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Promoting sustainable agriculture development by improving the efficiency of chemical fertilizers and soil nutritions

Li Jiyun, Liu Xiudi, Zhou Wei, Sun Jianhua, Tong Yiping, Liu Wenjie

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences

Li Zhensheng, Wang Peitian, Yao Shujing

Institute of Genetics, Chinese Academy of Sciences

Abstract—Deficiency of available phosphorus in soil is an important limiting factor for increasing agricultural yield. To breed the crop varieties which can efficiently utilize the phosphorus retained in soil together with reasonable use of phosphorus fertilizer is an effective way to solve phosphorus deficiency. Under the condition of intercropping maize and soybean, it was found molybdenum application can promote soybean to fix more nitrogen, thus increasing the yield of the two crops. To develop the high efficiency ammonium bicarbonate to improve the efficiency of nitrogen fertilizers is suggested.

Keywords: nutrient elements; efficiency untilization; root secretion; organic acid.

1 Introduction

With the increase of population and food production, the amounts of chemical fertilizers applied world wide were raised year by year. The amounts of chemical fertilizers applied in our country increased from 78000 tons to 20.1 million tons from 1952 to 1987(Qin, 1990) and the food production raised from 136.92 to 402.4 million tons, indicating the effect of fertilizers on crop yield increased but appearing in declining tendency. A report from the Institute of World Observation indicated that in the past 35 years, the amount of chemical fertilizers increased 8.3-fold but the grain output only increased 1.68-fold in the world, 12.3-fold fertilizer increased but only 1.3-fold grains increased during past 25 years in China(Li, 1993). All of these was closely related with organic fertilizer reduction, soil desertification, phosphorus being fixed in soil and N, P, K imbalance and so on.

Raising the efficiency of chemical fertilizer utilization and improving the utilization of soil nutrients by the crops are important ways to realize sustainable agriculture. On the other hand, controlling to use excess chemical fertilizer which cause environmental pollution is also of importance. For instance, a part of ammonium nitrogen applied can be oxygenated by aerobic bacteria and transformed into nitrate and absorbed by plant and finally causing aquatic system to be eutrophicated. The partly oxidized nitrogen can be transformed into subnitrogen and nitrogen. As these gases get into stratosphere and will effect the ozonosphere, and finally effecting human health(Sun, 1989).

Phosphorus is an essential element for plant growth, human health and animal vigor but some of the impurities accompanied. For example, 5 million tons of phosphorus fertilizer applied to soil, 10 tons of fluoride may be contained in the fertilizer and brought into soil. Some phosphorus fertilizer also contain rather high cadmium which will effect human health in kidney and bone. For instance, the famous tragedy boneachy disease in Japan caused by cadmium in polluted rice(Sun, 1989). The quality criterion of chemical fertilizer must made and the application of fertilizer must be rational. The documents issued by UN Conference on Environment and Development, 1992 indicated that lacking restriction in the use of chemical fertilizer and pesticides will affect human health directly(Sun, 1993).

2 Some measures taken for rational use of fertilizer and increase in the crop yield

2.1 Breed varieties for efficient utilizing soil nutrients

China has a huge population and a great amount of natural resources, but her resources per capita are lower than the other countries in the world. Facing the pressure of population, how should we develop the agriculture? In view of the experiences at home and abroad, the only way which can provide to be chosen is realizing sustainable agriculture by saving the natural resources. One of the measures is to release soil nutrition potential by following means: it was found that 43% farmland in the world and two-thirds in China are deficient in soil phosphorus and crops can not produce high yield, even though the nitrogen content is very high in soil. In the suburban areas of Beijing, it was reported that from 1976—1985, the amount of chemical fertilizers used were increased by 3.4 times but the grain output only doubled. We found one of the important factor was due to deficiency of the available phosphorus in soil or low phosphorus fertilizer used in this area.

World production of phosphorus fertilizer was 33.24 and 36.02 million tons in 1985 and 1990, respectively, 27 kg/ha in average. In China, 1.76 to 4.62 million tons from 1985—1990, 32 kg/ha in average, not enough for agricultural production. In addition, the efficiency of phosphorus utilization in soil is very low, especially in alkaline soil. For example, 75%—90% available phosphorus remained in the soil after one crop harvest(Li, 1992) and only 5%—10% efficiency of phosphorus utilization(Swaminathan, 1986).

2.2 The potential of utilization for soil phosphorus

In the farmland, forestland, barren land and meadow of loess plateau area, it was found that the available phosphorus was only 6.0, 8.8, 6.9 and 7.8 ppm, respectively while the total amount of phosphorus in the soil amounted up to 1230, 1160, 1270 and 1310 ppm, respectively, 205, 132, 184 and 167 times than the available phosphorus respectively. To transform phosphorus into available phosphorus in soil must be a large potential to compensate phosphorus needed.

The total phosphorus in soil layer being extended by the main root system of plant was estimated. In Table 1(Yang, 1992), total amount of phosphorus in the farmland was found to be 1230 ppm, the soil specific gravity in this area about 1.3, the main root system of the plant extended about 1 meter depth in soil and the amount of total phosphorus in 1 meter depth is estimated to be 15990 kg/ha, this is a considerable amount of phosphorus retained in the soil.

In the typical area of Huang - Huai - Hai plain, the situation of microelements in soils was similar to the phosphorus(Li, 1993). 85%, 38%, 30% deficient in zinc, boron and manganese respectively were found in our laboratory, but the total amount of these elements were about 100—300, 42—98 and 300 times higher than their available amounts respectively. It may indicate that large amount of mineral nutrient retained in the soil provide a possibility of using plant root system to transfer them into their available forms.

2.3 Study on characteristics of plant utilizing soil nutrients

Study on the transformation of nutrients stored or fixed in soil into available form needs the joint research by plant genetics and breeders, soil chemists, plant physiologists, microbiologists and organic chemists. Four international symposia on plant nutrient genetics have been held in the last decade and nutrients deficiency of plant, resistance to the damaged by salt and metal ions, identification of nutrition characteristics, genetic control and screening techniques and results on plant transferring and efficient utilizing nutrients have been reported. For example, in Australia there are low copper soil distributed widely, some wheat germplasm which can efficiently utilize soil copper was identified and screened, demonstrating that the gene(s) controlling this characteristics was located on the chromosome 5R. Tritcale line, 5RL/4AL and 5RL/5BL have been selected to be able in use as parent materials for wheat breeding(Duncan, 1990; Graham, 1984). Batten proved that some wheat varieties tolerant to low phosphorus soil are in relation to 1B/1R translocation lines of triticale(Graham, 1984).

Table 1 The comparison of total amount phosphorus to available form in farmland, forest land, barren land and meadow of loess plateau(Yang, 1992)

Category of land	Amount of soil sample	Form of phosphorus	Range of content, ppm	Average, ppm	Ratio Total /available
Farm land	3413	Total amount	140—2870	1230	
		Available amount	1—48.5	6.0	205
Forest land	113	Total amount	320—2850	1160	
		Available amount	1.9—48.5	8.8	203
Barren land	12	Total amount	980—1516	1270	
		Available amount	2—11.4	6.9	184
Meadow in	25	Total amount	630—2460	1310	
high mountain		Available amount	1—30	7.8	168

Some results in the study on the physiological mechanism of wheat efficiently utilizing insoluble phosphorus, zinc and boron of soil were obtained in 1991. Firstly, five hundred wheat varieties were identified and 18 of them which resist multiple diseases and loading were screened.

Their yield were tested with application of different elements and obvious different efficiency in utilizing phosphorus, zinc and boron were obtained, such as A167-168, 4271 and 82246-1-1-7 produced more than 400kg/mu(1 ha=15mu) with the CK treatment(Applied N, P, Zn and B fertilizers), but in the treatment without P, their yield came down to 250—280 kg/mu, while the two others, Ji87-4617 and 81(85)-5-3-3-3 yielded 364—355 kg/mu in CK treatment, keeping 311—340 kg/mu the highest in -P treatment (Table 2).

Table 2 Yield identification of various wheat varieties under different nutritional conditions in soils

Variety	Yield, relative		Classification	
	CK	−P	−Zn	−B
A167-168	412 (100)1	285(69)4	266(65)4	300(72)4
4271	407(100)1	251(62)4	325(80)3	401(99)1
82246-1-1-7	403(100)1	284(70)4	307(76)3	365(91)2
Xiaoyan No. 6	389(100)2	283(73)4	327(84)3	399(102)2
99201	388(100)2	291(75)4	377(97)2	385(99)2
Yanzhong 144	385(100)2	300(78)4	387(101)2	———
6154	375(100)2	255(68)4	361(96)2	292(78)4
Ji87-4617	364(100)2	311(85)3	———	———
81(85)5-3-3-3	355(100)2	340(96)3	359(101)2	———
Baiquan 3039	355(100)2	300(84)4	332(94)3	———
Shaan 213	347(100)3	279(80)4	345(99)3	348(100)3
Shi 87-5304	345(100)3	291(84)4	317(92)3	337(98)3
Jingsong No. 5	340(100)3	200(59)6	265(78)4	351(103)2
83 s -502	324 (100)3	235(72)5	———	369(114)2
90-6060	312(100)3	267(85)4	234(75)5	285(91)4
80-55	297(100)4	181(61)6	287(96)4	235(79)5
10927	287(100)4	253(88)4	267(93)4	324(113)3
85504-3-5-2d -7	244(100)5	229(94)5	223(91)5	———

* Yield=kg/mu(mu is Chinese unit; 1ha=15mu)

* * The criterion of yield classification: 1=401—450, 2=351—400, 3=301—350, 4=251—300, 5=201—250, 6=151—200kg/mu

2.4 Study on the mechanism of efficient utilization of soil nutrients

2.4.1 Effect of root secretion with soil pH

Four varieties were tested. It was shown that Ji87-4617 can secrete more organic acid from its roots, pH value decrease from 8 to 4.5 around the roots but Durum has only a little change. Xiaoyan No. 6 is better than Chinese spring and less than Ji87-4617.

2.4.2 Relationship between the amount of root organic acids and yields of various varieties

Analytical results indicated that the content of organic acids are in the order of malic acid> citric acid>succinic acid>fumaric acid >acetic acid>oxalic acid. The correlation between the root organic acids with yields is shown in Table 4, $r=0.76$ in control test and $r=0.96$ in low phosphorus treatment.

The above results may reveal that wheat breeding for efficient utilization of soil nutrients is a good way to realize sustainable agriculture.

Table 3 Organic acid content in the root and yield of variouswheat varieties under different treatment

Treatment	Variety	Content of organic acid, mg/kg							Grain yield, kg/mu
		Malic acid	Citric acid	Succinic acid	Fumaric acid	Acetic acid	Oxalic acid	Total amount	
Control	Shaan213	231.3	102.3	78.6	20.7	20.7	4.64	458.2	347
	Xiaoyan No. 6	198.9	136.5	82.2	21.8	19.1	4.29	462.8	389
	10927	217.6	95.0	49.1	14.0	10.3	4.50	390.4	287
	80-55	136.7	60.3	54.0	19.3	15.1	2.50	287.9	297
−P	Shaan213	289.1	153.0	77.4	20.7	15.9	3.03	559.1	279
	Xiaoyan No. 6	176.4	251.0	41.3	14.4	16.7	4.21	504.0	283
	10927	160.7	176.8	45.8	15.2	15.2	4.64	418.4	253
	80-55	112.0	52.0	71.2	11.0	13.3	3.78	263.3	181
−Zn	Shaan 213	504.6	163.0	53.0	42.9	14.0	3.75	781.3	345
	Xiaoyan No. 6	403.7	144.8	88.4	44.4	14.8	4.89	710.0	327
	10927	375.2	112.0	57.0	35.1	13.3	3.50	596.1	267
	80-55	304.2	135.3	66.7	34.5	17.6	3.30	561.7	287

* All samples were analyzed by Ion Chromatography Laboratory of Research Center for Eco - Environmental Sciences, Chinese Academy of Sciences(Mu, 1992)

Table 4 Correlation between organic acid and yield among varieties

Treatment	Yield and total amount of organic acid				Correlation coefficient, *r*
	Shaan 213	Xiaoyan No. 6	10927	80-55	
CK(+N+P+Zn+B)	347(458)	339(463)	287(390)	297(288)	+0.763
−P(N+Zn+B)	279(559)	283(505)	253(418)	181(263)	+0.966

* Numbers outside and inside of parentheses are yield of seeds (kg/mu) and total amount of organic acid (ppm), respectively

3 Applying molybdenum to soybean - corn intercropping system

Soybean can fix nitrogen 13.5 kg/mu from the air per year, equal to 28.5 kg sulphate ammonia and nitrogen of biological fixation in global ecological system is about 175 million tons per year, higher than that of synthetic ammonia(Prasad, 1987). Nowadays with the population increase and farmland decrease, biological fixation of nitrogen has been attracted attention again for saving chemical fertilizer. Tarhalker in India reported that the output of sorghum in single culture was 453 kg/mu (mu=1/15 ha), but sorghum in intercroping with soybean was 486.5 kg, increasing 7.4% with the addition of soybean 273 kg/mu(Swanmonathan, 1986).

Molybdenum(Mo) is the chief composition of nitrogenase, to be involved in the molybdoferredoxin. Heellreiged (Heellreiged, 1988) reported that cereal crops can absorb the nitrogen fixed by leguminous crop grown with it in the same field(Prasad, 1987). Applying Mo to fix more nitrogen, both in the pot culture and field experiments were carried out in our study in 1992. Treatments for control, adopted soybean - maize intercropping in the normal cultural conditions with $35m^2$ per plot area and three replications and 250g ammonium molybdate applied in the soybean rows per mu. The results indicated that in the treatment applied ammonia molybdate, the number of root nodules increased by 31% than that of in the control. The content of nitrogen and molybdenum in the plants and seeds of soybean and maize in Mo treatment was higher than that in the control test. The yield of soybean and maize increased by 20.5% and 21.3%, respectively(Zhou, 1993). These results indicated that applying molybdenum to cereal - legume intercropping system is an effective measure to increase nitrogen. The yield increase at the same cropping and the nitrogen remained in soil will supply the next crops(Table 5).

Table 5 Increase in legume root nodules and the yield of plants by applying molybdenum

Treatment	Number of soybean root nodules		Yield			
			Soybean		Corn	
	Average, 1 plant	Increase, %	Average, kg/mu	Increase, %	Average, kg/mu	Increase, %
Applied molybdenum	34±0.7	31.0	70.5±4.3	20.5	435±34	21.3
CK	26±1.5	—	58.5±5.8	—	359±25	—

4 Improvement of nitrogen fertilizer to raise efficiency of utilization

At present, urea, ammonium nitrate and ammonium carbonate amount to over 95 percent of the total amount of nitrogen fertilizer produced in China, of which ammonium bicarbonate is the largest, 56%. Ammonium bicarbonate acts faster on plant and not cause soil hardening and acidification but it has higher volatility, large hygroscopicity and short period of efficiency.

Li investigated the granular fertilizer technique for ammonium bicarbonate and deep - application to soil technique, increasing 2/3 the efficiency of fertilizer and the efficiency of utilization doubled. Prof. Li and his colleagues further developed the techniques to produce long - efficient urea and ammonium bicarbonate (Li, 1992).

Cao added inhibitor of urease to common urea, producing the long - efficient urea applied to area of 1.5 million mu(Cao, 1993). Now the Guangzhou Nitrogen Factory produced the coated urea, having released more than 3 million mu. There are more than 1000 factories producing ammonium bicarbonate fertilizer which is the largest amount of nitrogen fertilizer in our country. Zhang developed a new technique to produce the long - efficient ammonium bicarbonate, adding stabilizer into ammonium bicarbonate forming co - crystallization in the process of its production, thus increase the efficiency of nitrogen utilization by 20%—30% and its efficient period elongated twice. The same yield can be obtained while the amount of the fertilizer used is decreased by 20%—30%. A large number of field experiments were conducted in black earth, flood soil, brown soil, sandy soil, and red soil distributed in Hebei, Liaoning, Shandong, Hunan and Yunnan provinces(Table 6). Since 1993, there were 20 factories using this technique in ammonium bicarbonate production(Zhang, 1994).

It can be concluded that selecting the varieties which can utilize soil nutrients efficiently, applying molybdenum to cereal legume intercropping system and improving the quality of nitrogen fertilizer are the effective ways in applying less fertilizers, saving energy resources, protecting environment and promoting the development of sustainable agriculture.

Table 6 The percent age of yield increase in main crops by applying long - efficient ammonium bicarbonate indifferent areas

Food crop	Experimental area and number of times	Applying amount, kg/mu	Yield, kg/mu		Yield increase, %	
				Common fertilizer	Range	Average
Corn	11 experimental sites in Dalian, Shandong and Henan	40—60	397.4±88.4	355.6±109.7	6.1—17	12.8
Rice	6 experimental sites in Fengcheng and Shenyang, Liaoning	40—60	517.±103	466.3±106	8.2—19.9	11.0
Wheat	4 experimental sites in Shandong	40	356.5±5.9	321.7±13.0	6.7—15	10.8

* Both fertilizers are long - efficient ammonium bicarbonate and common ammonium bicarbonate

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