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Optimizing Resource Use Efficiency for Sustainable Intensification of Agriculture

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MICRONUTRIENT DEFICIENCIES OCCURRENCE, DETECTION AND CORRECTION: THE CHINESE EXAMPLE

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“Micronutrient deficiencies occurence, detection and correction: The Chinese example ”

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Abstract

Nutrient availability to people is primarily determined by the output of foods produced from agricultural systems. If agricultural systems fail to provide enough food diversity and quantity to satisfy all the nutrients essential to human life, people will suffer, societies will deteriorate and national development efforts will stagnate. Unfortunately, as a result of population pressures, many global food systems are not currently providing enough micronutrients to ensure adequate micronutrient intakes for all people. This has resulted in an increasing prevalence of micronutrient deficiencies (e.g., iron deficiency, and zinc deficiency) that now afflicts over three billion people globally, mostly among resource-poor women, infants and children in developing countries. The consequences of micronutrient malnutrition are profound and alarming for human existence. Agricultural approaches to finding sustainable solutions to this problem are urgently needed. This study was to investigate micronutrient deficiency, and crop yield responses to micronutrient fertilizers in China.

To evaluate availability of micronutrients in soils from China, total of 25285 soil samples were taken from all 31 provinces of mainland China, and analyzed in the CAAS-PPIC Cooperative Soil and Plant Analysis Laboratory with ASI procedure. Results indicated that micronutrient deficiency was an urgent problem in China. Zn deficiency was widely occurred across nation wide, especially in Northern China. Boron deficiency in Southern China was more serious than that in Northern, while Mn and Fe shortage was more commonly found in Northern China. Siginificant yield responses to micronutrients application were also found for selected crops in selected sites.

Introduction

The world population is expanding rapidly and will likely be 10 billion by the year 2050. Limited availability of additional arable land and water resources, and the declining trend in crop yields globally make food security a major challenge in the 21st century. According to the projections, food production on presently used land must be doubled in the next two decades to meet food demand of the growing world population. To achieve the required massive increase in food production, large enhancements in application of fertilizers and improvements of soil fertility are indispensable approaches.

Presently, in many developing countries, poor soil fertility, low levels of available mineral nutrients in soil, improper nutrient management, along with the lack of plant genotypes having high tolerance to nutrient deficiencies or toxicities are major constraints contributing to food insecurity, malnutrition (i.e., micronutrient deficiencies) and ecosystem degradation (Welch and Graham, 2002). Plant nutrition research provides invaluable information highly useful in elimination of these constraints, and thus, sustaining food security and well-being of humans without harming the environment. The fact that at least 60% of cultivated soils have growth-limiting problems with mineral-nutrient deficiencies and toxicities, and about 50% of the world population suffers from micronutrient deficiencies make plant nutrition research a major promising area in meeting the global demand for sufficient food production with enhanced nutritional value in this millennium (Cakmak, 2002; Biesaski et al., 2003; Savithri et al., 1998).

Status of micronutrient deficiency in China is not clear at present time, more than 20 years after the second national soil survey conducted in early 1980s (Wang et al., 2002; Zhu et al, 1994; He, 1988; Li, 1988). In order to probe micronutrient deficiency, 28258 soil samples were taken from 31 provinces in China for chemical analyses with ASI methods to give an overlook of micronutrient status in China. Field trials to study crop yield responses to micronutrient fertilizers were also discussed through the nation wide cooperative research net work of PPI/PPIC China Program. Results of the soil testing and selected field trials were summarized in this paper.

1 Materials and Methods

1.1 Soil sampling

Soil samples were taken at 0-20 cm depth of soil layers in nutrient monitored villages conducted by CAAS-PPIC research group across from 31 provinces of mainland China.

1.2 Soil samples analyses

Soil samples were analyzed in the CAAS-PPIC Cooperative Soil and Plant Analysis Laboratory with ASI (Agro Services International Incorporation) method (Hunter, 1983; Jin, 1996).

Field trials were set up based on results of soil analyses.

2 Results and Discussion

2.1. Micronutrients status in soils of China

2.1.1 Zinc

In order to evaluate soil micronutrient status, percentage of soils with the detection level of special nutrient (Such as Zn, Fe, B, Cu and Mn) below critical value was used in this study. Serious problems existed in soil Zn status that Zn deficiency occurred widely across the country, especially in Northern China. Of the total soil samples taken from Northern China, including Northeast, North central and Northwest provinces, 71.1% was below critical value of Zn (2µg/L). With the exception of Tianjin city, where only 13.7% of soil samples taken from Tianjin was below critical level. This is probably the results of high pH in soils of Tianjin, which is beneficial to Zn availability (Wang, 2005). The most severe Zn deficiency was found in Inner Mongolia, where 96.5% of the soil samples below Zn critical level (Table 1).

In comparison with Northern China, soils from Southern China showed better supply of Zn, with 48% of the soils showing Zn deficiency. In Southern China, soils from Zhejiang and Hubei provinces exhibited slightly Zn deficiency with 3.7% and 3.4% of soil samples below the critical level, respectively. However, soils from Anhui province manifested severe shortage of Zn with 85.3% of the soil showing Zn deficiency (Table 1).

2.1.2 Boron

Boron deficiency varied across different provinces. Generally speaking, B deficiency in soils from Southern China was more serious than that from Northern China. The percentage of total soil samples with soil available B below critical level (0.2µg B/L) was 16.9% and 34.0% for Southern and Northern China. In Liaoning province of Northeast China, 40.8% of soils were low in available B. While no B deficiency was found in Tianjin, due to the application of city waste as manure for vegetable production. As in Southern China, soils from Guangxi, Zhejiang, Jiangxi and Fujian manifested severe soil B deficiency with 58.8%, 62.2%, 65.8% and 74.2% of total soils from these provinces showing B deficiency (Table 1).

2.1.3 Manganese

25.4% of soils from Northern China were low in available Mn, while 16.3% of soil samples from Southern China showed available Mn below the critical level. Among soils from Northern China, Qinghai province ranked first with 66.5% of soils deficient in Mn, followed by Inner Mongolia and Tianjin with 45.8% and 39.2% soils below critical level, respectively. Soils from Northeast Heilongjiang, Jilin and Liaoning provinces were relatively high in Mn, with only less than 10% of the soils below the critical level. From Southern China, 43.8%, 37.8% and 33.3% of soils from Jiangxi, Sichuan and Tibet showing Mn deficiency, while in Yunan, Shanhai and Zhejiang, the percentage of Mn deficient soils was below 3% (Table 1).

Table 1 Percentage of soils with micronutrient content lower than critical value in different provinces in China（%）

Region	Province	Zn	Cu	Fe	Mn	B
Northeast	Heilongjiang	77	4.1	8.1	7.3	24.5
	Jilin	48.8	1.1	7.0	9.3	34.1
	Liaoning	52.3	2.2	1.9	9.3	40.8
Northcentral	Tianjin	13.7	0.7	12.0	13.2	0.0
	Beijing	80.2	6.8	15.3	39.2	33.3
	Shanxi	86.7	11.4	83.9	18.1	9.6
	Shandong	73.2	11.0	25.2	24.7	17.2
	Henan	84.0	31.2	57.3	34.1	27.6
	Hebei	70.0	6.1	34.1	32.8	24.1
Northwest	Inner Mongolia	96.5	39.1	55.3	45.8	19.9
	Gansu	70.1	20.5	57.8	24.2	0.5
	Shaanxi	69.3	13.5	91.2	14.4	4.6
	Qinghai	71.9	2.8	20.1	66.5	5.7
	Ningxia	88.0	28.5	39.2	31.3	5.2
	Xinjinag	85.2	17.8	35.0	10.5	5.9
Southwest	Chongqing	39.5	21.6	17.2	9.7	23.0
	Sichuan	67.4	6.9	24.5	37.8	10.3
	Tibet	61.2	2.3	3.1	33.3	2.3
	Guizhou	64.8	49.9	1.2	17.6	29.0
	Guangxi	24.3	12.0	0.4	23.1	58.8
	Yunnan	18.9	1.3	1.1	2.4	47.6
	Hainan	54.0	28.4	0.2	10.3	32.8
	Guangdong	26.2	9.2	0.2	13.6	32.1
Southeast	Shanghai	74.7	0	0	2.4	13.3
	Zhejiang	3.7	1.2	0	2.3	62.2
	Jiangxi	45.8	11.8	4.3	43.8	65.8
	Jiangsu	93.0	0	0.5	2.3	1.2
	Hubei	82.0	1.2	0.2	28.1	21.9
	Hunan	3.4	0	0	0.8	44.7
	Anhui	85.3	0.8	17.5	20.1	24.7
	Fujian	24.0	5.2	1.3	13.1	74.2

2.1.4 Iron

Iron deficiency is more commonly found in soils from North that that from South, with 36.2% of soils from Northern provinces showing Fe deficiency, while only 4.5% from south was below the Fe critical level. In the North, 91.2% and 83.9% of soils from Shaanxi and Shanxi provinces showed Fe deficiency. Soils from Northeast provinces showed slight Fe deficiency, with other provinces in the middle (Table 1).

Soils from South demonstrated less Fe deficiency as compared with North China. Percentage of soils from Sichuan, Chongqing and Anhui provinces showing Fe deficiency were 24.5%, 17.2% and 17.5%, separately, and that for other provinces was below 4.3% (Table 1).

2.1.5 Copper

Soil Cu deficiency was not as serious as other micronutrients in China, with 13.1% of soils from the North and 9.5% from the South showing Cu deficiency. In Inner Mongolia, Henan and Ningxia, 39.1%, 31.2% and 28.5% of total soils were below the critical level, which were the top three provinces showing serious Cu deficiency, followed by Gansu, Xinjiang, Shaanxi, Shanxi and Shandong with the deficiency percentage varied between 20.5%~11%. Other provinces including Heilongjiang, Jilin, Liaoning, Tianjin, Hebei and Qinghai showed less Cu deficiency, with percentage of soils below critical level less than 6.8% (Table 1).

The top three provinces from Southern China showing severity of Cu deficiency were Guizhou, Hainan and Chongqing with 49.9%, 28.4% and 21.6% of the soils with available Cu below critical level. The percentage for other provinces from South was under 12% (Table 1).

In national level, frequent distribution of micronutrient contents was developed (Fig.1).

Frequent distribution of micronutrient contents varied across different nutrients. For Zn, percentage of soils with detection value lower than 2 μg/L (critical value) was 61%, and the averaged value of Zn was 2.90 μg/L due to 12% of soil with Zn content higher than 4.0 μg/L; Although 24% of soils with B content lower than 0.2 μg/L (critical value), soil average B content was 1.38 μg/L, greatly higher than critical level, which maybe highly correlated with 66% of soils with detection B value over 0.4 μg/L; While distribution frequency for Fe, Mn and Cu was 19%, 19% and 9% with detection level below critical value (10 μg/L , 5 μg/L and 1.0 μg/L for Fe, Mn and Cu) respectively, and the averaged value for Fe, Mn and Cu were greatly higher than critical value, because the percentage of soils with detection level exceeded greatly the critical values. Micronutrient deficiency manifested from frequent distribution was similar to that in Table 1. The reason for the varied micronutrient distribution attributed to the wide range of soils taken from 31 provinces.

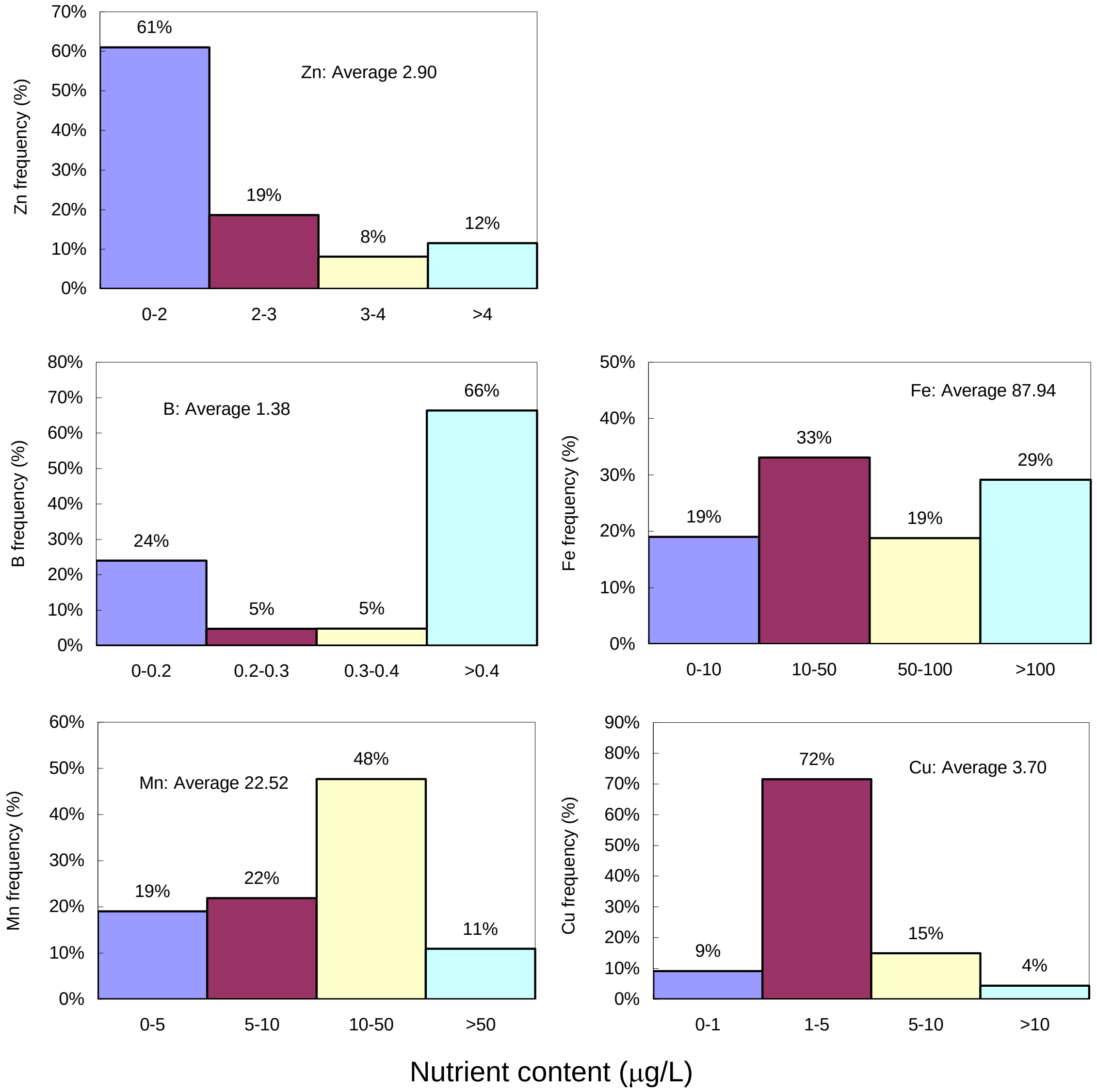

Fig.1 Frequent distribution of micronutrient contents in soils

2.2 Responses of micronutrient application on selected crops

2.2.1 Zinc

Zinc in soils is widely deficient in China (Table 1 & Figure 1). Field experiment conducted in Xinjiang province indicated that application of 15 kg/ha $ZnSO_4$ increased lint and seed cotton by 179 kg/h and 371.8 kg/ha, 9.5% and 8.6% more lint and seed cotton yield, compared with those without Zn addition. Three-year continuous experiment carried out in two sites of Shanxi province showed that application of 15 kg/ha $ZnSO_4$ increased corn yield by 14.6% for 2002, 9.3% for 2003, and 1.6% for 2004 in site 1. The same amount of $ZnSO_4$ increased corn yield by 11.5% for 2002, 6.7% for 2003, and 6.1% for 2004 in site 2. However, addition of 15 kg/ha $ZnSO_4$ in Sichuan province produced more corn yield by 1.6% for 2002, 10.8% for 2003 and 3.2% for 2004, respectively (Table 2). It was obvious that crop responses to Zn varied across different locations due to different soil types and different climate condition since availability of Zn is highly correlated to soil pH (Rengel and Marschner, 2005 ;El-Fouly et al., 2001).

Table 2 Crop responses to Zn fertilization

Year	Crop	Location	$ZnSO_4$ (kg/ha)	Yield（kg/ha）
2001	Cotton	Xinjiang	15	1564 (lint), 4681 (seed)
			0	1428 (lint), 4308 (seed)
2002	Corn	Linfen, Shanxi	15	5472
			0	4775
2003	Corn	Linfen, Shanxi	15	6957
			0	6364
2004	Corn	Linfen, Shanxi	15	7946
			0	7818
2002	Corn	Xinzhou, Shanxi	15	11643
			0	10443
2003	Corn	Xinzhou, Shanxi	15	9886
			0	9261
2004	Corn	Xinzhou, Shanxi	15	9400
			0	8854
2002	Corn	Jiangyan, Sichuan	15	5350
			0	5262
2003	Corn	Jiangyan, Sichuan	15	2988
			0	2697
2004	Corn	Jiangyan, Sichuan	15	7453
			0	7223

2.2.2 Boron

Field research results conducted in Xinjiang in the year 2001 indicated that 15 kg/ha boric acid application increased lint yield by 156 kg/ha (11.1%) and seed cotton by 438 kg/ha (10.3%). Experiment in Hubei province in 2004 demonstrated that 15 kg/ha boric acid application obtained only 52 kg/ha (1.6%) more seed cotton; while field trial in Gansu in 2002 showed that application of 15 kg/ha borax increased corn yield by 983 kg/ha, 16.6% more yield produced; Rapeseed field trial in Jiangsu province in 2003 indicated that addition of 7.5 kg/ha borax enhanced yield by 200 kg/ha (6%) (Table 3) . Similar to the crop responses to Zn, crop responses to B was also varied with different locations due to the different soil condition (Rengel and Marschner, 2005 ;El-Fouly et al., 2001).

Table 3 Crop responses to B fertilization

Year	Crop	Location	Boric acid(kg/ha)	Yield（kg/ha）
2001	Cotton	Xinjiang	15	1564(Lint), 4681(Seed）
			0	1408(Lint), 4243(Seed）
2004	Rapeseed	Hubei	15	3221
			0	3169
2003	Rapeseed	Jiangsu	15	3563
			0	3363
2002	Corn	Gansu	15	6893
			0	5910

2.2.3 Manganese

According to the field trial on cotton in Xinjiang province in 2001, 30 kg/ha $MnSO_4$ addition increased lint yield and seed cotton by 56 kg/ha and 284 kg/ha,12.9% and 11.1% more yield increment, and, peach number per plant, boll weight and boll number per plant increased by 1.9%, 1.3% and 10.8% as well (data not shown); Same amount of $MnSO_4$ in Shanxi province increased corn yield by 4.6%, 7.5% and 2.1% for the year 2002, 2003 and 2004, respectively (Table 4).

Table 4 Crop responses to Mn fertilization

Year	Crop	Location	$MnSO_4$(kg/ha)	Yield（kg/ha）
2001	Cotton	Xinjiang	15	1564(Lint), 4681(Seed)
			0	1385(Lint), 4213(Seed)
2002	Corn	Linfen, Shanxi	15	5472
			0	5230
2003	Corn	Linfen, Shanxi	15	6957
			0	6468
2004	Corn	Linfen, Shanxi	15	7946
			0	7783

2.2.4 Iron

Results conducted in Sichuan province indicated that spray of Fe-EDDHA enhanced contents of chlorophyll A, chlorophyll B and chlorophyll A+B in leaves of peach by 316%, 327% and 321%, respectively, because Fe is closely related to synthesis of chlorophyll (Abadial et al., 1999; Raven et al., 1999; Fodor et al., 1995; Imsande, 1998). Iron content was also confirmed to increase by 64.1% by Fe addition (Table 5). It was indicated that chelate Fe-EDDHA not only increased chlorophyll content, but also improved Fe nutrition in leaves of peach. A separate two field trials showed that yield and yield components of peanut increased by Fe-EDDHA addition. At site 1, compared to control without Fe, Fe application increased pod number, pod weight and kernel weight by 2.7%, 19.2% and 14.1%, separately, and yield increased by 11.1%, demonstrating that Fe increased peanut yield with larger “single sink”; At site 2, Fe application increased pod weight, kernel rate and yield by 5.9%, 3.2% and 10.0%, indicating that Fe increased peanut yield with larger “multiple sink” (Table 6).

Table 5 Fe spray on contents of chlorophyll and Fe in leaves of Peach (Chengdu, Sichuang province)

Treatment	Chlorophyll content (mg/g FW)			Fe content (mg/kg)
	Chlorophyll A	Chlorophyll B	Chlorophyll A+B	
Check	0.097	0.082	0.179	181.2
FeEDDHA	0.404	0.350	0.754	297.3

Table 6 Iron application on yield and yield components of peanut (Jiangyang, Sichuan province)

Location	Treat-ment	Pod number (Nut/plant)	Pod weight (g/100 nut)	Kernel weight (g/100 kernel)	Kernel rate (%)	Yield (kg/ha)	Increase (%)
Site 1	Check	7.35	132.4	47.6	71.0	3367.5	-
	FeEDDHA	7.55	157.8	54.3	69.1	3742.5	11.1
Site 2	Check	5.57	136.4	58.8	66.6	2425.5	-
	FeEDDHA	5.57	144.4	57.3	68.7	2667.0	10.0

2.2.5 Copper

Results from field trial conducted in Gansu province indicated that addition of 15 kg/ha $CuSO_4$ enhanced corn yield to 6,893 kg/ha, 43.0% more yield than control without Cu applied.

3. Conclusion

Micronutrient deficiency was an urgent problem in China. Zn deficiency was widely occurred across nation wide, especially in Northern China. Boron deficiency in Southern China was more serious than that in Northern, while Mn and Fe shortage was more commonly found in Northern China. .

Yield responses varied across different crops and different locations. Application of 15 kg/ha $ZnSO_4$ increased corn yield by 1.6%~14.6%, and cotton lint by 9.5% and cotton seed by 8.6%; Addition of 15 kg/ha boric acid produced 11.1% more lint yield and 10.3% more cotton seed, and 16.6% more corn yield, while 7.5 kg/ha borax produced 6% more rapeseed; Spray of FeEDDHA increased chlorophyll content of peanut by 321% and Fe content by 64.1%, and achieved 9.96%~11.14% more pod yield; Application of 30 kg/ha $MnSO_4$ obtained 12.9% more lint yield and 11.1% more cotton seed, and 2.1%~7.5% more corn yield; Addition of 5.2 kg/ha $CuSO_4$ enhanced 29.2% more corn yield.

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