This paper was peer-reviewed for scientific content.
Pages 419-422. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Land Application of Organic and Inorganic Fertilizer for Corn in Dryland Farming Region of North China

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ABSTRACT

In recent years burning straw can be seen everywhere in farming areas of China, causing several problems such as soil erosion, water runoff, and soil infertility, especially in dry land hilly areas due to the removal of crop residues and the loss of organic nutrients, as well as environmental problems. Field experiments on the incorporation of corn stover/cattle manure combined with chemical fertilizers were carried out at Shouyang Dryland Farming Experimental Station, located in the semi-humid arid region of North China. A 6 year study showed that N uptake by corn increased mainly with application of fertilizer N, and some years with the combined incorporation of corn stover and fertilizer N. The increased available N content in the tilth layer was mainly influenced by the application of cattle manure. When rates of fertilizer N exceeded 105 kg ha^{-1}, the downward movement of potential N from the root zone increased with increasing N application. The organic matter content in the soils treated with corn stover or cattle manure was kept in balance in the experimental conditions. Corn yield and water use efficiency were influenced significantly, not only by fertilizer N but also by incorporated corn stover. The results suggested that the highest N uptake, yield, water use efficiency and better N balance could be obtained at rates of 105 kg fertilizer N, 6000 kg corn stover, and 1500 kg cattle manure per hectare. The land application of organic and inorganic fertilizer showed great benefits not only for the increases in N uptake by plant and in soil available N, but also for the improvement of corn yield. The experiments supplied information on better land use of corn stover as an organic fertilizer with a right ratio of organic to inorganic fertilizer in dry farmland.

INTRODUCTION

The recycling and use of nutrients from crop residues or organic manure has been given more consideration for ensuring sustainable land use and agricultural production development. The impacts of crop residue on nutrient availability differ when residues are surface applied or incorporated into the soil. Rennie and Heimo (1984) found that incorporation of straw with the soil led to significantly lower barley yields than when the straw was left on the soil surface. Furthermore, surface placement of the straw reduced N immobilization as compared to straw incorporated into the soil. Soil-incorporated residues tend to decompose faster than surface residues and has a higher potential for N immobilization (Brown and Dickey, 1970), because of greater fluctuations in surface temperature and moisture and reduced availability of nutrients to microbes (Douglas et al., 1980; Schomberg et al. 1994). Schnürer et al. (1985) demonstrated that residue added to soil with manure or nitrogen fertilizer led to residue decomposition rates that were two times greater than when no amendments were added. Rasmussen et al. (1997) found standing straw residue appears to have a strong adverse effect on wheat yield, and decreases grain yield of winter wheat 13% compared with chopping. The lower spring corn yield has been found with stubble surface application, where the surface temperature during seedling period reduces by 2-6º, as compared with stubble removed, or incorporated treatment (Cai, 1998). The long term effects of the combined application of organic and inorganic fertilizers on improving soil fertility and crop yield have been well demonstrated in China (Lin and Lin, 1985; Xie et al., 1987; Chen et al., 1988; Chen et al., 1993; Liu et al., 1996), however, research on nutrient recycling when using crop residue /farm manure incorporated with chemical fertilizer still has been little reported. How to reuse straw, directly or indirectly as an organic fertilizer, is still under question (Zhao, 1996; Lu et al., 1996). The field experiments were conducted using corn stover and/or cattle manure incorporated with chemical fertilizers according to the local residue resource and production conditions. The objective of the study was to determine the influence of the combined incorporation of organic and inorganic fertilizers on N cycling and corn yield, optimize the combined rates of corn stover and cattle manure as well as chemical fertilizer. The study will provide information for better land use of corn stover as sources of organic fertilizers, to increase organic fertilizer input, improve soil-plant N nutrient and crop production in dry farming areas.

MATERIAL AND METHODS

Conditions of Experimental Station

Shouyang Dryland Farming Experimental Station established in Zongai, Shouyang county, Shanxi province, is located in Shouyang, Shanxi, located in the semi humid arid region of North China, continental monsoon climatic zone (112°4′–113°26′ East longitude, 37°32′–38°6′ North latitude). The average annual open water evaporation varies from 1600 to 1800, which is 3 times as much as the total mean annual rainfall of 520 mm. There are four distinct

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seasons with big seasonal temperature differences in the areas. The frost-free period is around 130 days. The area of spring corn, one crop per year, accounts for over 50% of the total area under food crops. The elevation of most land in the area is around 1066-1159 m above sea level. Severe water and soil erosion, as well as soil denudation affected by natural climatic factors (such as precipitation and monsoon) cause the formation of a loess hilly landscape. The nutrient level in most of the soil is low due to extensive cultivation, low fertilizer input, undeveloped husbandry production, insufficient organic manure source, and little use of crop residues.

Experimental design of the combined organic and inorganic fertilizer application

The field experiment of the combined organic and inorganic fertilizer application for spring corn (*Zea mays* L.) started in 1992 in Zongai village of Shouyang county, on a sandy clay cinnamon soil (Leptosols by FAO classification). The organic matter, total N, available N (NH_4^++NO_3^-), Olsen's P, and available K content of the soil were 25.7 g kg^{-1}, 1.04 g kg^{-1}, 54 mg kg^{-1}, 7.3 mg kg^{-1}, and 92.9 mg kg^{-1}, respectively. The soil pH was 7.87. To make the soil fertility uniform, millet (*Setaria italica* L) was grown for one year before the experiment. Plowing and incorporation of fertilizers in combination with harrowing in fall, and then seeding with no-till in spring were practiced. Chemical fertilizers were urea and super phosphate fertilizer; organic fertilizers included corn stover and cattle manure. The organic matter, total N, total P (P_2O_5), and total K content were 75.1%, 0.629%, 0.088%, and 0.717%, respectively for corn stover, and were 36.3%, 0.964%, 0.390% and 0.740%, respectively for cattle manure. The experimental layout was a 311-A Design (Xu, 1988) with two replications, plus a treatment 12 as a check (CK) (Table 1). The area of field plot was 6 x 6 m^2. The experiment was conducted from 1992 to 1998.

Table 1. Fertilizer treatments of the field experiment.

Treatments	Rates of Application (kg ha^{-1})		
	Fertilizer N	Corn Stover	Cattle Manure
1	105.0	3000	6000
2	105.0	3000	0
3	30.8	879	4500
4	179.3	879	4500
5	30.8	5121	4500
6	179.3	5121	4500
7	210.0	3000	1500
8	0.0	3000	1500
9	105.0	6000	1500
10	105.0	0	1500
11	105.0	3000	3000
12	0.0	0	0

Note: Fertilizer N :P_2O_5 = 1:1

Methods of sample analysis and data statistics

Soil and plant samples were collected after harvest. Soil samples were analyzed for available N and organic matter by the alkali-hydrolytic diffusion method and $K_2Cr_2O_7$ method, respectively. Plant samples were analyzed for total N with Kjeldahl method (Westerman, 1990.). Statistical analysis was conducted using the GLM and REG procedure of the SAS Institute, Inc. (1985).

Table 2. Residual nutrient contents in the soils with the application of fertilizer, corn stover and cattle manure. Values are averaged over 6 yr (1993-1998).

	Rates of application (kg ha^{-1})			Available N (mg kg^{-1})			Organic matter (g kg^{-1})	
No.	Fertilizer N	Stover	Manure	0-20	20-40 (cm)	40-100	0-20 (cm)	20-40 (cm)
1	105.0	3000	6000	81.9	61.8	28.5	24.2	19.0
2	105.0	3000	0	67.5	55.9	36.9	22.8	18.0
3	30.75	879	4500	71.1	50.1	34.0	22.2	18.5
4	179.25	879	4500	79.6	66.6	40.9	23.3	19.6
5	30.75	5121	4500	75.9	52.9	33.4	23.5	18.4
6	179.25	5121	4500	79.1	68.2	42.6	23.3	18.1
7	210.0	3000	1500	70.9	61.5	41.5	23.2	18.8
8	0.0	3000	1500	65.9	44.7	34.3	24.5	17.9
9	105.0	6000	1500	76.0	56.3	32.4	23.2	19.3
10	105.0	0	1500	67.7	46.7	37.0	23.1	19.0
11	105.0	3000	3000	71.6	46.1	27.2	23.5	18.3
12	0.0	0	0	63.5	49.6	25.9	23.3	18.7
						Pr > F		
F (Fertilizer)				NS	NS	NS	NS	NS
F^2				NS	NS	0.0028	NS	NS
S (Stover-incorp.)				NS	NS	NS	NS	NS
C^2 (Cattle Manure)				0.0490	NS	NS	NS	NS
F*C (Interaction)				NS	0.0033	NS	NS	NS

RESULTS AND DISCUSSION

N uptake by corn

The highest N uptake by spring corn was about 190kg ha^{-1}, obtained from the rate of 105 kg fertilizer N with application of corn stover (Treatment 9 and 1) (Fig. 1). Treatment 8 with organic fertilizer alone showed the same N uptake as the check (Treatment 12). N in corn stover accounted for around 40% of the total N in plant. Statistical results showed that N uptake by corn increased mainly with application of fertilizer N, and some years with the combined incorporation of corn stover and fertilizer N. This was because fertilizer N just as activator was helpful for accelerating decomposition of corn stover, also release of N from corn stover increased with added fertilizer N, thus causing an increase in N uptake. The results varied with the change of precipitation and soil nutrient status.

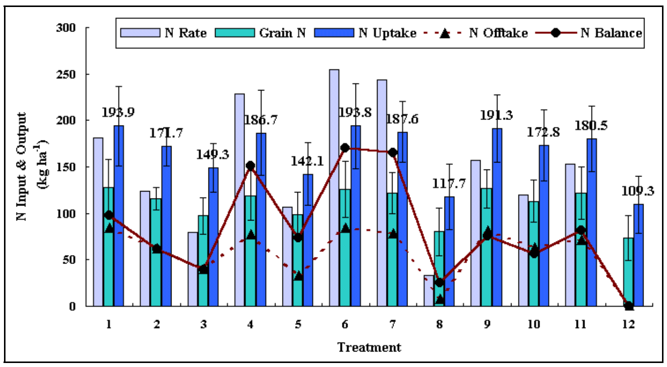

Figure 1 Nitrogen Input, N uptake and N Balance in Dry land Corn and Soil systems (Means over 6 yr, 1993-1998). Error bars indicate standard errors of the mean.

Residual soil available N

According to the results from soil nutrient analysis (Table 2), the increased soil available N in the tilth layer (0-20 cm) was mainly influenced by the application of cattle manure. The available N content in the 20-40 cm layer was also significantly influenced by the interaction between fertilizer N and cattle manure (F x C). However, the available N in the 40-100 cm layer increased with the application of fertilizer N. The fertilizer N moved down from root zone with summer rain in the excessive fertilizer rates (such as Treatment 4, 6, 7). The effects of fertilizer on the organic matter in the layers of both 0-20 cm and 20-40 cm were not statistically significant.

The application of fertilizer N combined with cattle manure and incorporated corn stover contributed to the increased soil available N and plant N uptake, respectively. Apparently, it was also affected by the mineralization of organic matter. The organic matter contents in the treated soils were not significantly different, indicating that the soils treated with corn stover or cattle manure had little net loss of soil organic matter.

Nitrogen balance

Around 60% of the total N uptake was from soil and 40% from fertilizer (Fig. 1); 30-50% of fertilizer N was recovered in the plant material, and 50-70% unaccounted for. The maximum N uptake occurred at the rate of fertilizer N 105 kg ha^{-1}. Above this rate, N uptake by corn no longer increased with increasing N application (such as treatment 4, 6 and 7), instead the extra N was subject to downward movement from the root zone with summer rain, causing the lower N apparent recovery compared with the treatment 9. The treatment 9 with the combined application of fertilizer N, corn stover and cattle manure at 105 kg ha^{-1}, 6000 kg ha^{-1} and 1500 kg ha^{-1} showed a higher N uptake, N off take, and a better N balance with a rational application of organic and inorganic fertilizer.

Table 3. The effects of fertilizer with corn stover and cattle manure on spring corn yield and Water Use Efficiency. Values are averaged over 6 yr. (1993-1998).

No.	Fertilizer N	Stover (kg ha^{-1})	Manure	Total Input N (kg ha^{-1})	Yield (kg ha^{-1}) †	Yield Increase %	N use efficiency	WUE (kg ha^{-1} mm^{-1})^{a}
9	105.0	6000	1500	157.2	8876 a	47.7	18.2	22.5 a
1	105.0	3000	6000	181.7	8777 a	46.1	15.2	20.4 ab
6	179.3	5121	4500	254.8	8251 ab	37.3	8.8	19.8 abc
11	105.0	3000	3000	152.8	8193 ab	36.3	14.3	20.0 abc
2	105.0	3000	0	123.9	8058 ab	34.1	16.5	18.8 bc
4	179.3	879	4500	228.2	7947 ab	32.3	8.5	18.8 bc
7	210.0	3000	1500	243.3	7931 b	32.0	7.1	19.1 bc
10	105.0	0	1500	119.5	7610 b	26.6	7.9	17.8 bc
5	30.8	5121	4500	106.3	7528 b	25.3	14.3	18.6 cd
3	30.8	879	4500	79.7	7280 b	21.2	15.9	17.3 d
8	0.0	3000	1500	33.3	6354 c	5.7	10.4	15.2 d
12	0.0	0	0	0.0	6009 c	-	-	13.8 e
					Pr > F			
F (Fertilizer)					0.0001			0.0001
S (Stover-incorp.)					0.0360			0.0094
C (Cattle manure)					NS			NS
F*S (Interaction)					NS			NS
Year					0.0001			0.0001

[a]Values with the same letter within a column are not significantly different at 5% level.

Corn yield and Water Use Efficiency

Statistical results showed that corn yield and WUE were significantly influenced by fertilizer N, then incorporated corn stover (Table 3). Results suggested that the highest N uptake, yield, WUE, and N use efficiency could be obtained at rates of 105 kg fertilizer N, 6000 kg corn stover, and 1500 kg cattle manure per hectare (Treatment 9 or Treatment 1 at 105, 3000 and 6000 kg ha^{-1}, respectively). Low inorganic fertilizer N applications (0 or 31 kg ha^{-1}) resulted in low yields even at a high level of organic fertilizer (corn stover + cattle manure) >4500 kg (such as treatment 3, 5 and 8), compared with the treatment 9. The yield was also limited by lack of organic fertilizer application even at an inorganic fertilizer rate of 105 kg ha^{-1} (Treatment 10). The recommended ratio of organic fertilizer N to inorganic fertilizer N in the experiments was about 1:2.

CONCLUSIONS

The experiment results showed that N in corn stover accounted for about 40% of the total N in plant, meaning that around 70 kg N per hectare from corn stover could be reused for N recycling in the soil-plant system if the N uptake by corn amounted to 190kg ha^{-1}. The incorporation of corn stover /cattle manure combined with mineral fertilizer not only could save mineral fertilizer, but also contribute to the improved plant N uptake or the increased soil available N, thus causing a positive effect on corn production. Results suggested that the higher N uptake, yield, NUE, and WUE could be obtained at rates of 105 kg fertilizer N, 6000 kg stover, and 1500 kg cattle manure per hectare, with a ratio of organic to inorganic fertilizer N about 1:2.

ACKNOWLEDGEMENT

The study was a part of the national dryland farming key project, which was conducted in 1990-1995, and continues in 1996-2000, financed by National Science and Technology Committee of China.

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