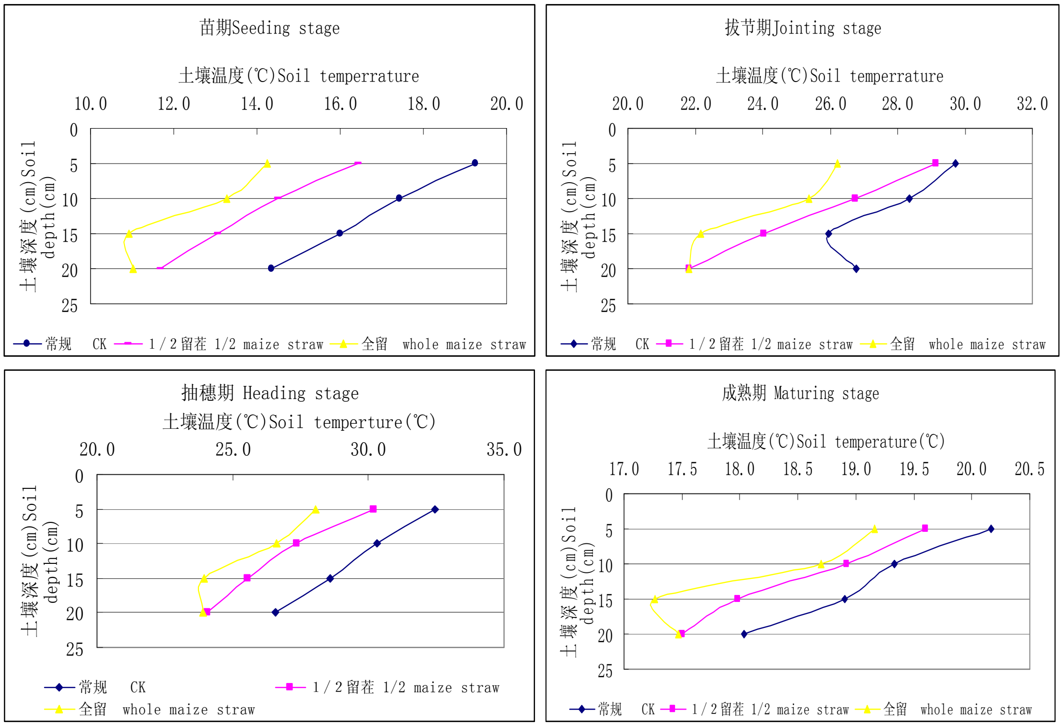


Figure 11. Soil temperature in the three treatments at different crop stages.

Conclusion

Results showed that treatments with full and 1/2 straw retention reduced yield, although they conserved more moisture. However, the overriding effect of the treatments was on soil temperature which reduced crop growth and resulted in fewer cobs per hectare.

Expt 5. **Maize conservation tillage trial (2007)**

The trial was planted in April 2007 with five treatments:

1. Traditional farming (ck): spring plough land (15cm-depth) after rain; harrow and apply plastic mulch, plant maize.
2. 1/2 straw retention: direct seeding (no tillage)
3. Full straw retention: direct seeding (no tillage)
4. 1/2 straw retention: plastic mulch, direct seeding (no tillage)
5. 1/2 straw residue: cover plastic mulch with cultivation

The trial was organized in a randomized block design with three replications. Seedrate was 30kg/. The trial was planted on raised beds with a bed width of 60cm and a furrow width 40cm. Bed height was 5cm and two rows of maize, spaced 40cm apart were planted on each bed with a spacing between plants in the row of 33cm. Plastic strips, laid on the beds, were 60 cm wide and there was a space between plastic strips of 40 cm. The maize was sown on the beds into holes in the plastic.

Results and Discussion

Effect on yield and other characters

Results showed that there were significant difference between treatments with plastic mulch and those without plastic mulch (Table 38). The treatments without mulch yielded considerably less than the treatments with plastic mulch.

Table 38. Maize yield in different tillage and mulch treatments

Treatment	Grain Yield t/ha
1. Check – Tilled with plastic	5.16
2. 1/2 straw retention: - no plastic, no tillage	1.09
3. Full straw retention: - no plastic, no tillage	0.80
4. 1/2 straw retention: with plastic mulch, no tillage	4.87
5. 1/2 straw residue: cover plastic mulch with cultivation	4.63
PF	**
LSD (1%)	1.04
CV%	60

Soil temperature differences between different trial treatments

Again there were significant difference between treatments with plastic cover and those without plastic – soil temperature without plastic mulch was 4-5°C below the soil temperature with plastic cover (Table 39), resulting in the large yield differences observed.

Table 39. Effect of different treatments on soil temperature. All treatments direct planted.

Treatment	Average Soil Temperature °C [#]
1. Check – Tilled with plastic	24.9 a
2. 1/2 straw retention: - no plastic, no tillage	20.5 b
3. Full straw retention: - no plastic, no tillage	20.0 b
4. 1/2 straw retention: with plastic mulch, no tillage	25.3 a
5. 1/2 straw residue: cover plastic mulch with cultivation	23.9 a

[#] Treatments that do not share the same letter are significantly different ($P<0.01$).

***Expt 6*. Winter wheat rotate Maize Conservation Tillage Trial**

Methods

The previous crop was zero tilled winter wheat. The maize conservation tillage trial was planted in March 2008. The 5 treatments were as follows:

1. Traditional tilling (ck): spring plough land (15cm-deepth) after rain. Harrow and apply plastic film, plant maize;
2. Early spring strip tilling only + plastic film;
3. Early spring strip tilling only + plastic film + straw cover (1.5 t/ha);
4. Early spring tilling (almost same as ck, but tilled land in early spring due to a snow in winter) + plastic film;
5. Early spring zero tilling + plastic film + straw covering (1.5 t/ha).

The trial used a randomized block design with three replications. The seeding rate was 30kg/ha. The trial was planted on raised beds with a bed width of 60cm and a furrow width 40cm. Two rows of maize, spaced 40cm apart were planted on each bed with a spacing between plants in the row of 33cm.

Results and Discussion

Effect on yield and net benefits.

Results showed that, as all treatments had plastic mulch, reduced-tillage treatments significantly increased maize yield y approximately 23%. There were no significant differences between the different reduced tillage treatments but all yielded significantly more than the conventionally tilled check (Table 40). These yield increases led to almost a 40% increase in net benefits with the reduced tillage treatments (Table 41).

Table 40. Comparisons of Maize yield under different tillage treatments.

Treatment	Average (kg/ha)	Increase over check (%)
1. Check. Traditional tilling with plastic film	4.74	0
2. Early spring strip tilling only + plastic film;	5.79	22.1
3. Early spring strip tilling only + plastic film + straw	5.76	21.5
4. Early spring tilling + plastic film;	5.85	23.4
5. No tillage + plastic film + straw	5.88	24
PF	*	
LSD (5%)	0.89	
CV%	11.9	

Table 41. Net benefits (USD) of different maize conservation tillage treatments

Items			Check	Conservation tillage (average)
Input $/ha	Labor input	Tillage	65.9	33.0
		Planting	44.0	44.0
		Management	44.0	61.5
		Harvesting	65.9	65.9
	Seed		52.8	52.8
	Plastic film		131.9	131.9
	Fertilizer	Urea	87.9	87.9
		Compound fertilizer	109.9	109.9
	Total		602.3	586.9
Output $/ha	Straw		347.3	419.8
	Yield		1138.6	1398.0
	Total		1485.9	1817.8
Net income $ /ha			883.6	1230.9
Benefit comparison %			0	39.3

Remark: CNY:USD=6.824:1

***Expt 7.* Maize Rotate Potato Conservation Tillage Trial**

Methods

The potato conservation tillage trial was planted on April 17, 2008 following a maize crop in the previous season. There were 5 treatments as follows:

1. Traditional tillage (CK)
2. 1/2 maize straw retained + strip tillage + plastic mulch
3. 1/2 maize straw retained +zero tillage+ plastic mulch

4. 1/2 maize straw retained + zero tillage
5. All maize straw retained +zero tillage

The trial used a randomized block design with three replications. The seeding rate was 1500kg/ha. Potatoes were planted in alternate narrow and wide rows. The spacing between wide rows was 60cm and the spacing between narrow rows was 40cm. Spacing between plants was 40cm.

Results and Discussion

Impact on yield and yield components

The yield results showed that reduced-tillage treatments had significant positive effects on yield, which was increased by over 10% when full tillage was not done (Table 42). All the zero tillage and strip tillage treatments yielded significantly more than the check and there was no effect of plastic mulch on yield. This led to an average increase in net benefits in the reduced tillage treatments of 27% (Table 43). The cost of the plastic mulch has not been included in this analysis, and therefore the treatments without the plastic mulch in fact had even greater net benefits – a lower cost of USD 131.9 and therefore net benefits of USD 1,216, 43% greater than the conventionally tilled check.

Table 42. Comparisons of potato yield under different tillage and plastic mulch treatments

	Treatment	Yield t/ha	Increase over check (+%)
1.	CK (+plastic)	12.3	0
2.	1/2 maize residue + Strip farming + plastic	13.6	11
3.	1/2 maize residue + Zero tillage+ plastic	13.5	10
4.	1/2 maize straw + Zero tillage, no plastic	13.4	9
5.	All maize straw + Zero tillage, no plastic	13.7	11
PF		*	
LSD (5%)		0.8	
CV%		4.5	

Table 43. Net benefits of different conservation tillage and plastic mulch treatments in potatoes.

Treatments			CK	Conservation tillage(average)
Input $ /ha	Labor input	Tillage	65.9	0.0
		Tillage+Planting	65.9	26.4
		Soil preparation	11.0	11.0
		Management and Harvesting	87.9	87.9
	Seed		219.8	219.8
	Herbicide		0.0	17.6
	Fertilizer	Urea	22.0	22.0
		Compound Fertilizer	123.1	123.1
	Total		595.7	507.8
output $ /ha	Yield		1446.4	1591.4
net income $ /ha			850.7	1083.7
Benefit comparison %			0	27.4

Remark: CNY:USD=6.824:1

CA machinery and equipment

CA equipment developed

Develop a Permanent Raised Bed No-Till (PRB-NT) Seeder for no-till planting maize and wheat in the provinces of Shandong, Henan and Ningxia. The seeder suitable for a 50 hp 4-wheel tractor could direct plant maize in chopped wheat straw and direct plant wheat in maize stubble (most maize stalks removed from field), place fertilizer deep and place seeds at the required depth. There was no similar type of seeder in China prior to this project.

Develop a Layered Bed Former. To make beds in loosened soil at beginning of PRB-NT system, the bed former would match the PRB-NT seeder for the provinces of Shandong, Henan and Ningxia. Select and improve a Maize/Minor Grain NT Seeder
PROJECT OBJECTIVES

Objective 1:

To provide no-till seeders and related implement to support the CA trials in Shandong, Henan, Ningxia and Inner-Mongolia.

There were two kinds of seeders needed for the project. The first of these was for Permanent Raised Beds with residue covered fields, called the PRB-NT seeder, for Shandong and Henan provinces. Because PRB-NT system was the main research technology of the project, it was a key machine, however, this seeder was not available in China, and indeed in the world, and thus a new development was needed. The second was a machine for working on the flat cropping area of Inner Mongolia and Ningxia provinces. This kind of NT seeder was available, but the performance was not acceptable and improvement was necessary.

Objective 2:

Cooperating with two private machinery manufacturers in Shandong and Inner-Mongolia to manufacture the proto-type seeders and encouraging the manufacturers to observe and participate in experiments, improving the prototype seeders and raising their production levels, to develop 1-2 prototypes of no-till seeders for CA extension in the dry land area of the 4 provinces.

Main Research Thrusts:

1）Develop a Permanent Raised Beds No-Till (PRB-NT) Seeder for no-till planting of maize and wheat in the provinces of Shandong, Henan and Ningxia. The seeder matched with 50 hp wheel s could direct plant maize in chopped wheat straw fields and direct plant wheat in fields with maize stubble (maize stalks removed from the field), while placing fertilizer deep and seeds at the required depth. As a seeder with these specifications was not available in China, it was necessary to develop a new machine.

2) Develop a Bed Former to make beds in loosened soil at the beginning of the PRB-NT system. The bed former would match the PRB-NT seeder for the provinces of Shandong, Henan and Ningxia.

3）Select and improve a Maize/Small Grain NT Seeder for Inner Mongolia. The seeder needed to be adequate for an 18 or 20 hp wheel tractor could direct plant maize or small grains (millet, sesame) into residues, place fertilizer at depth and place seed at the required depth.

4) Cooperate with a private farm machine manufacture in Shandong province to develop “PRB-NT seeder” and “Bed Former”, encourage the manufacture to participate in field trials and improve the seeder, and initiate commercial production. Cooperate with a private farm machine manufacture in Inner Mongolia to improve “maize/small grain NT seeder”, encourage the manufacture to participate in field trials and improve the seeder, and initiate commercial production.

OUTCOMES AND IMPACTS

Bed Former

According to the requirement of the project to test a PRB-NT system in Shandong and Henan provinces, a bed former was needed to make beds to be able to initiate the PRB-NT system. Agronomists of Shandong and Henan provinces defined the bed spacing, height and top width as 1350mm, 140mm and 950mm, respectively. Due to the wide bed spacing, using one pair of discs would be impossible to form the bed. To solve this problem, several pairs of devices were needed. Besides, if the bed former were mounted on the seeder, it would make the seeder too long to function properly in small fields and with small tractors. On the other hand, the PBR-NT system is not necessary to form beds every year: it only needs to form beds in the first year of system establishment. Therefore, a bed former was designed with 3 pairs of disks and 1 pair of chisels together to dig and move soil four times to form the bed appropriately, followed by the press roller to smooth the top of the bed. The sketch map of the bed former can be seen in Figure 12.

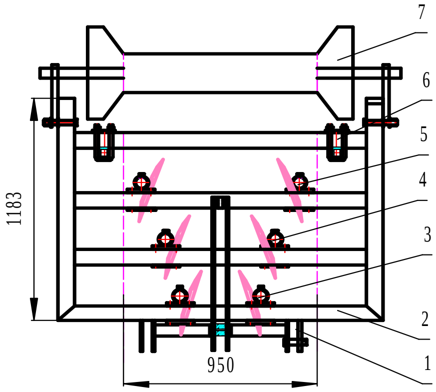


Figure 12. Sketch map of bed former
Notes – 1= Linkage frame, 2= Working frame, 3= Spherical disk, 4 =Spherical disk, 5= Jagged disk, 6= Plow, 7= Press wheel

The bed former was made in June 2005 in the Qingdao Wannongda Peanut Machinery factory. In the first trial, it was found that it was too light to dig the soil, and the function of the press wheel wasn't good. It was modified to include two aspects: the machine, including the frame, handles of digging devices and linkage parts were strengthened and the press wheel structure was changed from a holistic roller to an assembly of several cylinders.

The bed former was used to test reshaping ability before wheat planting in 2006. It was found that, without reshaping, the PRB-NT seeder had poor planting efficiency - specifically the seeds were placed quite shallow or even on top of the ground on both side rows. The bed former, equipped with disks and plows, improved the shape of the beds to help the seeder achieve better planting.

PBR-NT Wheat/Maize Seeder

According to the agricultural requirement, the seeder should be appropriate for direct seeding of maize into fully chopped wheat straw and direct seeding of wheat into maize stubble (maize stalks removed from the field) in areas with two crops per year. After discussion with project partners in Shandong, Henan and Ningxia, one PRB-NT seeder was designed for a 50 hp (Shanghai-50) tractor. The seeder can plant 6-rows of wheat or 2-rows of maize on each bed. A sketch map of the PBR-NT seeder is shown in Figure 13 and the set-up for planting wheat and maize is shown in Figure 14. The technical difficulties for the seeder included: easy blockage when there were many maize stalks or weeds in the field; need to plant both wheat and maize in PRB-NT; reshaping of beds while planting.

Design of the principal components

- The flat disk (4) was designed to cut the wheat straw and weeds on the bed and to reduce residue blockage.
- Opener and Frame: a tine opener was selected to place fertilizer and seed at the same time. Wheat seeding depth is 30mm-50mm, maize seeding depth 40mm-60mm, and the fertilizing depth 80mm-100mm.
- There are three beams on the seeder. When planting maize, the openers are installed on the back beam and the cutter devices installed on the middle frame, while when planting wheat, the openers are staggered on the middle and the back beams. Because the seeder needs to plant both wheat and maize, a dual-purpose feed roller for wheat and maize is employed to fit the requirement.

- Reshaping device and ground wheel. The bed reshaping device was designed to repair destroyed beds. The deflecting angle is a key parameter for reshaping effect and defined by field tests.
- The ground wheels run in the furrows, and drive the seed metering mechanism.
- The structure of combined press roller uses compacting wheels to press the sides of the beds if soil is loose after reshaping; press wheels are used to press on the planting zone with gap designed to enable easy passage of the maize stubble when planting.

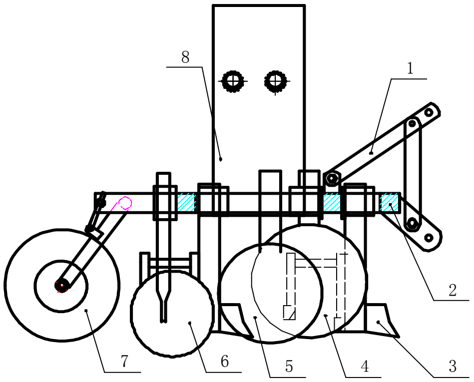
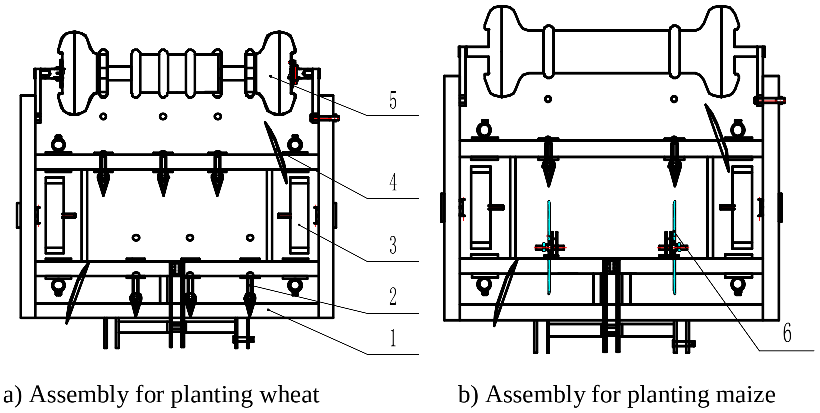


Figure 13. Sketch map of the PBR-NT seeder
1 Linkage frame 2 Working frame 3 Opener 4 Flat disk to cut straw 5 Ground wheel
6 Concave disk for reshaping 7 Combined press roller 8 Seed and fertilizer box

Assembling position



a) Assembly for planting wheat

b) Assembly for planting maize

Figure 14. Assembling sketch of PBR-NT seeder
1 Work frame 2 Opener 3 Ground wheel 4 Reshaping bed device
5 Combined press rollers 6 Cutting straw device

Field tests of the PBR-NT seeder

The first field test was done at 24/Jul/2005 and after improving the seeder, the second field test was done at 13/ Sep/2005 and the wheat emergence was good. According to the test results and the project partners' opinions, the seeder was improved in the following aspects: Reshaping devices were reduced from 4 to 2, as the devices were very close to the openers and easily blocked. Also the single drive wheel was changed to two ground wheels to improve the seed metering.

Four bed formers and 4 PRB-NT seeders were sent to Shandong, Henan, Ningxia and Beijing respectively. The PBR-NT seeders were used to plant wheat in Shandong and Henan Provinces. Field results showed that seeder performance was good and reached the anticipated goals.

The combination press roller had been improved with the diameter of hemisphere of the combination press roller reduced from 450cm to 350cm. So the hemisphere can keep a space with the bed bottom, it ensures the press-wheel can touch the face of seed zone.

Other parts of the combination press roller: The thickness of the diameter of the roller was increased from 2.5cm to 4cm to increase pressure.

Improvement of the opener: the tine point opener is suitable for making shallow furrows, e.g. less than 5cm. In this case it has good penetration, gives little soil disturbance but the soil disturbance and horizontal force are larger as the furrow depth increased.

The improved knife opener is suitable for making deep furrows, up to 10cm. In this case there is no big change in soil disturbance and horizontal force as furrow depth increases, and the opener has additional soil penetration and residue cut through ability.

The improved PRB-NT seeder was used to plant maize in fields covered with wheat residue in Beijing in June, 2006. The results showed the knife furrow opener on this machine can reduce the surface soil disturbance and fuel consumption. While in Beijing direct seeding maize into wheat residues was a success (because the wheat sown with two wide rows left for maize planting) but in some other conditions, where wider spacing wheat rows kept for planting maize are not kept, or where there are heavy weed populations on the bed, direct seeding of maize with this machine would be a problem.

The improved PRB-NT seeder was used to plant wheat into fields with chopped maize residues in Oct. 2006 in Beijing. Even with the chopped residues there were some residue blockage problems because of the very heavy maize residue levels, but the seeder worked adequately and completed planting on time. The emergence of wheat seedlings was acceptable.

The power driven PRB-NT seeder

At the beginning of 2008, the project team discussed the feasibility of adopting the power driven rotary blades to cut through residue and so increase the “anti-blockage” ability of the PRB-NT seeder. It is clear from 2 years of experimenting that the existing PRB-NT seeder could not plant wheat into beds covered with maize stalks. Also from two years research, a big problem was found in machinery system of PRB-NT: the tractor rear wheel axle width (< 1.5 meters) is less than that of all the grain combines (> 1.8 meters). Because of this any width of bed will be damaged by the combine wheel, or by tractor wheels: therefore the PRB-NT system is not yet ready for extension in Central China.

However to test whether the power driven mechanism can increase the anti-blockage ability enough to complete direct seeding of wheat into full maize residue covered beds it was decided to design a prototype model focusing on the anti-blockage results without worrying at this stage about wheel damage to the beds.

A diagram of the planting pattern of the new seeder matching with a 60hp tractor and which will plant 7 rows of wheat or 2 rows of maize is shown in Figure 15 and the principal characteristics are shown in Table 44.

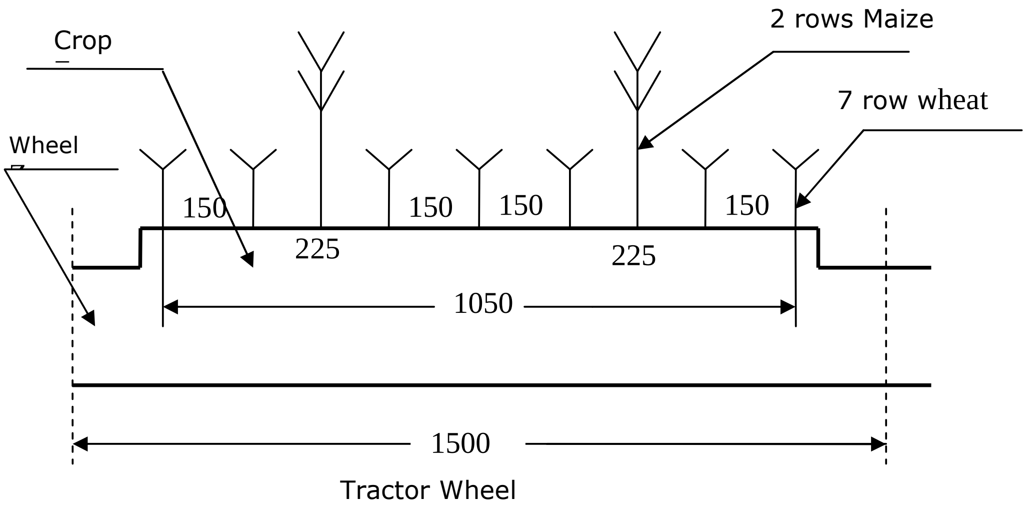


Figure 15. Sketch of Wheat and Maize rows

Table 44. Principal characteristics of the PBR-NT planter

Index	Parameter	Index	Parameter
Measurements Length×width×height	1730×1724×1430 mm	Seed depth (mm)	Wheat: 30～50 Maize: 40～60
Weight (kg)	335	Type of fertilizer metering	Feed roller
Row space (mm)	Wheat: 180 or 150 Maize: 650	Type of seed metering	Feed roller for both wheat and maize
Rows planted at a time	Wheat: 6 Maize: 2	Maximum seeding rate (kg/ hm^2)	Wheat: 450 Maize: 75
Fertilizer depth (mm)	80～100	Maximum fertilizer rate (kg/hm^2)	600
Work efficiency (hm^2/h)	0.3～0.53	Power (KW)	36.8

Table 45. The Main parameters of PD PRB-NT seeder

Parameter	Figure	Parameter	Figure	
			Wheat	Maize
Length×width×height（mm）	1978×1820×1440	Seeding depth (mm)	30～50	40～60
Weight (kg)	450	Fertilizer depth (mm)	80～100	80～100
Working width (mm)	1500	Sowing Rows	7	2
Work efficiency	0.27～0.53 hm^2/h	Row space (mm)	150 or 225	550
Tractor power (KW)	48	Chopper revolution	1250 r/min	1250 r/min

The new PD (power driven) PRB-NT seeder was designed and manufactured at Lu He farm machinery factory in Daxing District of Beijing. It was tested with direct seeding of maize into full wheat residues on beds after wheat had been combine-harvested in the middle of June 2008, and direct seeding wheat into chopped full maize residues on beds in early October 2008. The principal characteristics of the seeder are shown in Table 45.

The maize/small grain no-till seeder

The 2BM-5 no-till seeder was selected for Inner Mongolia and designed to be able to plant maize and small grains into straw mulch. Common tractor power is around 20 hp. However, the initial version gave poor results and was too fragile, and therefore improvement was necessary.

The main improvements carried out were as follows: a) The opener was changed from a narrow point type to a knife type, which gave it more cutting ability to cut residue and break through hard soil, and so be able to work in maize and rice fields with residues; b) the press wheel changed from a single unit model to individual units for each row to better follow the uneven upland terrain in Inner Mongolia; and c) the driving device was changed from the press wheel to a ground wheel to reduce slip and obtain more even seed distribution.

Deli New Technical-Equipment manufactory in Huhehot was selected as the manufacturer. Two units of the 2BM-5A no-till maize/small grain seeder were manufactured based on the improved plans. A Conservation Tillage conference was held in Huhehot on 18 Apr. 2006, and the experts and technicians that took part in the conference visited the machine exhibition. The 2BM-5A seeder was exhibited, and many visitors were interested in the no-till seeder.

The 2BM-5A NT seeder was tested in plots covered with maize stubble and with 15~25cm high standing maize stubble and 50cm row spacing in Inner Mongolia in April 2006. The test result showed the depth and seed and fertilizer metering could satisfy the expected agricultural requirements. The seeder was also used to plant wheat in Inner-Mongolia and Ningxia provinces, and 20 ha of NT wheat were planted in Pengyang of Ningxia. Furthermore, and as spin-off from the project, a trial of NT planted wheat into rice residues in the Yellow river irrigation area was successful and showed good performance of the knife opener to cut through the rice residue as well forming a perfect seedbed.

The function of the seeder was amplified to include no-till planting of wheat and so it can plant maize, small grains and wheat. In accordance with this the name of the machine was changed to 2BM-5X. Secondly, the drive wheel was moved to the back of the seeder from the middle to avoid the greater slippage and the blockage between the wheel and openers when no-till planting maize in fields covered with maize residue. After improvement, the seeder slippage was decreased and the performance improved (Figure 16). Third, the no-till seeder was improved with a much stronger frame and better precision in the manufacture. A total of 35 units of the 2BM-5X seeder were manufactured in 2007 and more than 50 units manufactured in 2008. The principal characteristics of the seeder are shown in Table 46.

The 2BM-5X NT seeder was used to no-till plant maize, spring wheat and winter wheat in Inner-Mongolia, Ningxia and Shanxi. When used to plant spring wheat in Inner-Mongolia in May and to plant winter wheat in fields covered with rice residue in Ningxia in October, the results showed that the seeder performance is good and the knife opener can reduce the surface soil disturbance. In direct seeding of maize, the 2BM-5X NT seeder performance was acceptable, but in some cases maize germination was poor due to insufficient pressure from the press wheel.

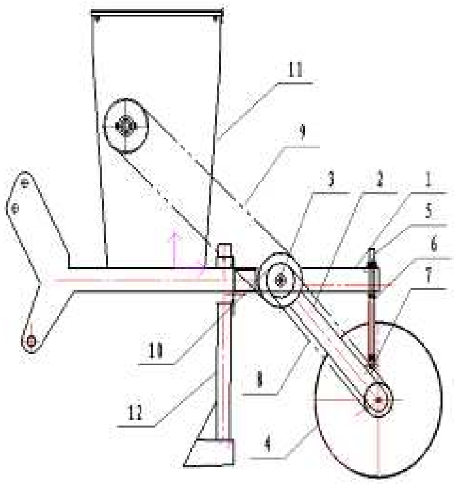


Figure 16. The driving wheel after improved design

Table 46. Main parameters of 2BM-5X NT wheat/ maize/small grain seeder

Index	Parameter	Index	Parameter
Dimensions: Length×width×height	1560 mm×1390 mm×1320 mm	Seeding depth (mm)	Wheat 30-50 Maize: 40~60 Minor grain:30~50
Weight (kg)	160-190	Fertilizer metering	Feed roller
Row spacing (mm)	Wheat 200 Maize: 500 Minor grain:250	Seed metering	Feed roller
Rows sown at one time	Wheat 5 Maize: 2 Minor grain:4	Maximum seeding rate (kg/hm^2)	Wheat 180 Maize: 75 Minor grain:45
Fertilizer depth (mm)	80～100	Maximum fertilizer rate (kg/hm^2)	450
Work efficiency (hm^2/h)	0.27～0.4	Power (kw)	13.2~14.7

3.2 Assess the consequences of the adoption of conservation agriculture practices on system productivity, income, livelihoods, equity, resource quality, water use, and soil erosion at the field, watershed and river basin levels.

Methods

To understand the status and development of conservation agriculture (CA) adoption in the Yellow River Basin, we conducted two rounds of field surveys (in 2005-06 and 2008) and collected all relevant literature (such as published papers, reports, government documents) that provided information and data on the adoption of CA. Based on the information and data collected from these surveys and the literature review, we gained a good understanding of CA adoption.

The field surveys and associated data work were organized by the Center for Chinese Agricultural Policy (CCAP), Chinese Academy of Sciences (CAS). The first survey was conducted in late 2005 and early 2006, and covered 49 villages, 292 households from 8 counties in 4 provinces of northern China. The four study provinces are all located in the Yellow River Basin (YRB): Ningxia and Inner Mongolia in the upper reaches of the YRB, and Henan and Shandong in the lower reaches of the basin.

Within each province, we selected two counties that had CA CPWF project activities. Within each county, we randomly selected a set of villages and households. One set of villages was drawn from villages that were being targeted for the extension of CA projects. A list of these villages was provided to the authors by the agricultural department of each county. The other set of villages was drawn from the remaining villages in the county (i.e., those with no known participation in a formal CA extension project—though in some cases there were local extension agents promoting different variants of CA technology). The CA demonstration projects and extension efforts were almost all funded by either the central or regional government, or some international organization (such as a CGIAR center) and carried out by local extension agronomists and professors from local agricultural universities. Our sample villages were randomly selected in parts of China where, according to many key informants (including agronomists and other agricultural scientists), CA technology had the best chance of being adopted. Finally, within the sample villages, a minimum of five households were randomly selected and surveyed. In the villages that had CA projects, the sample households included both households participating in CA extension projects and non-participating households.

Within each sample village, two surveys were carried out. The first was a village-level survey with key village leader informants. The village survey gathered general information about the village (e.g., demographics, per capita income, infrastructure, land use, the main cropping rotations, crop productivity and major village income sources), as well as specific information related to the adoption (or lack thereof) of CA technology. Questions were asked about machinery availability and use, the importance of livestock, residue use, soil information and government subsidies. Detailed information was recorded on the nature of the CA technology extension program (if there was one). The second part of the survey targeted sample households in the sample villages. The household survey enumerators gathered detailed information on each household’s demographic structure, employment history, and asset base, and on the income stream of family members.

We also recorded data on a plot by plot basis on farmers’ production efforts. For households that had not adopted any CA technology, two plots were randomly selected from the set of plots planted to crops that accounted for the largest share of the household’s cropping activities. For those households that had adopted CA technology, one plot planted under CA technology was selected, and one without CA technology. Wherever possible, we tried to select the second plot to be planted to the same crop that was being cultivated with CA technology. For all plots, enumerators asked farmers to recount detailed information regarding inputs (e.g., fertilizer and labor input) and outputs (e.g., yields) as well as plot characteristics (e.g., distance from the household and plot quality).

In 2008, CCAP conducted the second round of field surveys in the Yellow River Basin. In this survey, we focused mainly on wheat producing regions in the Yellow River Basin. Since there are no wheat producing areas in Inner Mongolia, we did not visit the villages there, only in the three other provinces (Ningxia, Henan and Shandong). In this survey, we tried to revisit the same villages as in our 2005 baseline sample; we also added new villages that were not included in the baseline survey. Unlike 2005, the survey team did not select villages randomly, but instead selected those villages where some farmers had adopted CA. These villages have been influenced both directly and indirectly by our project. We selected both rainfed and irrigated villages, for a total of 14 villages in three provinces.

In each village, 12 farmers were selected to attend our focus group discussion. When selecting farmers, based on their per capita income, we divided the farmers into three groups: poor farmers whose income was lower than the village average, normal farmers whose income was equal to village average and rich farmers whose income was higher than the average income of the village. We also randomly selected four farmers from each group of farmers to attend our discussion. Besides considering income levels, we also tried to strike a balance between female and male farmers.

For the focus group survey, we designed semi-structured questionnaires together with CIMMYT scientists. The questionnaires included the following: village characteristics, farm size, household characteristics, resource endowments, land use, production goals and market access; wheat production systems characteristics (rotations, implements used, residue management practices, yields and input and output prices); CA adoption status, implementation levels and characteristics; advantages and disadvantages of CA adoption; environmental benefits and constraints to CA adoption.

To gain a better understanding of the determinants of CA technology adoption, it was necessary to conduct a multivariate analysis to separate the influence of each factor. Applying 2005 field survey data, we constructed the following econometric model to explain the determinants of CA adoption measured at the village level:

$$y_{ik} = \alpha + \beta S_{ik} + \gamma P_{ik} + \delta I_{ik} + \varepsilon_{ik} \quad (2.1)$$

where yik represents CA adoption in village k in year i. It is a dummy variable: if the village adopts any type of CA technology (either Full or Partial), yik = 1; otherwise, yik = 0. The rest of the variables explain adoption of CA technology. The vector of Sik represents a set of socio-economic variables, measured by the share of the family's labor working off-farm; per capita cultivated land area; share of cultivated land that is irrigated; and the distance from the household to the township.

We also included two policy variables (Pik). The first variable measures whether or not there is an active subsidy policy in the village that encourages the purchase of machinery (which is equal to 1 if village farmers can obtain the subsidy, and 0 otherwise). The other policy variable measures if there is a local regulation that is being implemented that bans the burning crop residue (measured as 1 if village leaders know there is such a policy, and 0 otherwise).

Finally, we included a variable to measure the extent of the government's effort to promote CA technology. Specifically, the variable (Iik) measures the influence of whether there was a CA technology extension project in the village or not. This variable is measured as a dummy variable. If there was an extension project in the village at some time in the past (or currently), the variable is equal to 1; otherwise, it is zero. The symbols α, β, γ, δ and ϕ are parameters to be estimated, and ε_{jk} is the error term assumed to be uncorrelated with the other explanatory variables in the model.

To understand why some households adopt CA technology and others do not, we constructed the following econometric model at the household level:

$$T_j = \varepsilon + \varphi H_j + \eta P_j + \varsigma I_j + \omega_j \quad (2.2)$$

where Tj represents adoption of CA technology by household j. In our analysis, this is a dummy variable which is set equal to 1, if the household adopts any kind of CA technology (either Full or Partial); otherwise, Tj = 0. The rest of the variables explain CA adoption at the household level (and in many cases are similar to those used in equation 1). The vector, Hj, represents household socio-economic characteristics that affect adoption. Most importantly, we included two household variables that measure the family's labor (share of family members in the off-farm sector) and land endowments (per capita cultivated landholdings). We also included other variables as controls (e.g., age and education of household head). A wealth variable (measured as the value of the family's housing assets) was included as a control for whether or not the household was facing a liquidity constraint. In addition, we also controlled the possible influence of soil type on CA adoption, measured by the share of loam plots and share of clay plots on the farm.

In addition to household-specific variables, we included a number of policy and extension variables. The variable (Pj) is a variable that measures whether or not the household knows there is a residue burning ban. If the respondent knows about this policy, Pj =1; otherwise, Pj =0. In addition, we included a variable, Ij, to measure the influence of whether there is a CA technology extension project in the village or not. If the household has participated in a CA extension project, Ij =1; otherwise, Ij =0. The symbols ε, φ, η and ς are parameters to be estimated and ω_j is the error term assumed to be uncorrelated with the other explanatory variables in the model.

To explore the impacts of CA adoption on agricultural production (crop yield, labor and machine input), poverty and the environment, we not only performed literature reviews and applied our field survey data, but also used descriptive statistics and conducted econometric analysis. The following econometric model has been constructed to understand the impacts of CA adoption on crop yields:

$$y_{ijk} = \alpha + \beta T_{ijk} + \gamma I_{ijk} + \delta H_{ijk} + \phi O_{ijk} + \mu Z_{ijk} + \varepsilon_{ijk} \quad (3.1)$$

where y_{ijk} represents wheat or maize crop yields in village k, household j and plot i. In the model, we specified crop yields (kg/ha) as the log term. The rest of the variables are those variables that explain crop yields.

The vector of T_{ijk} is of our variable of interest, representing adoption of CA technology. For this set of variables, we had two options. The first option is to treat CA adoption as one variable; farmers may adopt any kind of CA technology (reduced till or residue retention separately or together). If farmers adopt any kind of CA technology, $T_{ijk} = 1$; otherwise, $T_{ijk} = 0$. The second option is to treat T_{ijk} as three variables. The first variable refers to reduced till adoption; if adopted, it equals 1, otherwise it equals 0. The second variable refers to adoption of residue retention; if adopted, it equals 1, otherwise, it equals 0. The third variable refers to adopting reduced till and residue retention together; if adopted, it equals 1, otherwise, it equals 0.

In addition to the CA adoption variable, we also included many other variables to control the influence of other variables on crop yields. The vector of I_{ijk} represents a set of production input variables measured by fertilizer cost per hectare, labor use per hectare, machine cost per hectare and value of other inputs per hectare. We transferred them into log term. The vector of H_{ijk} represents a set of household characteristics, measured by the age of household head (and its square term) and education of the household head. The vector of O_{ijk} represents a set of plot characteristics. First, we included variables that reflect the influence of soil quality, as two dummy variables: one to measure if plot quality is the best in the village; if it is, $O_{ijk} = 1$, otherwise, $O_{ijk} = 0$. The other variable measures if plot quality is good in the village; if it is, $O_{ijk} = 1$, otherwise, $O_{ijk} = 0$. Second, the variable distance from home has also been included as a variable representing plot characteristics. The vector of Z_{ijk} represents other control variables, such as production shocks measured by yield reduction due to production shocks, years of adopting conservation technology, whether planting in one season (if one season, it is set to 1, otherwise, 0), dummy for use of plastic mulch and village dummy. The symbols α, β, γ, δ, ϕ and μ are parameters to be estimated, and the error term ε_{ijk} is assumed not to be correlated with the other explanatory variables in the model.

To understand the impact of CA adoption on labor input, we have specified the following econometric model:

$$L_{ijk} = \alpha + \beta T_{ijk} + \gamma P_{ijk} + \delta H_{ijk} + \phi O_{ijk} + \mu Z_{ijk} + \varepsilon_{ijk} \quad (3.2)$$

where L_{ijk} represents labor input (total working days in the growth period) for wheat or maize production in village k, household j and plot i. The rest of the variables are those variables that explain crop yields. The vector of T_{ijk} represents CA adoption, which is similar to that in equation 3.1. The vector of P_{ijk} represents one vector of variables that measure the price of both product and input, such as the price of wheat (or maize), price of labor, seed, fertilizer and machine service. In this model, we also included H_{ijk} and O_{ijk} to represent household and plot characteristics that have similar specifications as that in equation 3.1. For the other control variables of Z_{ijk}, unlike in equation 3.1, we did not include the dummy variable use of plastic mulch; instead, we included the opportunity cost of farm labor measured by the share of labor doing off-farm work; the other three control variables in the vector of Z_{ijk} are similar to equation 3.1.

To gain an understanding of the impact of CA adoption on poverty, we built the following econometric model:

$$V_{jk} = \alpha + \beta T_{jk} + \delta H_{jk} + \phi O_{jk} + \mu Z_{jk} + \varepsilon_{jk} \quad (3.3)$$

where V_{jk} represents the poverty status of household j in village k. This is a dummy variable; if the per capita income in the household is below the extreme national poverty line, we consider the household to be poor, i.e., the variable V_{jk} is set to 1, otherwise, it equals zero. The rest of the variables are those variables that explain crop yields. The vector of T_{ijk} represents CA adoption. In this model, we only treated this variable to be one; if farmers adopt any kind of CA technology, it equals to 1, otherwise, it equals zero. The vectors of H_{ijk} and O_{ijk} represent household and plot characteristics. The specifications of household variables are similar to those in equation 3.1. In this model, we included more variables to measure plot characteristics such as land area, number of plots, share of plots with irrigation, share of simple plots, share of loam plots, share of clay plots, share of first-class plots and share of saline soil plots. For the other control variables of Z_{ijk}, unlike in equation 2.1, we did not include a dummy variable for use of plastic mulch; instead we included the opportunity cost of farm labor measured by the share of labor doing off-farm work; the other three control variables in the vector of Z_{ijk}, they are similar to equation 3.1.

Results and Discussion

Characteristics and extent of adoption

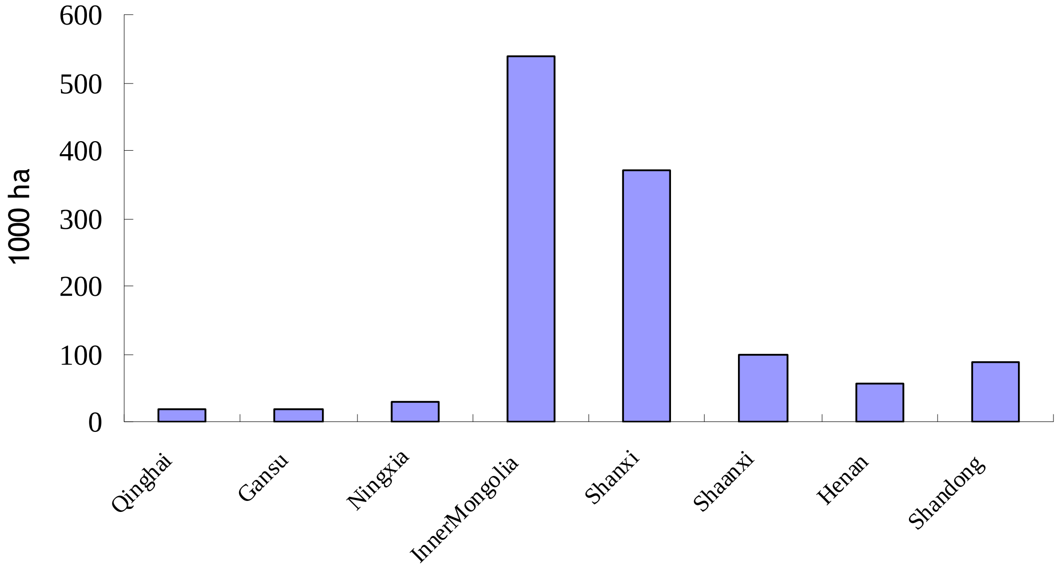


Figure 17. Areas of CA adoption in eight provinces in the Yellow River Basin (2006-2007).

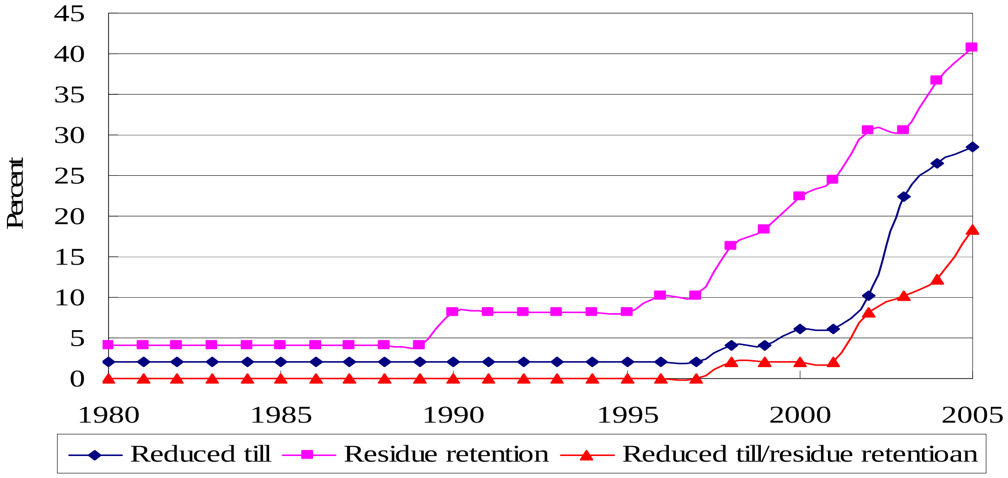


Figure 18. Share of villages adopting CA technology, 1980-2005.

Table 47. Share of sown areas adopting various tillage systems for wheat and maize in the Yellow River Basin (%).

			Ningxia	Henan	Shandong	Total
Wheat (2008)						
Full CA	Reduced tillage with crushed residue cover	2008	1.4	30.4	56.6	35.4
		2005	0.0	20.0	40.8	24.6
	Reduced tillage with whole residue cover	2008	0	0.02	0	0.01
		2005	0	0	0	0
	Reduced tillage with stubble retention	2008	0	0	0	0
		2005	0	0.03	0	0.01
Partial CA	Reduced tillage	2008	4.3	0.0	0.0	0.9
		2005	0.0	0.0	0.0	0.0
Maize (2007)						
Full CA	Zero tillage with crushed residue cover	2008	0.2	0.0	17.2	7.4
		2005	0	0	16.7	7.14
	Zero tillage with whole residue cover	2008	0.0	100.0	66.1	64.0
		2005	0	100	66.7	64.3
	Zero tillage with stubble retention	2008	0.1	0.0	0.0	0.0
		2005	0.0	0.0	0.0	0.0
Partial CA	Zero tillage	2008	4.2	0.0	16.7	8.0
		2005	0	0	16.7	7.1

Data source: Field survey conducted by Center for Chinese Agricultural Policy, Chinese Academy of Sciences, in 2008.

Of the three principles of CA, minimal soil disturbance and permanent soil cover are the most (generally) the defining components of CA. In this connection, we have classified CA technology into “Full CA” technology, and the second, “Partial CA” technology. If farmers adopt both no-till (or reduced till) and residue retention technologies at the same time, we call this Full CA technology. If farmers adopt only reduced or no-till technology or only residue retention, we call that Partial CA technology. It should be noted that Full CA technology is basically consistent with what is called CA technology in the literature. In some cases, partial adoption is the first step towards full adoption.

The government in China did not emphasize CA until the early 1990s (Yang and Song, 2007). In 1991, cooperation between the Australian Centre for International Agricultural Research (ACIAR) and the Chinese Ministry of Agriculture (MOA) established a CA research center and an active research program in Shanxi Province. After 2000, CA development in China accelerated. In 2002, substantial test and demonstration work was initiated, supported by a special Central Government fund. In 2005, the government expanded the support for CA demonstration and extension. Today there are 15 CA Demonstration Provinces and 167 Demonstration Counties supported at the national level, and 262 Demonstration Counties supported from provincial budgets.

The development and promotion of suitable equipment received attention and a handful of major machinery manufacturers, collaborating with scientists and engineers, began to adapt and sell zero and reduced till equipment with substantial subsidies from national and provincial governments. As a result of such demonstration activities and strong policy support, it is estimated that by the end of 2007 the CA adoption area in China reached 2.16 million ha. Demonstration Provinces included Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang Provinces.

Development of CA in the Yellow River Basin is similar to the national trend. The first year of CA adoption in the YRB was probably 1992 in Linfeng and Shouyang counties of Shanxi Province. Until now, as shown in Figure 17, the CA adoption areas in Inner Mongolia are the highest, reaching 539,000 ha[1]. However, in Gansu Province, the adoption area is only 19,000 ha, the lowest in all provinces. For other provinces, CA adoption areas range from 20,000 to 372,000 ha (Zhao and Xu, 2006; http://www.sxnj.org.cn/zyxx/06sxbhx.doc). We also examined the adoption rate by share of sown areas adopting CA. Results show that based on the adoption rate, CA adoption in Shanxi Province is the highest, reaching 9.7% in 2006. The lowest CA adoption is in Henan, reaching only 0.4%.

In the following discussion we seek to track the adoption of CA technology in the Yellow River Basin using two sets of measures derived from our survey data. First, we use a village-level measure. According to this measure, a village is considered to have adopted CA technology (either Full or Partial) if at least one plot of one farm in the village uses the technology. While this does not mean that all, or even most, farmers in a village are using a given technology, information on how many villages have at least one farmer using a technology provides an understanding of how spatially pervasive a practice has become. It also provides a convenient way to track the dissemination of each technology over time. The second measure, percentage of sown area on which a new technology is being used, is a measure of the actual extent of adoption at the farm level.

Village adoption of CA technology

According to our survey, using the village-level measure of CA technology adoption, Partial CA technology expanded from the late 1990s to the early 2000s. In the 1980s, adoption rates of reduced till and residue retention (by themselves) were both low (Figure 18). On average, only 2% of villages had any farmers that practiced reduced tillage. In 4% of villages there was at least one farmer that had adopted some form of residue retention technology. Moreover, during the 1980s the rise in the share of villages in which a farmer was adopting reduced till/residue technology was almost zero. Adoption of residue retention, which grew slowly in the early 1990s, accelerated after the mid-1990s. Although adoption rates of reduced till started more slowly, farmers began to adopt reduced till in the late 1990s. By the last year of our data collection, there was at least one farmer using residue retention in 40% of our sample villages, and in more than 25% of the sample villages, at least one farmer was practicing reduced till.

The adoption path of Full CA technology differs somewhat from that of Partial CA technology (Figure 18). In fact, from the early 1980s to the late 1990s, there was not even one farmer in one village who had adopted Full CA technology. In the late 1990s, the share of villages rose slightly, to 2% of villages. After 2001, however, adoption of Full CA technology (at least one household in each sample village) rose gradually. From 2000 to 2005, the share of villages adopting Full CA technology increased to 16%.

Differences across provinces. Although adoption rates using village-level measures were fairly low across our whole sample (at least until the last years of our study), we did observe differences among provinces in the adoption paths of CA technology. For example, in 92% of villages in Henan Province at least one farmer used residue retention technology in 2005. In contrast, farmers in only 17% of villages in the Ningxia Province sample villages used this technology. Adoption of residue retention in Shandong and Inner Mongolia Provinces were intermediate.

There are also variations among provinces in adoption levels of reduced till in 2005 (Table 47): In 62% of villages in Inner Mongolia, at least one household adopted reduced till technology. However, reduced till could only be found in 8% of villages in Ningxia Province and in no villages of Shandong Province.

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[1] http://www.nxny.gov.cn /ReadNews.asp/NewsID=352405

In the case of adoption of Full CA technology using the village-level measure, there were also differences across the sample provinces. In 39% of villages in Inner Mongolia, at least one farmer adopted Full CA technology. The levels were lower in Henan (16%) and Shandong (17%). Strikingly, no villages among all the sample villages in Ningxia Provinces adopted Full CA technology—despite government efforts to promote the technology.

Household-level adoption measures

The most striking findings of our adoption analysis were revealed when using household-level measures of CA adoption. When measuring the share of total area within the sample villages that is devoted to CA technology, we found that, in fact, while Full CA technology adoption level was low (3%), Partial CA technology adoption reached 31% in 2005. It should be noted that these adoption levels need to be kept in context, i.e., they occurred in areas where the government is actively extending the technology. We believe if one were to do a wider, fully random sample of villages, adoption levels of Full CA technology would almost certainly be lower. Hence, at least in 2005 in our study areas, adoption rates of Full CA technology—or the most comprehensive set of practices that are consistent with the Blue Revolution technology package—were very low.

Adoption based on the 2008 survey

According to the field survey conducted in three provinces of the Yellow River Basin in 2008, when CA adoption was assessed by crop (wheat and maize), the adoption rate of Full CA was higher than our findings in 2005 which studied CA adoption by plot. For example, the average adoption rate of Full CA for wheat in three provinces increased from 25% to 35% (Table 47). For the Full CA, the most important technology is reduced tillage with crushed residue cover. The adoption rate for the other two CA component technologies was almost zero. The Full CA technologies were adopted mainly by farmers in Shandong and Henan Provinces; in Ningxia Province, the adoption rate was very low. Compared with Full CA, the adoption rate of Partial CA was much lower, less than 1% in 2008. The CA adoption rate was higher for the maize crop. In both 2005 and 2008, the share of sown area adopting Full CA for maize was more than 71%, mainly in Henan and Shandong Provinces. The main type of Full CA technology for maize is zero tillage with complete residue cover. Similarly, the adoption rate of Partial CA (mainly zero tillage) is much lower than that of Full CA technology.

Determinants of CA adoption

Table 48. Village socio-economic characteristics and CA technology adoption.

	Adoption[a]	Non adoption	t-test
Socio-economic factors			
Share of off-farm labor (%)	33	24	2.20**
Per capita cultivated land area (ha)	0.32	0.25	3.57***
Share of irrigated land area (%)	17	9	4.52***
Government policies			
Villages having machine subsidies (%)	11	2	1.66
Villages knowing of policy banning burning residue (%)	62	38	2.15**
CA relevant projects			
Villages having only CA project (%)	33	6	4.23***

Data source: Authors' survey.

[a] Adoption implies that villages adopted at least one kind of CA technology, either Full or Partial.

Table 49. Household characteristics and adoption of CA technology components.

	Adoption[a]	Non adoption	t-test
Socio-economic factors			
Share of off-farm labor (%)	29	17	4.05***
Per capita cultivated land area (ha)	0.45	0.37	1.41
Share of irrigated plots (%)	32	23	2.31**
Households having draft animals (%)	15	57	8.21***
Value of house (yuan)	33733	17219	3.94***
Government policies			
Households knowing of policy banning burning Residue (%)	31	19	2.53**
CA relevant projects			
Households participating in CA project (%)	39	6	7.53**

Data source: Authors' survey.

[a] Adoption implies that villages adopted at least one kind of CA technology, either Full or Partial.

Table 50. Regression analysis of the determinants of CA technology adoption at the village level.

	CA technology adoption (Fixed-effect model)		
	(1)	(2)	(3)
Policy intervention			
Subsidy for machinery	0.453		
(1=yes; 0=no)	(1.85)*		
Residue burning banned		0.484	
(1=yes; 0=no)		(3.47)***	
Project implementation			
Have CA project[a]			0.561
(1=yes; 0=no)			(4.07)***
Village characteristics			
Share of off-farm labor	1.088	0.446	0.979
	(2.24)**	(0.91)	(2.27)**
Share of irrigated area	1.510	0.670	1.331
	(2.29)**	(1.01)	(2.28)**
Per capita cultivated land	0.067	-0.176	0.649
Area (ha)	(0.11)	(0.32)	(1.14)
Distance from township (km)	-0.017	-0.018	-0.012
	(0.79)	(0.92)	(0.64)
Constant	1.468	0.779	1.088
	(2.23)**	(1.20)	(1.84)*
Observations	98	98	98
R^2	0.36	0.46	0.50
F test	4.91	7.41	8.70

Absolute value of t statistics in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%.

[a] Villages having CA project implemented by other programs or organizations.

Note: (1) to (3) indicates 3 different kinds of complementary model specification.

Table 51. Regression analysis of the determinants of CA adoption at the household level.

	CA technology adoption	
	(1)	(2)
Policy intervention		
Residue burning banned (1=yes; 0=no)	0.443 (1.72)*	
Project implementation		
Participation in CA project[a] (1=yes; 0=no)		1.121 (3.28)***
Household characteristics		
Share of off-farm labor	0.755 (1.97)**	0.730 (1.88)*
Share of irrigated plots	0.419 (1.25)	0.248 (0.71)
Have draft animals (1=yes; 0=no)	-0.529 (1.93)*	-0.414 (1.50)
Value of house (yuan) (log)	0.184 (2.01)**	0.200 (2.12)**
Per capita cultivated area (ha)	0.198 (0.88)	0.305 (1.27)
Age of household head (years)	-0.191 (2.45)**	-0.217 (2.81)***
Age of household head, squared	0.002 (2.43)**	0.002 (2.79)***
Education of household head (years)	-0.054 (1.42)	-0.062 (1.57)
Share of loam plots	-0.302 (0.74)	-0.252 (0.60)
Share of clay plots	-0.595 (1.69)*	-0.559 (1.52)
County dummy	--[b]	--[b]
Constant	4.344 (2.19)**	3.889 (1.98)**
Observations	288	288
Pseudo R^2	0.46	0.48
Chi^2	183.23	191.80

Absolute value of z statistics in parentheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

[a] These households participate in CA project implemented by the Challenge Program.

[b] Regression results were omitted due to the limit of length of the paper.

Note: (1) and (2) indicates 2 different but complementary kinds of model specification.

To meet the goal of identifying factors associated with CA technology adoption, in this section we will first look at cross tabulations between measures of CA technology adoption and a set of socio-economic factors that define the nature of China's villages and the farmers who live there. We will also attempt to determine whether policy and extension/research projects' efforts to provide information to producers about the benefits of CA technology are correlated with adoption rates.

Some of the most distinctive characteristics of producers who adopt CA technologies compared to those who do not are access to household labor and land resources. Results show that in villages adopting CA technology, the share of the labor force that works off-farm (33%) is higher than in villages without CA technology (24%) (Table 48). Therefore, according to our data, if farmers have better off-farm opportunities, they appear to be more interested in adopting CA technology. Within China, our descriptive data suggest that those villages that have more of their labor force in the off-farm sector have an higher opportunity cost for labor, and are more interested in the labor-saving benefits of CA technology.

Our survey data also indicate that farmers in villages that have more land are more likely to adopt CA technology. Our data suggest that when land is less dear, farmers are relatively more interested in adopting CA technology, even though there may be a yield penalty (or at least no yield gain) in the short run. Hence, in the case of labor (assuming more off-farm labor means higher opportunity cost for on-farm work) and land (assuming less land means land is scarcer and the implicit returns to land—or the rent—are higher), the value of factor endowments appear to affect the interest in CA technology of farmers living in China's villages.

Beyond factor endowments, access to policy support may also influence the adoption of technologies (CIMMYT 1993; FAO, 2001). Before investing in any soil or water conservation practice (or any new technologies), farmers have to be convinced that the benefits will be greater than the costs (given constant risk), and farmers often have to overcome some type of constraint (Ervin and Ervin, 1982; Reardon and Vosti, 1995; Clay et al., 2002). Because these uncertainties and constraints may mean that farmers do not see immediate gain from the technology, government support policies (for financial aid and infrastructure construction) are often associated with successful CA adoption (Reardon and Vosti 1997; Malla 1999; Sanders and Cahill 1999; Bekele 2003). Specifically, when the government provides subsidies or loans to encourage adoption, we would expect to see more adoption.

The data from our study sites, in fact, do show this. When examining the data on village-level measures of adoption, we see that if the government provides subsidies for machinery used for developing CA technology, the probability of a farmer in a village adopting CA technology is higher. Results also show that if the cost of replacing existing machines is relatively low, it is easier to extend CA technology in the field.

Policies can also create barriers. For example, because of concerns about air pollution, many localities in China (and elsewhere in the world) are taking steps to prohibit the burning of agricultural residue. If farmers cannot burn residue, they have to spend money to haul it away and dispose of it; the cost of technologies that do not require removing residues would then be lower. In fact, our data show that in villages where the government does not allow farmers to burn crop residue in the field, CA adoption occurs at a higher rate.

Finally, having access to information on the attributes of the new technology and how to use it in the field should also improve the likelihood of adoption. Therefore, we can expect areas with access to extension agents promoting CA technology to adopt the technology at higher rates. According to our data, in villages where farmers were using CA technology, there was a relatively good opportunity for farmers to access information about the cost and benefits of CA technology (33% of adopting villages). In contrast, in villages that did not adopt any kind of CA technology, only 6% of farmers had had any opportunity to participate in a CA technology extension project.

Similar results are found when looking at the household-level measures of technology adoption (Table 49). For example, if the household has more family members working off the farm, the probability of the household adopting some type of CA technology is higher. Households with more land also seem relatively more willing to adopt CA technology. Hence, in our household descriptive statistics, as in the village-level descriptive statistics, there is evidence that the scarcity of factor endowments plays an important role in encouraging technology adoption. Interestingly, Lin (1992), in a paper on hybrid rice adoption, found similar results in his sample of Hunan farmers.

Our household level data also suggest that policy and extension can play a role in encouraging adoption. First, households with less wealth, adopt less. This could mean there is a wealth constraint, since CA technology does involve some potential yield loss and investing in new machinery. Therefore, it is not surprising that results of our village-level descriptive statistics found that government subsidy policies helped encourage CA adoption.

In addition, although adoption rates are relatively low, there are still differences between farmers in regions affected by different government regulations and between farmers who have differential access to government extension programs. For example, in the case of households that adopted CA technology, 31% of them stated that they lived in villages in which the government does not allow burning of crop residues, but only 19% of non-adopters lived in such localities. The importance of extension efforts is also evidenced by the fact that 39% of households that had adopted some type of CA technology had at some point in the past participated in an extension training program on CA technology, whereas only 6% of non-adopting households had done so.

During estimation, we tried several different specifications for both the village-level (equation 2.1) (Table 50) and household-level models (equation 2.2) (Table 51). Since there may be a correlation between the error terms and the key right hand side explanatory variables, we used a fixed effect approach to control for all unobserved non-time varying factors. There may also be multicollinearity between several of our key policy variables. For example, it could be that in places where government bans the burning of crop residue, it also gives subsidies to farmers for purchasing machinery. The same is true in areas that have promoted CA technology (perhaps the same areas that provide machinery subsidies or ban residue burning). In other words, it is possible that policies come in packages, which would make identifying individual effects difficult. Because of this, in our analysis, we deal with this by considering policy variables separately.

In using a fixed effects approach to estimate equation 2.1, it appears that our models perform relatively well. The goodness of fit measures, the R^2 statistics, range from 0.36 to 0.50 for the village-level mode (Table 50). These high measures mean that the fit is relatively good for this type of analysis. The household-level model also performed well. The relative high Pseudo R^2 (from 0.46 to 0.48) statistics and high Chi2 (from 183 to 192) statistics show the model fits well (Table 51).

The relatively satisfactory performance of the model can also be analyzed from the coefficients of some of the control variables. Many of the coefficients of control variables in the equations have the expected signs and are statistically significant. For example, as estimated in the household-level model, farmers cultivating predominantly clay soils rarely adopt CA technology (Table 51). In fact, extension agents do not encourage using CA technologies on clay soils because water penetration and germination is poorer in such soils if CA technology is used. Adoption of CA technology is also significantly correlated with age of household.

More importantly, we found in the multivariate analysis—as was so clear in the descriptive statistics—that CA adoption is affected by the factor endowments that characterize villages and farm households. Specifically, the coefficients of variables measuring the opportunity cost of the farm household (the share of the village/family labor force that works off-farm) are positive and statistically significant in both the village- and household-level models (Tables 50 and 51). Although the coefficient of the land variable is not significant, the sign suggests that farmers with more land (or villages with farmers with more land) adopt CA technology more frequently. Hence, factor endowments appear to be one of the most important determinants of CA technology adoption.

We also saw evidence in our multivariate analysis that switching technologies may be expensive (or at least risky). From our household-based analysis, the coefficient of the wealth variable (which is positive and significant) suggests that rich farmers are more likely to adopt CA technology than poor ones (Table 51). In addition, the coefficients of variables that measure the presence of local machine-subsidizing policies (which could help alleviate the wealth constraint) is positive and statistically significant in the village-level model (Table 50). Together, these results suggest that, *ceteris paribus*, a policy that seeks to assist farmers in financing initial adoption indeed appears to promote the adoption of CA technology.

Our results—also as seen in the descriptive statistics—demonstrate the importance of other policy efforts, including government initiatives to run extension projects. First, when policies banning residue burning are well promoted (and perhaps effectively enforced), village- and household-level regressions show that CA adoption rates rise (Tables 50 and 51). Moreover, when villages host extension projects featuring CA technology, coefficients of variables measuring these extension efforts are positive and statistically significant.

Impacts of CA adoption on Agricultural Production, Poverty and Environment

Based on the literature review, we found that, in most cases, CA can increase wheat yield. Eighty-three percent of studies reported that after CA adoption, wheat yield increased, and only 17% reported that CA resulted in wheat yield reduction. Although we found some negative impacts of CA on wheat yield, we did not find any negative impact on maize yield in the literature.

Table 52. Impacts of CA adoption on wheat and maize yields based on the field survey conducted in the Yellow River Basin, 2008.

Change in yield		Share of villages (%)	Range of yield change (%)
Wheat			
	Increase	47	2 - 47
	Decrease	53	1 - 69
Maize			
	Increase	27	11 - 31
	Decrease	73	8 - 40

Data sources: Author’s data.

Table 53. Crop yield and CA adoption.

	Non-adoption	Reduced till + residue retention	Reduced till	Residue retention
Wheat yield (kg/ha)	3225	2220	2700	3150
Maize yield (kg/ha)	4478	5010	4350	3188

Data source: Authors' data. Notes: drawn from households which planted wheat or maize.

Table 54. Regression results of the impacts of CA technology on wheat yield.

	Log of wheat yield per hectare (kg)	
	(1)	(2)
CA technology		
Adoption of reduced till and residue retention (1=yes; 0=no)	0.005 (0.05)	
Adoption of reduced till (1=yes; 0=no)		-0.008 (0.07)
Adoption of residue retention (1=yes; 0=no)		-0.035 (0.24)
Adoption of both reduced till and residue retention (1=yes; 0=no)		-0.238 (0.96)
Production inputs		
Log of fertilizer cost per hectare (yuan)	0.112 (3.79)***	0.112 (3.80)***
Log of labor use per hectare (days)	0.020 (0.74)	0.016 (0.60)
Machine cost per hectare (yuan)	0.000 (0.53)	0.000 (0.27)
Log of value of other inputs per hectare (yuan)	-0.015 (0.35)	-0.018 (0.40)
Household characteristics		
Age of household head	-0.002 (0.13)	-0.002 (0.18)
Age of household head, squared	-0.000 (0.23)	-0.000 (0.17)
Education of household head	0.010 (1.31)	0.010 (1.34)
Plot characteristics		
Dummy of best plot (1=yes; 0=no)	0.129 (2.42)**	0.132 (2.45)**
Dummy of good plot (1=yes; 0=no)	0.032 (0.68)	0.036 (0.76)
Distance from home	-0.041 (1.48)	-0.045 (1.60)
Production shocks Yield reduction due to production shocks	-0.008 (6.05)***	-0.008 (5.97)***
Other control variables		
Years adopting CA	0.014 (0.24)	0.041 (0.56)
One season dummy (1=yes; 0=no)	0.018 (0.23)	0.039 (0.50)
Village dummy	——	——
Constant	5.704 (12.89)***	5.725 (12.87)***
Observations	305	305
R-squared	0.91	0.91

Absolute value of z statistics in parentheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 55. Labor and machine input under conventional and conservation agriculture.

	Wheat	Maize
Labor input (days/ha)		
Conventional agriculture	120	240
Full CA technology (reduced till and residue retention)	45	135
Machine input (yuan/ha)		
Conventional agriculture	690	310
Full CA technology (reduced till and residue retention)	175	150

Data sources: Authors' survey.

Table 56. Regression results of the impacts of CA technology on poverty.

	If under extreme poverty line	
	Coefficient	t
CA technology		
Adoption of any reduced till and residue retention tech.	-0.508	1.90*
Household characteristics		
Age of household head	-0.008	0.13
Age of household head, squared	0	0.19
Education of household head	-0.038	1.09
Plot characteristics		
Land area (mu)	-0.034	2.85***
Number of plots	-0.026	1.28
Share of irrigated plots (%)	0.448	1.3
Share of plain plots (%)	0.007	0.03
Share of loam plots (%)	-0.168	0.49
Share of clay plots (%)	-0.327	1.07
Share of first-class plots (%)	-0.544	1.41
Share of saline soil plots (%)	-1.933	0.75
Opportunity cost of farm labor		
Share of labor doing off-farm work (%)	-1.662	4.55***
Production shocks		
Yield reduction due to production shocks	0.019	2.22**
County dummy		
Constant	1.288	0.78
Observations	288	
Pseudo R-squared	0.18	

Absolute value of t statistics in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%.

Based on our 2005 field survey, and applying both descriptive statistic and econometric analyses, we found that CA did not increase crop yield significantly (Table 53). Compared with wheat yields of farmers adopting CA technologies (2220 kg/ha), yields of conventional farmers was higher (3225 kg/ha) (Wang et al., 2007). However, farmers adopting CA had higher maize yield (5010 kg/ha) than non-adopting farmers (4478 kg/ha). Crop yield is influenced not only by tillage technologies (such as CA or conventional tillage), but also by many other socio-economic variables. To determine the real impact of CA technologies on crop yields, we established econometric models for both wheat and maize yields. Econometric results show that CA adoption did not significantly increase or reduce wheat yield, since the coefficients of CA variables in the models are not statistically significant. The econometric model for maize yield (not shown) was similar. In sum, CA adoption had no significant impact on crop yield.

In our 2008 field survey, we again asked farmers about the impacts of CA on wheat and maize yields (Table 52). It seems that in some areas of the YRB, in the beginning of CA adoption, crop yield increased, while in other areas, crop yield decreased. For example, our survey found that in 47% of villages, after CA adoption, wheat yield increased 2-47%, while in 53% of villages wheat yield decreased 1-69%. Similarly, maize yield increased 11-31% in 27% of villages, and decreased 8-40% in 73% of villages.

Farmers provided some explanation for the positive and negative impacts of CA on maize and wheat yields. Farmers in Henan and Shandong Provinces considered that yield increase was due to the preservation of soil moisture. Conversely, they believed that yield decreased as a result of the deleterious effects of poor seed drills on soils. Seed varieties and climate change are two other important reasons for yield reduction. Farmers in Ningxia Province gave three reasons for yield reduction after CA adoption: (1) CA does not preserve soil moisture; (2) manure cannot be used on the fields; and (3) weed problems worsen after CA adoption.

Cost-saving effect of CA adoption

Based on either descriptive statistics analysis or econometric analysis, the 2005 survey results show that CA adoption can significantly reduce labor input. Full CA adoption can reduce labor input of wheat production by 50% (Table 55), while Partial CA can effect a reduction of 33-67%. For maize production, Full CA can reduce labor input by 46%, and Partial CA can reduce labor input 15-46%. We found similar data for potato and oats. The labor effect is not hard to understand: since CA farmers do not need to prepare the land; their labor input for land preparation is zero. However, farmers who do traditional tillage have a labor input of 10.5 days per ha. For other activities such as harrowing, fertilizer application, seeding, weeding and cleaning residue, labor requirements of CA farmers are lower than those of farmers who do not adopt CA. In our econometric model for wheat labor input, the dummy variable of CA adoption is negative and significant, which means that after controlling other factors, farmers adopting CA will significantly reduce labor use (about 33%). We found results for maize production were similar to those for wheat production. Econometric results showed that compared with traditional agriculture, labor input for maize production under CA can decrease by about 86%.

Based on our 2008 field survey, most farmers also think that CA can reduce production costs, especially for labor input. Results show that 100% of villages in Ningxia and Shandong Provinces and 80% of villages in Henan Province responded that CA can save input costs. Farmers in Ningxia Province said that CA significantly reduced labor input and saved time, mainly because after adopting CA, tillage and sowing are done once, instead of two or more times, thus reducing the farm production process. Farmers in Henan Province thought CA can save labor and time, but requires more machinery investment (to replace existing machines with CA machines). Another issue mentioned by farmers in Henan Province is that after adopting CA, weeds in the field increased. Farmers in Shandong Province said that due to the reduction in farm procedures (especially tillage and sowing), CA can reduce production investment and save labor input. In addition, tillage and sowing are now done in a more timely fashion, and production efficiency has increased. However, as in Henan Province, farmers in Shandong Province thought that after adopting CA, they needed to invest in replacing the existing farm machines with CA machines.

Due to the reduction of production costs, the research also shows that CA can increase farmer income. Some 60% of literature reported that CA can increase farmer income by less than 30% (Zhao and Shi, 2006). A further 20% of literature found that after adopting CA farmer income can increase by 40% to 60% (Gao, 2006). The remaining 20% of literature demonstrates that CA even can increase farmer income by more than 70% (Ma et al., 2006).

We conducted both descriptive and quantitative analysis using econometric models to identify the actual impact of CA technologies on poverty (Table 56). Based on descriptive analysis, we found that compared with the group that did not adopt any CA technologies, the adopting group had a lower share (about 4%) of households under the extreme poverty line2. The results of our econometric model are consistent with our descriptive analysis. Our regression results show that many coefficients of our control variables have the expected signs and are statistically significant. Importantly, we found that adoption of CA technologies can significantly reduce poverty by 5%.

Based on our 2008 field survey, CA adoption has some influence on women's labor input and non-farm labor time. For example, 33% of villages in Ningxia Province reported that due to CA adoption, labor intensity decreased. Mechanization of CA means women's work is enough for agriculture, and more labor force can go outside to find non-farm jobs. In Henan Province, 100% of villages reported that due to CA adoption, women's labor time increased, since most men looked outside for non-farm jobs. In addition, they said there are more weeds in no-tillage plots, which need more labor to eliminate weeds. In Shandong Province, no villages reported that CA influenced the labor input of women.

Most villages in our 2008 field survey reported that their environment have been influenced by the adoption of CA. On average, 71% of villages reported that their environment has been influenced. In Shandong Province, 83% of villages have been affected. In Ningxia and Henan Provinces, this number is 67% and 60%, respectively.

Some farmers said that CA has some effect on water use efficiency, but their responses differ by region. For example, in Shandong Province, 50% of farmers said it saved water by 20% to 50%. The other half of farmers said that there was no change at all. In Ningxia Province, most farmers said they did not observe such effects. Only one said water evaporation decreased, but that the capacity for saving rainfall decreased, too. Rain is lost because of the smooth land surface. In Henan Province, the majority answered that there were no changes. Only one village said that it did not save water, but wasted 50% water.

Some farmers pointed out that soil quality improved due to CA adoption. In Henan Province, 60% of villages said there were no changes, and 40% said soil quality was better, but they were not able to specifically quantify the improvement. In Shandong Province, 50% of villages said that the soil is getting better, but again without detailed knowledge of the changes. The rest were not aware of any change at all. In Ningxia Province there was no awareness of the impacts of CA on soil quality.

Reduced soil erosion as a result of CA adoption was also reported by some farmers. In Henan Province, 60% of farmers do not know, 20% think it is getting less but could not quantify the reduction. In Shandong Province, the majority answered that there were no changes; only one village said they were unable to respond, for lack of understanding. However, in Ningxia Province, farmers were unaware of the impacts of CA on soil erosion.

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[2] The extreme poverty line is 693 yuan (USD 99) per capita.

Increased soil organic matter content is another possible, positive environmental effect of CA adoption. In Henan Province, 80% of villages said they had no idea, while 20% said organic matter content increased 0.03%, e.g., from 0.05% to 0.08%. In Shandong Province, two out of three villages had no idea. The others said it increased. One of them said determination of potassium increased by 10%. However, in Ningxia Province, no one knows the impact of CA on organic matter content.

Conservation agriculture can also reduce chemicals use. In Henan Province, 60% of villages said there was no change, while 40% said it increased by 20-50%. In Shandong Province, the majority answered that there were no changes. Only one village said that pesticide use decreased by 10%. However, in Ningxia Province, no one knew of such impact of CA.

Conclusion

The data used in this report come from our field survey in four provinces of northern China. The survey covered 49 villages, 292 households, and 579 plots in 8 counties of these four provinces. Based on the survey, we classified CA technology into Full CA (or Real CA) and Partial CA (or Nominal CA) technology.

Results show that Partial CA technology began to be adopted in the early 1980s, and accelerated in the 1990s, especially the late 1990s. Unlike Partial CA technology, adoption of Full CA technology did not begin until the late 1990s. Overall, adoption rates of CA technology (either Partial or Full) are still very low. The adoption rate for Partial CA technology (especially residue retention) is higher than the adoption of full (or Real) CA (such as reduced till and residue retention together) which is almost zero.

We found that policy intervention, CA project implementation, and some socio-economic factors are all related with CA technology adoption. Results show that policy interventions (such as machinery-subsidizing policies and policies banning residue burning) can play a role in promoting CA adoption. Effectively implementing CA projects can accelerate CA, and CA adoption is constrained by labor opportunity, irrigation conditions, and draft animals.

Based on these findings, it seems that if China implements the policy banning residue burning well, conducts more CA demonstrations, provides more labor opportunities and better irrigation, and if the cost of replacing existing machines and draft animals is low, CA technology will be adopted in the country quickly. However, for now, labor in China is intensive, and the ability of farmers to replace existing machines or animals is still low. In the future, increasing labor opportunities and farmers’ capital investment capacity, and implementing more CA demonstrations and improving irrigation will facilitate CA technology adoption.

Based on our 2005 field survey, we found that CA did not increase crop yield significantly. In our 2008 field survey, we asked farmers about the impacts of CA on wheat and maize yields. It seems that in some areas of the Yellow River Basin, at the beginning of CA adoption, crop yields increased, while in other areas, crop yields decreased.

The 2005 survey results show that adopting CA can significantly reduce labor input. Based on our 2008 field survey, most farmers also think that CA can reduce production costs, especially for labor input.

Due to reduction of production inputs, studies have also found that CA increases farmer income: 60% reported that CA can increase farmer income by nearly 30%. Based on descriptive and quantitative analysis using econometric models, we found that adoption of CA technologies can significantly reduce poverty by 5%. Based on our field survey in 2008, CA adoption has some influence on the labor input of women and non-farm labor time.

Conservation agriculture adoption has three types of environmental impacts: (1) it contributes to increasing water use efficiency; (2) it increases soil moisture and reduces soil water evaporation by about 30%; and (3) it can reduce runoff of surface water by about 60%. Also, because some or all residues are retained on the soil surface, not burned, environmental pollution is reduced. During the 2008 field survey, 71% of villages reported that their environment had been influenced by CA adoption. Some farmers said that the CA had some effect on water use efficiency, but their responses differ by region.

3.3 Encourage the development of a policy environment that does not discriminate against conservation agriculture practices and of input, equipment and rental markets needed to make conservation agriculture practices generally accessible.

Methods

The project design engaged senior leaders from each of the seven participating organizations in order, *inter alia*, to facilitate the communication of project results to policy makers at national, Provincial and County level, related to CA promotion including national and regional plans, CA extension programs and subsidies on CA equipment. Relevant officials from MOA, Provincial and Local Government were regularly invited to visit field demonstration sites and observe the performance of CA in farmers' fields. Project results were shared regularly with the Yellow River Commission so Basin planners and policy makers could incorporate the implications of the field research into decisions on Basin development. Project scientists engaged in relevant debates, for example the potential of CA to mitigate dust storms affecting Beijing through CA.

Results

The socioeconomic surveys identified policy and socio-economic factors which are important drivers of wider adoption of CA technology. Results show that policy intervention (such as machinery subsidy policy and policy of forbidding burning residue) can play some role in promoting the adoption of CA technology.

At a national level, project leaders contributed to the CA component of the national Five Year Plan which targeted resources for the promotion of CA in China. The incorporation of the CA blueprint in the national plan is a major accomplishment. In addition, the implications of the project results were brought to the attention of the Minister of Agriculture.

At the provincial level, some project staff participated in provincial meetings on machinery subsidy in order to decide which farm equipment should receive subsidy from the National Government. As a consequence, one of the no-till seeders developed with project support has been added to the Agricultural Machinery Purchase Allowance list, implying a subsidy for farmers equivalent to 40% of purchase price, thus promoting manufacture and sales of the no-till seeder.

The Yellow River Commission was regularly briefed on project results through visits of project staff and participation in the Yellow River Commission Forum in 2007. Commission leaders are aware of the potential of CA to contribute to water-efficient sustainable development in the Basin.

Conclusion

There has been a high level of engagement with policy makers at national, Basin, Provincial and County levels which has developed an understanding of the potential for CA and the required adjustments to policy. It is expected that the benefits of these project actions will continue to be seen with ongoing adjustments to future plans and policies to support CA.

3.4 Strengthen the capacity of local partners to conduct collaborative research and development on conservation agriculture in a partnership mode with multiple stakeholders.

Methods

The project worked with seven major local partners, including the Chinese Agricultural University, research organizations or universities in five Provinces, and station and adaptive researchers and extension workers in five pilot Counties. Furthermore the project worked with farm equipment factories in three Provinces. Through these local partners, several hundred professional research and extension staff improved their management of CA trials and demonstrations. In addition, the project attracted students to contribute to the analysis of research results in the course of their thesis work. While many of the partners had strong scientific capacity for research on varieties, agronomy, soil management and economic analysis, it was recognized that innovation for CA is complex and demands systems and participatory research. While the project sought to strengthen component research field skills, especially through one-on-one mentoring by international scientists, workshops and an international study were organized in order to strengthen capacity to design, manage and implement collaborative multi-stakeholder collaborative research and development.

Results

Some 50 students in partner institutions received, or will shortly receive, Bachelors, Masters or Ph D degrees based on project research data and supervised by project scientists. Another valuable capacity building activity was the regular "on the job" advice and mentoring of international scientists from CIMMYT and IMWI on the management of research and demonstration fields, interpretation of results, and on hydrology and crop modeling using DSSAT. International scientists from CIMMYT introduced new research tools such as the GreenSeeker NDVI sensor to estimate nitrogen use efficiency and web based knowledge sharing tools. One innovation in capacity building was the organization of the traveling workshops around mid-year to review and learn from the field activities in each pilot County. This successfully brought together multi-disciplinary groups of research, academic and extension staff from different partner institutions to visit, once per year, the field work of a couple of Provinces and learn together through discussions of site selection and characterization, experimental design, specification of treatments (especially the timing and tillage practices, and the height and nature of retained crop residues) and interpretation of results.

In terms of more formal capacity building, more than 50 researchers participated in the Participatory Research Workshop in 2006 or the Impact Pathways Workshop in 2007. The former was restricted to project researchers and covered participatory diagnoses, on-farm research, and participatory farmer evaluation. The workshop evaluation recorded a substantial increase in participants' understanding and knowledge. With strengthened skills, these partner staff demonstrated greater confidence and effectiveness in managing participatory demonstrations. The Impact Pathways Workshop was attended by scientists from project partners, as well as staff from other Basin projects, and brought a new paradigm to the networks of actors which advance innovation and the multiple channels through which farmers acquire and benefit from improved CA technologies. One study tour was organized to India for partner scientists to observe the rapid spread of CA in north-west India.

There has been two-way benefit from the exposure of participating scientists in the Ghana (Yan Changrong) and Addis (staff member from Yan Changrong's team) workshops, and the study tour to India. Collaborating scientists have acquired a greater understanding of the biophysical and socioeconomic aspects of resource-productivity enhancing technologies and their adoption.

Conclusion

The project made substantial contributions to the capacity of partners, both in the science of CA and the innovative approaches to multi-stakeholder CA R&D through formal and informal capacity building. Given the great importance and need for continuing adaptation and expansion of CA to other Counties and Provinces in China, there is arguably high value (and evident strong demand) for continued capacity building in innovative approaches to collaborative R&D for CA.

4 INTERNATIONAL PUBLIC GOODS

The positive results from this project are relevant to rainfed areas outside the four target Provinces and outside China. Site-similarity analysis will aid the targeting, i.e., definition of the most likely areas of extended impact to other areas with similar agro-ecologies and relevant institutional settings, including water scarce and also cool temperate environments, e.g., in Central and South Asia. CPWF and the international centers (CIMMYT and IMWI) could facilitate the dissemination of the IPGs in various ways, including the presentation of project results in workshops and even the World Congress on Conservation Agriculture. Publications (in English language for the international community) resulting from this project, intended both for the scientific community and for the general public, will spread the knowledge outputs of this research, including the existence of the patents, and awareness of the benefits of conservation agriculture on farmer livelihoods, the natural resource base and the environment.

5 OUTCOMES AND IMPACTS

Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
National planners	Incorporation of a CA component (or "blueprint" in the Five Year Plan developed with input from project scientists	Deeper understanding of CA, both its performance in the field and the policy/institutional support needed for adoption.	Sharing of experience with CA performance and constraints to adoption across participating Provincial project leaders. Study tour to India. Mentoring from senior international scientists.	Substantial increase in resources for CA R&D in China
Yellow River Basin Commission leaders	Incorporating the potential role of CA into analyses underlying strategic plans for the Basin	Increased knowledge of water productivity from CA	Briefing YRB on project results; involvement of YRB staff in project workshops and field visits	Changes expected in future strategies and plans
Provincial Ministries of Agriculture planners and research managers	Focused support to CA promotion, e.g. addition of CA equipment developed with project support to the list of subsidized equipment	Knowledge of improved CA no-till planters developed with project support	Selection of well-placed Provincial project leaders; sharing of experience across leaders; international study tour; documentation of CA performance and required equipment and policies	Increased manufacture, sales and use of CA no-till seeders developed with project support in several provinces
Farm machinery factory managers	Improvement of CA equipment design and range of options for farmers	Exposure to alternate equipment designs; engagement in farmer participatory evaluation of equipment in the field	Communication of improved equipment features, and of farmers' needs	Increased sales of certain CA equipment developed with project support

County research and extension staff	Increased support to CA research and to CA promotion	Better understanding of CA options to increase incomes and reduce environmental problems including dust and straw burning	Invitations to County officials to CA field demonstrations; briefing on CA performance; documentation in Chinese	Adoption in pilot Counties

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

From policy makers to farmers there is a greater understanding of the potential of CA to contribute to sustainable development. One notable outcome is the greater understanding of the potential role of CA in sustainable development by leaders of the Yellow River Commission. The capacity and profile including visibility built through the project enabled project organizations to submit successful proposals for science funding, and be awarded 5 national CA and 10 provincial CA projects, thus leveraging the CPWF investment in China. While the outcomes in terms of policy makers have been referred to above, including a CA component in the national Five Year Plan, there have been major outcomes and impacts at the local level in pilot Counties through demonstration and training. For example, more than 5000 farmers took part in project training courses or field days at the CA demonstrations, and they will have shared their observations on CA with other farmers in their villages. The socio-economic survey results show that the adoption of technologies of CA, although still low at a national level, speeded up during the current decade. The results of the socioeconomic survey and the field trials and demonstrations substantially influenced the preparation of an Asian Development Bank loan proposal for China.

Naturally, the impacts at farm level of CA adoption have been substantial (numbers of farmers are great even if proportion of adopters is still low). Increased farm incomes have arisen from the 25% or more reduction in production costs, and according to the survey results the adoption of CA technologies significantly reduced farm household poverty. As well as increasing income, CA has increased the water use efficiency and nutrient use efficiency, and also reduced soil erosion from wind and water.

All the above have potential for strong impact: however, the greatest potential for impact would lie with incorporation of the CA blueprint in the National Plan will have the, through increased adaptation, subsidies and extension effort, especially in the context of growing environmental challenges in rural China. The farmer beneficiaries will benefit from increased income and improved soil health (physical assets). The expansion of the YRB CA R&D to other Basins in China would increase spillover benefits.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

Ongoing mentoring of CA technology/package adaptation in the current and other Provinces/basins in China; monitoring of adoption and identification of CA performance, policy and institutional constraints to adoption; capacity building at Provincial and County levels; maintenance of international links and networks for international CA knowledge sharing.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

Incorporation of the “CA blueprint” in the national Five Year Plan was hoped for but not expected – whereas improvements in plans for CA at Provincial and County level were expected.

Why were they unexpected? How was the project able to take advantage of them?

Normally beyond reach of a small project. Because of early CA field results and international experience gained through the study tour of the senior project leaders, the potential of CA was brought to the attention of the national Minister of Agriculture and national planners.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

Advance the training in participatory research and impact pathways. Increase the knowledge sharing through Chinese language web CA knowledge platforms within the Basin; and strengthen English language links to Asian and OECD countries’ experience with CA, through, for example, participation in international conferences on CA.

6 PARTNERSHIP ACHIEVEMENTS

With the implementation of this project, participants improved their research capacities greatly and established more extensive collaborative relationships across Provinces and with other countries.

7 RECOMMENDATIONS

Given the importance of increasing water productivity and reducing poverty in the YRB and China, the first recommendation is to reinforce and expand the platform for CA R & D in China – focusing on further research on selected CA production and policy issues and expanding the project footprint on the ground beyond the current pilot Counties.

While science is strong in Chinese organizations, strengthening international partnerships on CA is a priority. In particular, continuing exposure to cutting edge science, e.g., GreenSeeker NDVI sensors and research methods, e.g., impact pathways and participatory research, would be of immense value to CA in China.

Further research should be conducted on variety selection and supporting cultivation technology to perfect CA technology, for which linkages to sources of international germplasm, equipment and research would be beneficial. Clearly, simply copying the methods and technologies from other places will not be effective. The research and demonstration of CA systems needs to be targeted to various local conditions, in relation to socio-economic and environmental circumstances.

Farmer training will have to be strengthened to improve farmers' knowledge and skills related to CA technology. For instance, farmer perceptions of CA systems is one two of the major impediments to the expansion of CA. It is important to convey a whole CA system approach rather than individual component technologies.

Public private cooperation is required for the development of appropriate CA equipment.

A scientists-technicians-governments-factories-farmers innovation system should be tested and expanded for a long-term expansion of CA systems.

Policy making should pay attention to the ecological and environmental benefits of CA which complement the benefits from productivity and poverty reduction. With feasible CA technologies now demonstrated, the government can consider the strengthening of the implementation of the policy of forbidding burning residue.

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