Increasing water use efficiency for dryland maize in China by improved nutrient management practices

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1. Abstract

Rainfed crop production in northern China is constrained by low and variable rainfall, and influenced by management practices. This study explored the long-term effects of various combinations of maize stover, cattle manure and mineral fertilizer (NP) applications on maize (Zea mays L.) yield and water use efficiency (WUE) under reduced tillage practices, at Shouyang Dryland Farming Experimental Station in northern China from 1993 onwards. The experiment was set-up according to an incomplete, optimal design, with 3 factors at five levels and 12 treatments including a control with two replications.

Grain yields were greatly influenced by the amount of rain during the growing season (GSR), and by soil water at sowing (SWS). Annual grain yields ranged from 3 to 10 t ha^{-1} and treatment mean yields from 4.2 to 7.2 t ha^{-1}. The WUE ranged from 40 in treatments with balanced nutrient inputs in dry (soil /or weather) years to 6.5 kg ha^{-1} mm^{-1} for the control treatments in wet years. The WUE averaged over the 15-year period ranged from 11 to 19 kg ha^{-1} mm^{-1}. Balanced combination of stover (3000-6000 kg), manure (1500-6000 kg) and N fertilizer (105 kg) gave the highest yield and hence WUE.

In conclusion, balanced nutrient inputs gave the highest yield and hence WUE. Possible nutrient management options under variable rainfall conditions to alleviate occurring moisture stress for crops must be tailored to the rainfall pattern. The potentials of split applications, targeted to the need of the growing crop (response farming), should be explored to further improve grain yield and WUE.

Keywords: Crop residue, Dryland, Fertilizer, Maize, Manure, Nutrient management, water use efficiency (WUE)

2. Introduction

Northern China has a large region of dryland farming, which accounts for about 55% of the nation's total cultivated land area (Xin and Wang, 1999). Much of the land in this region is hilly and rainfed. Water scarcity and a large variation in inter-annual and intra-annual rainfall are the main constraints to rainfed crop production. The large seasonal and annual variations in rainfall are also a cause of soil and water losses on sloping lands during the summer rainy season. Seasonal drought with heavy winds often occurs in winter and spring. Maize accounts for 22% of the total area of food crops, and 26% of the total food production in China (China Agricultural Yearbook 1999). Yields of maize vary greatly from year to year, mainly because of the variable (unpredictable) rainfall and wind erosion in spring (Wang et al. 2006). These effects are exaggerated by the current practices of removing crop residues from the field after harvest, to leave the ploughed soil bare during winter, and to plough the soil again in spring after fertilizer application. These practices commonly lead to soil drying and severe wind erosion in early spring, thus causing a reduction in spring crop seedling emergence. Erosion of fertile top soil by wind and runoff, removal or burning of crop residues have led to nutrient depleted soils (Rees et al. 1997; Cai et al. 2002). Reduced tillage was introduced in the study area in the early 1990s and it showed to be highly effective in decreasing soil drying and wind erosion, especially with integrated conservation tilleage and improved nutrient management practices (Wang et al. 1999; 2001; 2003, 2006). The objective of our study is to optimize the combined application of NP fertilizers, maize stover and cattle manure under reduced tillage practices. We therefore assessed the long-term effects of these applications on maize grain yield and water use efficiency.

3. Materials and methods

The ongoing long-term field experiment started in 1992 at the Dryland Farming Experimental Station in Shouyang, Shanxi province (112°-113°E, 37°-38°N) in northern China. The area has a mean altitude of 1100 m above sea level and a continental monsoon climate with an average annual rainfall of 520 mm. Severe erosion in the past has led to the formation of a hilly landscape. The dominant cropping system is continuous spring maize, which accounts for over 50% of the total area for crop production. The study area is representative of a typical farming region dependent on rainfall. Spring drought often is a limiting factor for seed germination and the emergence and growth of spring maize. The experimental site has a sandy loam cinnamon soil, classified as Calcaric-Fluvic Cambisols (ISS-CAS 2003; IUSS 2006). At the start in 1992, soil pH was 7.9, and SOC and soil organic N (SON) contents were 15 and 1.0 g kg^{-1}, respectively. Available soil P and soil K in the top 20 cm soil were low to medium, judged on the basis of P-Olsen (7.3 mg kg^{-1}) and NH_4OAc extractable K (84 mg kg^{-1}).

The experiment was set-up according to an incomplete, optimal design (Xu, 1988) with 3 factors (NP fertilizer, maize stover and cattle manure) at five levels and 12 treatments, including a control treatment. Fertilizer NP applications were 0, 31, 105, 179 and 210 kg ha^{-1}. Maize stover applications were 0, 879, 3000, 5121 and 6000 kg ha^{-1}. Cattle manure applications were 0, 1500, 3000, 4500 and 6000 kg ha^{-1}. This experimental design allows the use of a minimal set of factors of the variance-covariance matrix and provides a maximal efficiency of the experiment. The procedures of this design are explained in Khuri and Cornell (1987).

Plots (6 x 6 m^2) were laid down randomly in duplicate. The N and P fertilizers were urea (46% N) and superphosphate (7% P) in a ratio of N to P of 1:0.44. Maize stover and cattle manure were obtained from local farms. The weighted mean contents of organic matter, total N, total P (as P) and total K were 75%, 0.63%, 0.039% and 0.72% for maize stover (ratio of N:P:K=100:6:114) and 36%, 0.96%, 0.17% and 0.74% for cattle manure (ratio of N:P:K=100:18:77), respectively. Maize stover (s), cattle manure (m) and fertilizers (f) were broadcast and incorporated into the soil after maize harvest in the fall by ploughing (20 cm deep). Seeding was done in spring, at the end of April, with no tillage. Locally recommended maize varieties were used. Maize was seeded at distances of 60 cm between rows and at 30 cm within the rows. Mean plant density was 55555 per ha.

Grain yields (GY) and crop residues of maize were determined at harvested in October. Soil samples for moisture determination were taken at depths of 0-10, 10-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180, 180-200 cm at seeding and after harvest per plot. Apparent water use or apparent evapotranspiration (ET, in mm) was calculated from the change in soil water contents between SWS (soil water at seeding) and SWH (soil water at harvest) plus GSR (growing season rainfall), viz. ET = (SWS-SWH) + GSR. Hence, we assumed that there were no losses via deep drainage and runoff during the growing season. Apparent water use efficiency (WUE, in kg ha^{-1} mm^{-1}) was calculated as GY/ET.

Statistical analyses were done using GLM, REG and RSREG procedures of the SAS Institute, Inc. (2004). The mean pairwise comparison was based on the DUNCAN test at the 0.05 probability level (at $P \leq 0.05$).

4. Results

4.1 Mean grain yield and water use efficiency

Mean grain yield (GY), water use (ET) and water use efficiency (WUE) are shown in Table 1 (Note that treatments are in the order of increasing GY). The control (treatment 12) had the lowest GY (4.2 t ha^{-1}) and WUE (11 kg ha^{-1} mm^{-1}), and treatment 9 (with f=105, s=6000, and m=1500 kg ha^{-1}) the highest GY (7.2 t ha^{-1}) and WUE (19 kg ha^{-1} mm^{-1}). Clearly, balanced combinations of NP fertilizer, stover and manure gave the highest mean yield, and the slight differences in GY between treatments 11, 1 and 9 were not statistically significant. Doubling NP fertilizer applications and halving the stover application (comparison of treatments 7 and 9) gave statistically significant lowering of GY, suggesting above optimal N application in treatment 7. Mean ET did not vary much among treatments (range 392 to 412 mm), while WUE varied greatly between treatments (Table 1).

Table 1 Effects of combined applications of NP fertilizer (F), maize stover (S) and manure (M) on grain yield (GY), Water Use Efficiency (WUE) and Evapotranspiration (ET) per treatment, averaged over the whole experimental period (1993-2007). Data from 0-200 cm soil depth.

Tmt.	F, kg ha^{-1}	S, kg ha^{-1}	M, kg ha^{-1}	GY, kg ha^{-1}		WUE, kg ha^{-1} mm^{-1}		ET, mm	
12	0	0	0	4233	f	11.1	f	391.7	b
8	0	3000	1500	4989	e	13.0	e	413.0	a
3	31	879	4500	5851	d	14.5	d	401.6	ab
10	105	0	1500	6256	cd	15.5	cd	399.6	ab
5	31	5121	4500	6396	c	16.6	bc	398.3	ab
7	210	3000	1500	6438	c	16.3	c	405.9	ab
4	179	879	4500	6459	c	16.2	c	407.9	ab
2	105	3000	0	6531	bc	16.4	c	407.5	ab
6	179	5121	4500	6593	bc	16.7	bc	407.1	ab
11	105	3000	3000	6729	abc	16.7	bc	409.5	a
1	105	3000	6000	7050	ab	17.9	ab	407.1	ab
9	105	6000	1500	7230	a	18.7	a	396.9	ab

Note: Values with the same letter within a column are not significantly different at 5% level using the DUNCAN test of SAS

4.2 Annual variations in grain yields and water use efficiency

Annual variations in grain yield were large, ranging from about 3,000 in the dry (soil /or weather) 1999 to more than 10,000 kg ha^{-1} in treatments with balanced fertilization in the wet 1994, 1996 and 1998 (data not shown). Grain yields in all treatments tended to decrease with time during the experimental period. Statistical analyses indicated that differences in GY between treatments and between years were related to added fertilizer and stover (but not to added manure), and to SWS and the rainfall during the periods April-June, July and August-October (Table 2). The similar trends in measured and calculated GY explained satisfactorily by this model (results not shown) suggest that the decreasing trend in GY in our experiment is mainly related to the changes in rainfall during the growing periods, especially highly sensitive to rainfall in July (at tasseling). The WUE ranged from 40 in treatments with balanced nutrient inputs in dry (soil /or weather) 1997 to 6.5 kg ha^{-1} mm^{-1} for the control treatments in wet 1995, 2002 and 2004 (data not shown). The control treatments usually had the lowest WUE and treatments with balanced nutrient inputs the highest WUE in almost all years.

Table 2 Coefficients of the regression models for grain yield (GY) as function of NP fertilizer (both linear (Fertilizer) and quadratic (Fsq)), maize stover, and manure, soil water at sowing (SWS) and rainfall during the periods April-June (R(A-J)), July (R(J)) and August-October (R(A-O)), for the whole experimental period 1993-2007.

Dependent Variable	Param.*)	Intercept	Fertilizer	Stover	Manure	R(A-J)	R(J)	R(A-O)	SWS	Fsq
GY	PE	-4700	29.4	0.14	0.08	4.7	22.9	3.1	14.7	-0.11
R^2=0.60,	SE	1091	5.3	0.06	0.06	2.7	2.4	1.4	2.6	0.03
N = 64	tValue	-4.3	5.5	2.4	1.4	1.7	9.6	2.3	5.7	-4.44
	Pr>|t|	<.0001	<.0001	0.017	0.16	0.08	<.0001	0.02	<.0001	<.0001

* PE = Parameter Estimate; SE=Standard Error; Pr = probability-value (p-value)

5. Conclusions

The results of this long-term field experiment show that balanced combinations of stover, manure and NP fertilizer gave the highest yield and hence WUE. The huge annual variations in grain yields and WUE suggested that there be scope for improvement of water use efficiency by split applications. The improved nutrient management requires rainfall to be taken into account in a dynamic approach to explain the interactions between GSR and the effects of NP fertilizer, stover and manure under variable rainfall conditions.

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