Tillage and Residue Effects on Rainfed Corn Production in Northern China

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Abstract: Field studies on tillage and residue management for spring corn were conducted at two sites, in Tunliu (1987-1990), and Shouyang (1992-1995) counties of Shanxi province in the semi-humid arid regions of northern China. This paper discusses the effects of different fall tillage (winter fallow tillage) and residue application methods on soil water profile with time and water use, as well as corn yields.

Conservation tillage practices for corn in Shouyang resulted in significantly higher soil water contents, especially in the 0-100 cm profiles during April-July and September, than under conventional tillage, providing more available water for corn growth due to increased soil water storage during the rainy season. Conservation tillage with residue application practices generally led to yield advantages. Increases of 18-26% were found for reduced tillage with residue incorporation over the conventional systems. Yields under no-till were equivalent to those from conventional methods, especially in dry years.

These results suggest that the following two alternatives -both reducing the number of secondary tillage passes after the main operation for spring corn production systems:

- using deep ploughing with incorporated straw and fertilizers after harvest in fall, and no-till seeding practices
- using subsoiling between rows or no-till with residue mulching after harvest in fall, and no-till seeding practices.

INTRODUCTION

China has a large region of dryland farming in the north, which accounts for about 56% of the nation's total area. Development of dryland farming in the region is constrained by: 1) adverse weather, topography and water resource conditions; 2) low fertility soils; and 3) poor soil management. Much of the land in the semi-humid arid region of Northern China is hilly and rainfed. The seasonal drought periods cause a reduction in both spring corn seedling emergence and winter wheat growth (the two crops most commonly grown) during most years. Conventional farming practices with intensive cultivation, low fertiliser or manure input, and little use of crop residue cause soil, water and nutrient losses, soil quality degradation (low soil organic matter, fragile soil physical structure, less water and fertiliser use efficiency), and unstable land productivity in these senstitive areas. Since the 1980s national research projects on dryland farming, including conservation tillage studies initiated by the Chinese Academy of Agricultural Sciences (CAAS) have been carried out in the semi-humid arid regions of northern China. During 1980-1985 research on the effects of different tillage measures on soil water storage and conservation for rainfed wheat production, followed by research during 1985-1990 on the effects of alternative tillage techniques for wheat and corn production in Tunliu, Shanxi (Gao, *et al*., 1990, 1991; Wang, *et al*., 1995), and during 1990-1995 studies on conservation tillage in combination with machinery use and agronomy in dryland farming were conducted in Linfen, Shanxi and Shouyang, Shanxi (Cai *et al*., 1994, 1995, 1998; Cai and Wang, 2001; Wang and Cai, 2000). Recently, studies on conservation tillage were carried out on the sloping loess soils in Luoyang, Henan

(Cornelis *et al*., 2002). Preliminary results showed that conservation tillage practices improved water storage, crop yield, and water use efficiency.

The objectives of abovementioned studies were to determine the effects of different tillage and residue application methods on the amount of soil water stored in the profile over time, and the effects on crop yields and water use efficiency, for both winter wheat and spring corn. This paper will only report on the research findings for spring corn. The outcome of the experiments will provide information on the suitability of conservation tillage (no-till, and reduced till) and residue management (mulching or incorporation) methods for crop production systems in the semi-humid by arid regions of Northern China.

MATERIALS AND METHODS

Experimental location, climate and soils

The twp research sites for spring corn: Tunliu and Shouyang are located in Shanxi province, in the 'semi-humid by arid' region of Northern China. A brief description of the research sites is given in Table 1. Spring corn is the main crop grown under the one crop per year cropping system in Shouyang. The annual regional precipitation shows large variations from year to year and uneven distributions within seasons. High rain intensity and frequent rainstorms occur during the summer season (June to September) when about 60-70% of the annual precipitation occurs. Water shortages occur during the period of maize emergence in spring. The average annual 'open pan water evaporation' varies between 1600 and 1800 mm. Only about 24% of the summer rainfall can be stored in the soil (Cai *et al*., 1995). Seasonal drought with heavy winds often occurs in the winter and spring, and the wind exacerbates soil drought. The large annual precipitation variation and seasonal water shortages cause a reduction in spring corn seedling emergence and large yield variations from year to year.

The soil nutrient levels in the area are low due to extensive cultivation, low fertiliser input, little use of crop straw, and wind and water erosion. The soil organic matter, total N, available N (NH_4^++NO_3^-), Olsen' s P, and available K content of the soil were 11.4-25.7 g kg^{-1}, 0.87-1.10 g kg^{-1}, 55-83 mg kg^{-1}, 4.6-10.6 mg kg^{-1}, and 93-140 mg kg^{-1}, respectively. The soil pH is above 8.0. In Tunliu (Wang, *et al*., 1995) soils usually have a shallow top layer and a hard pan (bulk density about 1.4 Mg m^{-3}) between 17-27 cm depth due to traditional moldboard ploughing over many years. This causes a decrease in rainwater infiltration and an increase in surface runoff during summer fallow in the rainy season. Slopes are gentle (1-3%).

Table 1 Locations and conditions of the research sites.

Site	Location	Elevation (m)	Soil type*	Annual rainfall (mm) Average	Max.	Min.	Annual ave temperature (°C)	Frostfree period (day)	Crops
Tunliu	113°E, 36°N	950	Sandy clay loam (Luvisols)	550	917	312	9.4	160	Winter wheat; Spring corn
Shouyang	112°E, 37°N	1100	Sandy clay loam (Leptosols)	520	806	235	7.4	130	Spring corn

* Source of soil classification: FAO/UNESCO, 1993

Experimental treatments

A summary of the treatments in the two sites is given in Table 2.The corn cultivars Zhongdan 3 (Tunliu) and Chidan 14 (Shouyang) were used, at a seeding rate of 30 kg ha^{-1}. The inter-row and row spacing was 30x60 cm. Fertilisers were applied prior to seeding: Tunliu: 138 kg N ha^{-1} (urea) and 84 kg P_2O_5 ha^{-1} (superphosphate), in Shouyang these rates were 150 and 75 resp. Plot size in Tunliu 1333 m^2, in Shouyang 390 m^2. The experiment in Tunliu had a sub-treatment with corn stover mulching at 4500 kg ha^{-1}.

Table 2. Agronomic treatments

Treatment	Description
Tunliu	
CT: conventional	ploughing (22-25 cm depth) after spring corn harvest and then harrowing at 2 times in fall, and shallow ploughing, applying fertilisers and harrowing during the next spring
NT: no-till	no tillage after harvest in fall, and using one pass seed and fertiliser application with a no-till planter in spring
DP: deep ploughing, straw incorporated	deep ploughing, (25-28 cm depth) thereby incorporating straw and chemical fertilisers in fall
Shouyang	
CT: conventional	ploughing (22-25 cm depth) and harrowing in fall; ploughing and applying fertilisers next spring; harrowing and seeding by animal (or machinery); weed control by hand
NT-S: no-till, standing corn stalk	keeping the corn stalk standing after harvest in fall; using one pass seed and fertiliser application with a no-till planter in spring; weed control using herbicides
NT-F: no-till, whole corn stalk mulch	as NT-S, corn stalks are flattened on field
DP: minimum tillage, fertilisers and corn stalk incorporated	deep ploughing (25-28 cm depth), thereby incorporating straw and chemical fertilisers in the fall; harrowing in early spring and rolling before sowing; one pass seeding by machinery or animal
SS: minimum tillage i.e. subsoiling with whole corn stalk mulch	subsoiling between rows (at 60 cm interval), keeping whole corn stalk mulch after harvest in the fall; one pass seed and fertiliser application with a no-till planter in spring, weed control using herbicides
DP+MB: Mulch-before	as DP, mulching before seedling emergence (after sowing)
DP+MA: Mulch-after	as DP, mulching after seedling emergence

Measurements and determinations

Data were collected to allow determination of annual rainfall, growing season rainfall, soil water at sowing (SWS), water contents during growing season, soil water at harvest and water use (ET), grain yield of corn and water use efficiency (WUE). *Precipitation* was measured at the sites and at the local weather stations. *Soil water* was determined gravimetrically by sampling from 0-200 cm soil depth before sowing, after harvest, and during growing periods. *Evapotranspiration* (ET) was determined during the growing periods, using the seasonal rainfall and soil water consumption data during the growing periods. The crop *yields* were determined at harvest and water use efficiency (WUE) was estimated by the ratio of yield to ET. *Statistical analysis* was conducted using the GLM and REG procedure of the SAS institute, Inc. (1985).

RESULTS AND DISCUSSION

Yield responses to tillage methods

There was not much difference in evapotranspiration during spring corn growing periods among the treatments, but residue mulching combined with tillage treatments caused an increase in Tunliu (Table 3), where yields decreased by 8%, 14%, and 5% with NT, but increased by 2%, 21% and 18% with DP (ploughing with stover incorporated in fall), respectively, during 1987, 1988 (the wet year) and 1989, as compared with the conventional tillage method ($P<0.0031$). The evapotranspiration during spring corn growing periods in Shouyang mostly was reduced with conservation tillage practices compared with CT ($P<0.0368$). DP had the highest corn yields, which were 26%, 35% and 11% higher than that of the CT treatment, respectively, in 1993 (although suffering from a hailstorm), 1994 and 1995 ($P<0.0053$). NT and SS had the same effects on corn grain yields, which were increased by 18-22% and 6% in 1994 and 1993, respectively, but decreased by 11-14% in 1995 (the wet year), as compared with that of the CT treatment. Residue application time had a great influence on corn yields in Shouyang. Yields increased by 55% and 9% in 1993 and 1994, respectively, with DP+MA (deep ploughing and stover mulching after seedling emergence). Yields decreased by 12% and 5% in 1993 and 1994, respectively, with DP+MB (deep ploughing and stover mulching before seedling emergence), which was caused by the lower soil temperature at seeding. The WUE for spring wheat were improved with DP: an increase of 36% in 1993 and 29% in 1994 in Shouyang ($P<0.0793$), and an increased of 20% in Tunliu ($P<0.0252$). Statistical results showed that DP had significant yield advantages for spring corn, which were about 26% (on the 6yr average) and 18% (on the 3yr average) higher, respectively, in Shouyang and Tunliu than with CT.

Table 3. Effects of tillage methods on corn yield, ET (evapotranspiration) and WUE (water use efficiency)

Year	Treatment	Yield (kg ha^{-1})	-CT† (±%)	ET (mm)	-CT† (±mm)	WUE (kg mm^{-1}ha^{-1})	-CT† (±)
Tunliu							
1987	CT conventional	6624	-	452	-	14.7	-
	NT no-tillage	6105	-8	449	-3	13.6	-1.1
	DP deep ploughing	6753	2	453	1	14.9	0.2
1988	CT conventional	3155	-	445	-	7.1	-
	CT+M conventional plus mulching	3830	21	458	13	8.4	1.3
	NT no tillage	2723	-14	450	5	6.0	-1.1
	NT+M no-tillage plus mulching	2593	-18	485	40	5.4	-1.7
	DP deep ploughing	3830	21	452	7	8.5	1.4
	DP + M deep ploughing plus mulching	4496	43	459	14	9.8	2.7
1989	CT conventional tillage	5386	-				
	NT no-tillage	5111	-5				
	DP deep ploughing	6362	18				
Pr>F		0.0031		NS		0.0252	
Shouyang							
1993	CT conventional tillage	2612	-	415	-	6.3	-
	NT-S no-tillage, standing corn stalks	2993	15	399	-16	7.5	1.2
	NT-F no-tillage, flattened corn stalks	3188	22	386	-29	8.3	2.0
	DP deep ploughing	3303	26	386	-29	8.6	2.3
	SS subsoiling	3092	18	375	-40	8.3	2.0
	DP+MB deep ploughing plus mulch before	2298	-12	365	-50	6.3	0.0
	DP+MB deep ploughing plus mulch after	4059	55	371	-44	11.0	4.7
1994	CT conventional tillage	5166	-	478	-	10.8	-
	NT-S no-tillage, standing corn stalks	5181	0.3	437	-41	11.9	1.1
	NT-F no-tillage, flattened corn stalks	5465	6	461	-17	11.9	1.1
	DP deep ploughing	6966	35	489	11	14.3	3.5
	SS subsoiling	5462	6	450	-28	12.2	1.4
	DP+MB deep ploughing plus mulch before	4890	-5	413	-65	11.9	1.1
	DP+MB deep ploughing plus mulch after	5634	9	464	-14	12.2	1.4
1995	CT conventional tillage	5702	-	691	-	8.2	-
	NT-S no-tillage, standing corn stalks	5093	-11	653	-38	7.8	-0.4
	NT-F no-tillage, flattened corn stalks	4916	-14	655	-36	7.5	-0.7
	DP deep ploughing	6318	11	679	-12	9.3	1.1
	SS subsoiling	5105	-11	681	-10	7.5	-0.7
Pr>F		0.0053		0.0368		0.0793	

†Difference from conventional tillage

Yield responses to residue application methods

Yield responses to the methods of residue application were different among the experimental sites. For spring corn production systems in Shouyang, where the annual average air temperature was about 7°C, the highest yields were obtained by deep ploughing with residue incorporated (DP). Subsoiling with residue mulching (SS) had lower yields than DP. The same yield responses to deep ploughing were observed in Tunliu, showing that soil temperature is one of the most dependent factors for spring corn emergence.

To further identify the effects of residue application combined with tillage practices, statistical analyses, using the GLM procedure of the SAS (1985), were conducted, to determine the effects of 1) residue application; 2) residue application types; and 3) tillage types. Yields with residue-treated tillage practices generally were higher than with the conventional method. Corn yields with residue-treated in Tunliu significantly increased by 4% compared with the non residue-treated tillage method ($P<0.0241$). For spring corn in Shouyang and in Tunliu residue incorporation caused significant yield advantages of 26% and 16% ($P<0.01$), respectively, over the non residue-treated method. For tillage types, reduced tillage methods (such as DP) in Tunliu caused about 18% yield advantages ($P<0.05$).

Soil water profile with time

Conservation tillage practices on corn in Shouyang also showed increased soil profile water contents with time during corn growing periods, and especially a significant influence on the 0-100 cm profiles during April-July and September with NT and SS, as compared with CT (Table 4).

Table 4. Effects of tillage methods on average monthly soil water contents (mm) during corn growing periods from 1992-1995 in Shouyang (0-100 cm soil depth)

Treatment	APR	MAY	JUN	JUL	AUG	SEP	OCT
CT conventional tillage	198 b	183 c	187ab	195b	204a	188b	195a
NT-S No-tillage, standing stalks	207ab	202ab	191ab	206b	206a	199a	200a
NT-F No-tillage, flattened stalks	205ab	199ab	195 a	209b	216a	207a	100a
DP deep ploughing	201 b	191bc	183 b	195b	208a	186b	202a
SS subsoiling	214 a	206 a	189ab	234a	213a	201a	203a
Pr>F	0.0313	0.0009	0.0669	0.0013	NS	<0.0001	NS

Note: values with the same letter within a column are not significantly different at 5% level.

CONCLUSIONS

Conservation tillage practices for corn in Shouyang resulted in significantly higher soil water contents, especially in the 0-100 cm profiles during spring corn growing period, as compared with CT, indicating that conservation tillage influenced the depth of soil water profile, caused increased soil water storage during the rainy season, and provided more available water for corn use.

Results from corn tillage studies at 2 sites in the semi-humid arid regions of Northern China showed that residue application methods combined with tillage caused different yield responses to conservation tillage. Residue application methods had a great influence on corn yields in these regions. Corn yield in Shouyang and in Tunliu by residue incorporation, increased by 26%, and 16%, respectively, over the non residue-treated method. Reduced tillage methods for corn (such as DP) in Tunliu caused about an 18% yield increase. Conservation tillage for spring corn had significant effects on both yields and water use efficiency. Conservation tillage showed significantly decreased evapotranspiration rates in Shouyang (with an annual ave. rainfall of 450-520 mm), while it increased ET in Tunliu (with an annual ave. rainfall of 550-570 mm).

All conservation tillage (no-till and reduced tillage) with residue application practices have shown promise in the improvements of yield advantage, which was about 18-26%. Yields with NT were equivalent to those from conventional methods, especially in dry years, while negative yield responses with NT were found during wet years (such as 1988 in Tunliu and 1995 in Shouyang).

For spring corn conservation tillage systems, these results suggest that two alternatives -both reducing the number of secondary tillage passes after the main operation- may be considered:
1) *deep ploughing with incorporated straw and fertilisers after harvest in fall*, next year harrowing in the spring and rolling before sowing, then one pass seeding by machinery or by animal;
2) *subsoiling between rows or no-till with residue mulching after harvest in fall*, and seeding in the next spring with a one pass seed and fertiliser application by a no-till planter, in combination with weed control by herbicides.

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