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Effect of fertilization on yield of soybean in rotation and continuous cropping in Northeast China

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Introduction

The Northeast of China is the country's main area of soybean (*Glycine max* L. Merr.) production. To maximize their economic benefit on limited farmland, during the last decades farmers had to grow soybean continuously on the same fields, which resulted in a large-scale reduction of yield (Liu, 1993; Sasser and Uzzell, 1991).The main causes for the yield reduction of soybean in continuous cropping system are (i) damage caused by pests such as root miner and cyst nematode diseases such as root rot (Xu *et al.* 1995; He *et al.*, 2003) and (ii) poisonous effects of the intermediate products from decomposing soybean residues near the roots or from root exudates (Liu, 2001). As a result, the roots' function to absorb and transport nutrients and to fix N has been weakened or partly lost (Liu, 1993; Han *et al.* 1998). It may thus be necessary to increase the nutrient concentration in the soil, to improve the roots' function to absorb nutrients, to provide enough photosynthates for growth and development of roots, and to enhance early lateral root development. The approach used is called 'nutrition cure' (Han, *et al.* 1999). Results showed that nutrient cycling can increase soybean yields by overcoming physical, chemical and biological constraints (Banding, *et al.* 2000). The experiment of which data are presented here was conducted to examine the effects of the application of different nutrients on soybean grown in rotation and continuous cropping systems.

Materials and Methods

The experiment was conducted on a typical black soil (Table 1), located near the town Hailun in Heilongjiang province in Northeast China, with a 125 d frost-free growth season and an annual rainfall of 500-600 mm.

Table 1. Physico-chemical properties of the experimental soil (0-20 cm) near Hailun, Heilongjiang Province, NE China

Organic matter ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Total P ($g\ kg^{-1}$)	Total K ($g\ kg^{-1}$)	Available N ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)	pH (H_2O)
69.8	3.1	1.7	25	333	68	209	6.1

The rotation systems used for the fertilizer experiments comprised (i) an annual rotation of corn-soybean, (ii) continuous soybean for 2 years and (iii) continuous soybean for 5 years, both followed by corn. The plots to which the following fertilizers were applied in triplicate measured 0.7 m x 1.5 m and were each surrounded by a waterproof boarder:

(1) Nitrogen applied as urea (45%N) at 0, 41, 55, 69, 83 and 97 kg N ha^{-1} with all plots receiving a basal dressing of 30 kg P ha^{-1} applied as double super phosphate ($CaH_4(PO_4)2\ H_2O$; 20%);
(2) Phosphorus at 0, 15, 30, 45, 60 and 75 kg P ha^{-1} with all plots receiving a basal dressing of 26 kg N ha^{-1};
(3) Potassium applied as potassium sulfate (K_2SO_4; 42% K) at 0, 19, 38, 57, 76, 95 and 114 kg K ha^{-1} with all plots receiving a basal dressing of 26 kg N ha^{-1} and 30 kg P ha^{-1};
(4) Zinc at 0, 6.8 and 10.1 kg ha^{-1};
(5) Manganese at the rates of 0, 6.4 and 9.7 kg ha^{-1};
(6) Boron fertilizer at rates of 0, 0.8 and 1.2 kg ha^{-1};
(7) Molybdenurn at rates of 0, 5.4 and 8.1 kg ha^{-1};
(8) Magnesium at rates of 0, 1.4 and 2.1 kg ha^{-1}.

To the control treatment as well as to treatments 4-8 26 kg N ha^{-1} and 30 kg P ha^{-1} were applied and all microelements used were of analytical grade (Zn as $ZnSO_4 \cdot 7H_2O$ with 22.5% of Zn; Mn as $MnSO_4\ H_2O$ with 32.2% of Mn; B as $Na_2B_4O_4 \cdot 10H_2O$ with 112% of B; Mo as $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ with 53.8% of Mo; Mg as $MgSO_4 \cdot 7H_2O$ with 14.2% of Mg. All mineral fertilizers were applied 10 days before sowing at 0-15 cm depth. Soybean, cv. Heinong 35, was sown on May 15 and harvested on October 15 from 2006 to 2008.

Results and discussions

Nitrogen

Compared to the annual rotation system, the number of nodules decreased by 50% in the 2-year and 77% in the five-year continuous soybean system (Table 2). As a result, the above-ground of soybean crop developed poorly. The results showed that N application at 41and 55 kg ha^{-1} increased nodule number by 15%-19% in rotation soybean. Nitrogen application increased the number of available nodules of the 2-year rotation system by 39%-77% and in the 5-year soybean system by 133%-233%.

Table 2. Effect of N fertilization on the number of effective nodules of soybean (No. $plant^{-1}$) under continuous cropping and rotation system in a field experiment in NE China (2006-2008).

N levels (kg ha^{-1}	Stubble	Annual soybean-corn rotation	2 years soybean-corn rotation	5 years soybean-corn rotation
0	Available nodules	26	13	6
	Increase (%)	-	-	-
41	Available nodules	30^{**}	19^{**}	14^{**}
	Increase (%)	15.4	46.2	133.3
55	Available nodules	31^{**}	23^{**}	18^{**}
	Increase (%)	19.2	76.9	200
69	Available nodules	22	21^{**}	20^{**}
	Increase (%)	-15.4	61.5	233.3
83	Available nodules	18	20^{**}	19^{**}
	Increase (%)	-44.4	53.8	216.7
97	Available nodules	15	18^{**}	17^{**}
	Increase (%)	-42.3	38.5	183.3

** Indicates a significant treatment difference at P< 1% level.

The results show that moderate N application promoted nodule development even in rotation soybean (Figure 1). However, at higher N applying rates, the number of nodule decreased likely reflecting an inhibitory effect of excessive N on nodule formation. After 5 years of continuous soybean cropping, the roots' ability to N_2-fixation, N-absorption and -transport weakened.

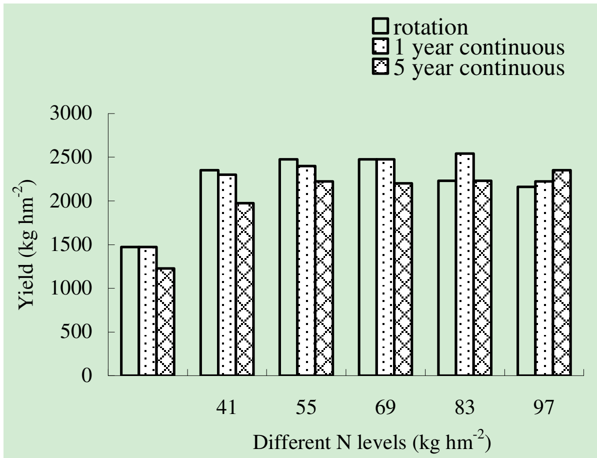

Figure 1. Soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Phosphorus

Soybean yield in the annual rotation increased remarkable with P application, particularly at 60 kg P ha^{-1} (Figure 2). At 15 and 30 kg P ha^{-1} the yield of 2-year soybean-corn rose substantially. The P fertilizer rate, at which soybean yield reached its peak in the annual rotation was higher than that in a 5-year soybean rotation (Figure 2).

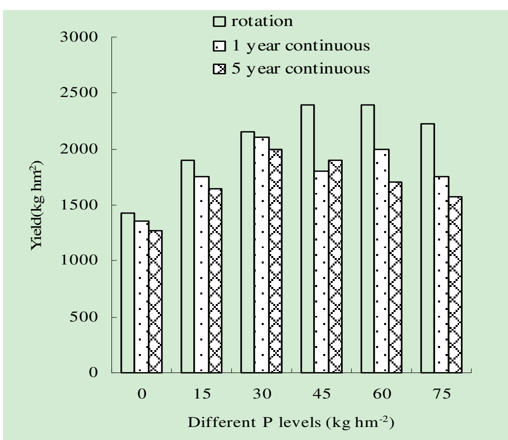

Figure 2. Effect of P application on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Potassium

Potassium alone had no significant effect on soybean yield across all rates applied. However, when combined with N and P, soybean yields increased substantially. Potassium-induced yield increases may also result from an enhanced resistance of soybean plants to diseases, pests and to lodging (Han et al. 1996).

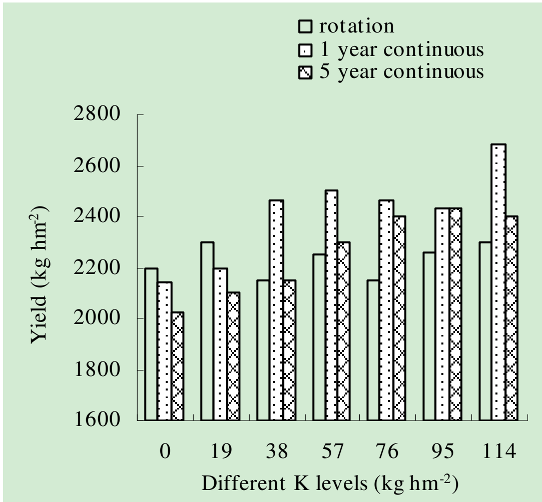

Figure 3. Effect of K application on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Zinc

In the annual rotation system no effects of Zn application on soybean yield were observed. However, in 2- and 5-year soybean rotations soybean yields increased by 8%-25% after Zn application. This effect of Zn fertilization was possibly due to the large amounts of P fertilizer applied in continuous soybean systems leading to an unbalanced P/Zn ratio in the soil and in the soybean plant, which finally affected plant growth.

Table 3. Effect of Zn application on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Soybean-corn rotation system	Control	Zn at 6750g ha^{-1}		Zn at 10130 g ha^{-1}	
	Yield ($kg\ ha^{-1}$)	Yield ($kg\ ha^{-1}$)	Increase (%)	Yield ($kg\ ha^{-1}$)	Increase (%)
Annual rotation	2371	2429	2.41	2438	2.81
2-year soybean	2076	2238**	7.80	2324**	11.93
5-year soybean	1819	2105**	11.71	2276**	25.13

Manganese

Manganese application had no noticeable effect on soybean yield in the annual rotation system, but increased soybean yield by 8%-25% in 5-years continuous soybean (Table 4).

Table 4. Effect of Mn on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Soybean-corn rotation system	Control	Mn at 6440 g ha^{-1}		Mn at 9660 g ha^{-1}	
	Yield (kg ha^{-1})	Yield (kg ha^{-1})	Increase (%)	Yield (kg ha^{-1})	Increase (%)
Annual rotation	2371	2467	4.02	2429	2.41
2-year soybean	2076	2238**	7.80	2295**	10.55
5-year soybean	1819	2029**	11.52	2114**	16.23

Boron

Like Mn also Br had no effect on soybean yields in annual rotation system (Table 5).

Table 5. Effect of B on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Soybean-corn rotation system	Control	B at 800 g ha^{-1}		B at 1200 g ha^{-1}	
	Yield (kg ha^{-1})	Yield (kg ha^{-1})	Increase (%)	Yield (kg ha^{-1})	Increase (%)
Annual rotation	2371	2333	-1.61	2371	0
2-year soybean	2076	2181**	5.05	2257**	9.17
5-year soybean	1819	2057**	13.09	2142**	16.75

Mo

Mo did not increase the yield of soybean in the annual rotation system, but effectively enhanced soybean growth by 10%-15 in 5 year continuous soybean system (Table 6).

Table 6. Effect of Mo on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Soybean-corn rotation system	Control	Mo at 5830g ha^{-1}		Mo at 8070 g ha^{-1}	
	Yield (kg ha^{-1})	Yield (kg ha^{-1})	Increase (%)	Yield (kg ha^{-1})	Increase (%)
Annual rotation	2371	2314	-2.41	2362	-0.40
2-year soybean	2076	2276**	9.63	2233**	12.39
5-year soybean	1819	2010**	10.47	2086**	14.66

Mg

Magnesium enhanced soybean growth in the annual rotation system where its application at 2 kg ha^{-1} led to a 7% yield increase. In the 5-year rotation system Mg increased soybean yield by 9%-21% (Table 7).

Table 7. Effect of Mg on soybean yield in an annual rotation with corn, a 2 year soybean-corn rotation and a 5 year soybean-corn rotation on a black soil in NE China (2005-2008).

Soybean-corn rotation system	Control	Mg at 1420 g ha^{-1}		Mg at 2130 g ha^{-1}	
	Yield ($kg\ ha^{-1}$)	Yield ($kg\ ha^{-1}$)	Increase (%)	Yield ($kg\ ha^{-1}$)	Increase (%)
Annual rotation	2371	2476	4.41	2543**	7.23
2-year soybean	2076	2267**	9.17	2295**	10.55
5-year soybean	1819	2200**	20.94	2190**	20.42

Conclusions

Nitrogen, P and K played an important role in increasing soybean yield of 5-year continuous soybean cropping on black soils in NE China. The data indicate that the application of macro- and micronutrients can lead to significantly increased soybean yields at the farmers' level.

Acknowledgements

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