CHAPTER 2

LITERATURE REVIEW

2.1 Definition and Measurement of Rice Grain Quality

Quality of rice is normally defined as physical and biochemical characteristics of the grain (Juliano, 1985). Generally, qualities of rice grain include the appearances, milling, cooking, eating, and nutritional qualities. These qualities are normally judged by various parameters, i.e. brown rice, milled rice recovery, head milled rice yield, grain size and shape, chalkiness, translucency, gel consistency, gelatinization temperature, amylose content, protein content and mineral contents (Webb, 1979; Luo, 1990).

Appearance and milling quality include a number of physical characteristics of rice grain. Among these characteristics, grain length, head rice recovery, chalkiness, foreign matters, and color are the main indicators (Juliano, 1993).

Cooking-eating quality is generally determined by the following grain properties, gel-consistence, gelatinization temperature, and amylose content of rice grain. These properties related to volume expansion, cooking time, water absorption during cooking, hardness, whiteness and dullness of cooked rice (Juliano, 1985).

Nutritional quality simply refers to protein content of rice grain. In addition, amino acid and mineral contents such as iron, zinc, and calcium are also considered as indicators of nutritional qualities (Juliano, 1993).

Many national programs have characterized the grain quality of their popular rice varieties and germplasm collection entries. Different countries have their own measures of quality and systems of control, but such measures and systems of control lack uniformity among countries (IRRI, 1991). The "high quality" rice are usually adjudged either by the international criteria (FAO) or by national standard. At present in Yunnan, 10 surperior quality rice varieties were recommended based on the national standards for high quality rice given by Central Chinese Agricultural Ministry (Table 2.1).

Table 2.1 The NY122-88 Chinese Agricultural Ministry criteria for high quality rice.

Characteristics	Non waxy				Waxy			
	Indica		Japonica		Indica		Japonica	
	I	II	I	II	I	II	I	II
output of brown rice %	>81	>79	>83	>81	>81	>79	>83	>81
milled rice recovery %	>72	>70	>74	>72	>72	>70	>74	>72
head rice yield %	>59	>54	>65	>60	>59	>54	>65	>60
grain length mm	6.5-7.5	5.5-6.5	5.0-5.5	5.0-5.5	6.5-7.5	5.5-6.5	5.5-6.5	5.0-5.5
grain L/W ratio	>3	2.5-3.5	1.5-2.0	1.5-2.0	>3.0	2.5-3.5	1.5-20	1.5-2.0
chalkiness ratio	<5	<10	<5	<10				
chalkiness size %	<5	<10	<5	<10				
translucency	semi	semi	semi	semi				
gelatination temp.	>4	>4	>6	>6	>6	>6	>6	>6
gel-consistence mm	>60	41-60	>70	61-70	>100	>95	100	>95
amylose content %	17-22	<25	14-18	<20	0	<2	0	<2
protein content %	>8	>8	>7	>7	>8	>8	>7	>7

Abstracted from: Xiong Z.M. (ed.). 1992. *Rice in China.*

2.2 Importance of Rice Grain Quality

The market price of rice depends upon grain quality, thus the benefits from quality improvement are likely shared by consumers and producers (IRRI, 1993).

Based on Lancaster's (1966) consumption theory and Ladd and Suvannunt (1976) consumer goods characteristics model (CGCM), most of the studies used hedonic price model to estimate consumer preferences for rice grain quality. The model assumes that consumer demand is based on product utility, which is a function of product characteristics. As Unnevehr et al. (1985) illustrated that rice price the consumer pays equal the sum of values of characteristics of rice as shown in the equation below.

$$P_R=\sum_{j=1}^{n} X_{Rj}P_{Rj}+u$$

Where P_R= market price of rice;

X_{Rj}= amount of characteristics j in one unit of rice;

P_{Rj}= implicit value of characteristics j; and

u= random error

The implicit price model has been applied to identify the importance of quality characteristics of rice in some of Southeast Asia countries. The estimation of grain quality characteristics for three countries are presented in Table 2.2. This table indicates that preferences for good milling quality and aroma are similar and has expected sign (positive) in all countries, but preferences for shape and chemical attributes vary from country to country as well as from culture to culture (Unnevehr et al., 1985).

Table 2.2 Regression estimates of implicit prices for grain quality characteristics in three southeast Asian countries (dependent variable is price in USc/kg; t-statistics in parentheses).

Country regression	*Philippines*	*Indonesia*	*Thailand*
No. of samples	107	118	86
Intercept	35.16 (4.38)	-0.19 (-0.02)	14.71 (2.62)
White (%)	0.34 (3.18)	1.14 (5.39)	0.30 (3.47)
Brokens (%)	-0.12 (-5.10)	-0.18 (-4.58)	-0.15 (10.57)
Chalkiness score	-0.38 (-3.17)	0.00 (0.00)	-0.15 (-1.10)
Shape (L/W)	2.85 (1.68)	-4.68 (-2.31)	2.47 (2.29)
Amylose (%)	-1.12 (-9.49)	0.14 (0.53)	-0.02 (-0.22)
Gel consistency (mm)	-0.01 (-0.35)	0.05 (0.96)	0.02 (1.14)
Alkali spreading value	1.94 (4.20)	1.92 (2.26)	-0.04 (-0.12)
Aroma		9.07 (6.71)	5.89 (6.00)
R^2	0.71	0.64	0.89
Durbin watson	1.55	1.77	1.80

Source: Unnevehr et al., 1985.

Abansi et al. (1993) extended hedonic price model (Figure 2.1), which involved more prices determinations for rice. That is, market price of rice is determined by physicochemical characteristics of rice and socioeconomic characteristics of consumers. Results indicated that the price paid by urban consumers is affected significantly by grain length, head rice recovery, presence of foreign matter, amylose content, and alkali spreading value. Rural consumers base their purchasing decisions on a slightly different set of characteristics, i.e. whiteness, head rice recovery, foreign matter content, amylose content, and alkali spreading value. As income levels rise, consumers become more discriminating. High income consumers purchase rice based on quality characteristics and attach higher implicit prices to these attributes than do low and medium income consumers.

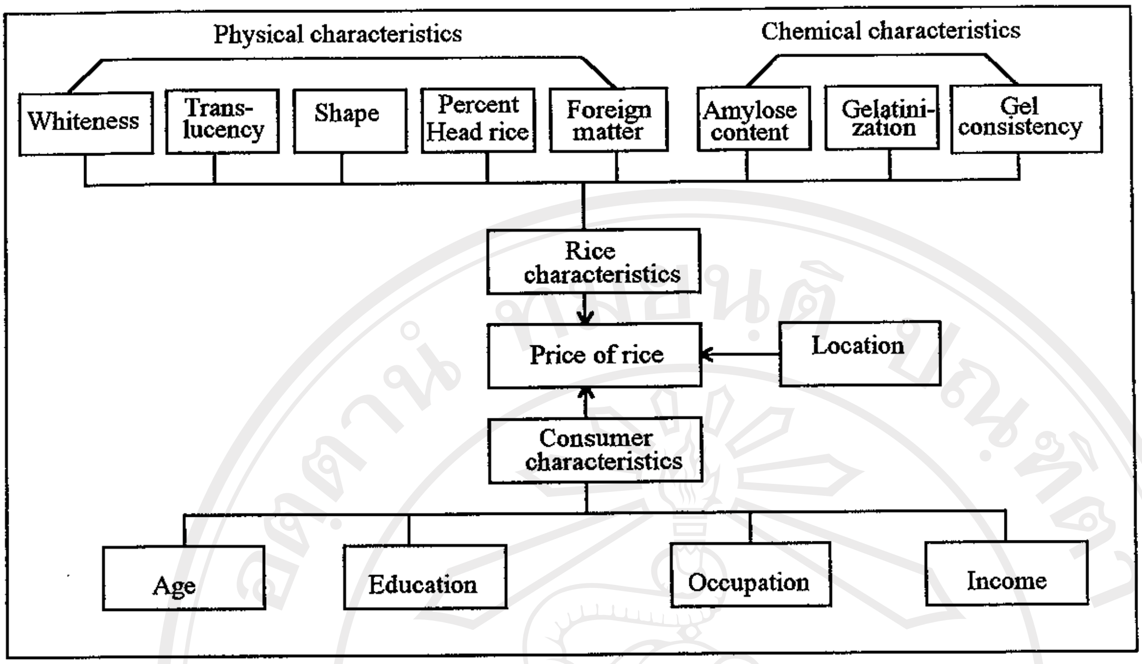

Figure 2.1 Schematic diagram of rice characteristics and consumer traits affecting the price of rice (extended hedonic model).
Source: Abansi et al., 1993.

The important quality characteristics of rice in China are mainly adjudged on the basis of personal observations of consumers preferences. These characteristics included aroma, chalkiness, and amylose content of rice grain which are generally considered as the important quality characteristics in Yunnan (Yang, 1992). The role of each quality characteristics is also taken into account for rice quality evaluation through standardization of national grading systems which developed by Central Chinese Agricultural Ministry (Table 2.3). Nevertheless, there is still no study concerning the relationship between market prices of rice and quality characteristics of rice grain in Yunnan.

Table 2.3 NY 122-88 Chinese Agricultural Ministry standardization of national grading systems for rice quality evaluation.

Weighting characteristics	Grade	Grade classification		
		High	Medium	Low
		I	II	below II
Milling quality	16			
out put of rough rice %		4	3	2
milled rice recovery %		5	4	3
head milled rice yield %		7	5	3
Appearance quality	25			
grain length mm		2	1	0
grain L/W ratio		3	2	1
chalkiness ratio		8	6	4
chalkiness size %		4	3	2
translucency		8	6	4
Cooking-eating quality	26			
gelatination temperature		4	3	2
gel consistency mm		8	6	4
amylose content %		14	11	8
Tasty quality	30			
smell		3	2	1
color of cooked rice		5	4	3
grain shape & taste of cooked ric		17	14	1
texture of cold-cooked-rice		5	4	3
Nutritional quality	3			
protein content %		3	2	1
Total grades	100	100	76	52

Data source: Xiong Z.M. (ed.). 1992. *Rice in China*

2.3 Factors Affecting Rice Quality

Rice grain quality can be affected by genetic factor, environmental factors, and processing (Juliano and Duff., 1989). Environmental and handing conditions during ripening, harvest, post harvest, and processing can enhance or impair grain quality. Varieties directly determine some quality characteristics and interacts with environment and processing to influence other characteristics indirectly (Table 2.4). Varieties are different in crack resistance, for example, the varieties influence head rice recovery in combination with drying and milling techniques (IRRI, 1993).

Table 2.4 Effects of variety, environment, and processing on rice grain qualities.

	Influence of*		
Characteristics	Production envir.	Processing	Variety
Size and shape	+	+	+
Degree of milling	+	+	+
Head rice	+	+	+
Translucency	+	+	+
Aroma	+	+	+
Foreign matter	0	+	+
Damaged grains	+	+	+
Amylose content	+	+	0
Gelatinization temperature	+	+	0
Gel consistency	+	+	0
Grain elongation	+	+	+

*+ = has influence, 0 = no influence.
Source: Unnevehr et al., 1993.

Grain shape and size are genotypically determined (Juliano et al., 1985). Opastrakul (1995, personal communication) and Attaviriyasuk et al. (1975) pointed out that increment nitrogen fertilizer application would increase the physical characteristics of rice grain (length, width, and thickness).

Mattews et al. (1970) noted that medium grain rice was more resistant to cracking than long grain rice during milling. The degree of chalkiness, which varied greatly among cultivars, was found to be negatively related to rice milling quality (Nakatat et al., 1973; Chang et al., 1979). Rice milling quality was also found to be influenced by post harvest factors such as dry temperature (Wright and Warnock, 1983), rice processing (parboiling) (De Datta, 1981), and the milling process (Esmay et al., 1979; Sahay et al., 1980). Jongkaewwattana (1990) showed that plant type, grain filling process, and grain characteristics are intricately related to each other and have a definite influence on the potential milling quality of rice. It seemed that the differences in head rice recovery among cultivars were associated with growth duration of cultivars. Geng et al. (1984) reported that head rice recovery decreased during the replacement of intermediate and late maturity cultivars by very early and early cultivars in California.

Many studies have been conducted to investigate the factors affecting protein content of rice grain. It has been reported (Juliano et al., 1985b) that protein content tends to increase with wide spacing or in borders and in response to high nitrogen application. Juliano (1993) cited that short growth duration and cloudy weather during grain development, as occurs in the wet season, may increase protein content. Stress such as drought, salinity, alkalinity, high or low temperature, diseases or pests may increase the protein content of rice grain (Juliano, 1993). An increase in protein content is essentially at the expense of a reduction in starch content. In addition, Gomez et al. (1985) found that high radiation during period of grain development tended to reduce protein content of rice, while increasing of temperature at grain developmental stage could increase or had no affect on grain protein. Mineral nutrition can also affect the protein content of rice grain. Huang (1990) found that soil organic matter, total nitrogen, exchangeable calcium, available copper and molybdenum and total chlorine all tend to increase grain protein content. As growth duration increases, brown rice protein content decreases (IRRI, 1988). The protein of grain showed different responses when rice grown in irrigated and upland culture (Villareal, 1990).

It was identified that the factors affecting protein content of rice were also associated with amylose content of rice grain. Previous documents indicated that amylose content of rice were significantly correlated with temperature, nitrogen supply, and milling degree, but the responses varied with various genotypes (Resurreccion et al., 1977). Recent studies also suggested that amylose content was directly affected by water supply during process of grain filling (Seerhai, 1995).

The mineral content of grain is affected by mineral content of the soil and the irrigation water. Kitagishi et al., (1981) found that pollution of irrigation water with mine tailings has resulted in high cadmium content in some Japanese rice.

2.4 Role of Phosphorous and Zinc Supply in Plant Growth and Grain Quality

2.4.1 General functions of P and Zn

Mineral nutrients have specific and essential functions in plant metabolism (Marschner, 1986). As summarized in Table 2.5, mineral nutrients are required for various process related to the formation and function of chloroplast. The functions of mineral nutrients that may serve as a constituent if organic structure, as an activator of enzyme reactions, or as a charge carrier and osmoregulator. Mineral nutrients can affect net photosynthesis in various ways.

Table 2.5 Examples of direct and indirect roles of mineral nutrients in photosynthesis.

Process	Mineral nutrient*	
	Constituents of organic structure	Activators of enzymes, osmoregulation
Chloroplast formation		
Protein synthesis	N,S	Mg,Zn,Fe,K,(Mn)^a
Chlorophyll synthesis	N, Mg	Fe
Election transport chain		
PSII+I, photophosphorylation	Mg,Fe,Cu,S,P	Mg,Mn,(K)
CO_2 fixation	___	Mg,(K,Zn)
Stomata movement	___	K,(Cl)
Starch synthesis, sugar transport	P	Mg,P,(K)

*Mineral nutrients are in parentheses where their role is based mainly on indirect evidence
Source: Marschner H. J. 1986.

The role of phosphorous supply on plant growth and development is its effect on the phytohormone balance and its function in photosynthesis process, especially in starch synthesis and sugar transport (Marschner, 1986). Phytates are presumably involved in the regulation of starch synthesis during grain filling (Michael et al., 1980).

Zn acts either as a metal component of enzymes or as a functional, structural, or regulatory cofactor of a large number of enzymes. Under condition of Zn deficiency, the changes in metabolism are quite complex (Marschner, 1986). Zn may also be incorporated as component of proteins and other macromolecule (Brown et al., 1993). Many of the physiological perturbations resulting from Zn deficiency are associated with the disruption of normal enzyme activity, thus zinc-deficiency induced inhibition of photosynthesis is coincident with a decrease in activity key photosynthetic enzymes. Zn is known to be required for stabilization of biomembranes by interaction with photophollipids and sulfhydryl groups of membrane protein. Zn play a key role in stabilizing enzymes and controlling the activity of RNA degrading enzymes. Thus, Zn may play a role in controlling gene expression. In addition, Zn may also play a role in the metabolism of starch. Jyung et al. (1975) found that the starch content, activity of starch syntheses and the number of starch grains were depressed under Zn-deficiency in beans. A reduction of starch formation under Zn deficiency has been confirmed in other crops. Finally, Zn is associated with auxin metabolism, i.e. IAA and GA. Supplementation of Zn to Zn-stressed plants (maize, barley, and oat) not only increased growth but also increased levels of gibberellin-like substances (Suge et al., 1986).

2.4.2 Effects of P and Zn on grain quality

♦ **Phosphorous**

The influence of P supply on grain yield and quality is multidimensional. There are many references concerning their influence on yield and quality of cereal crops (rice, wheat, corn) (Shi, 1988).

The effect of phosphorous supply on amylose synthesis is not as profound as that of nitrogen. However, the level of phytase phosphorous plays an important role in the process of starch synthesis of rice grain at 15 days after flowering (Ogawa et al., 1979).

Mosuolofu and Fuleite (Afudaoning, 1992) stated that there was a positive correlation existed between P supply and protein content of grain, but it might be a negative influence of P supply on protein synthesis in some cereal crops.

There are not many previous studies on the effect of P supply on protein content of rice grain. Nevertheless, Shi (1988) noted that under the condition of optimum nitrogen, the total percentage of protein content of rice grain might increase slightly as phosphorous supply increases. Similarly, it has also been documented (Table 2.6) that there was a positive correlation between P supplies and protein contents of wheat grain (Afudaoning, 1992).

Table 2.6 The effect of P fertilizer supply on quality of wheat grain.

Treatment (P_2O_5kg/ha)	Grain Yield (Dan/ha)	Protein Content (%)	Gluten (%)	Translucent (%)
P0	15.8	14.9	28.0	67
P20	16.6	15.8	29.0	69
P40	17.8	16.5	31.0	71
P60	18.9	17.9	33.0	74
P40+20	18.8	18.2	33.0	73

Source: Afudaonig, 1992.

An adequate supply of P in early stage of plant growth is important in laying down the primordial for the reproductive parts of the plants. Shi (1992) reported that P fertilizer (combined with N and K) improved grain filling rate and grain weight. Apart from that, P was considered to be associated with the seed formation.

It has not been known whether higher P supply could improve P content of rice grain, but it has been found that there is a positive correlation between P content and protein content in rice grain (Zhang, 1993).

- **Zinc**

Zinc has long been known as an essential micronutrient for improvement of yield in rice. Research on nutrition of zinc in rice was stimulated by early work of Yoshida (De Datta, 1981).

The adequate zinc supply is important for protein synthesis. It was documented that, there was a positive correlation existed between zinc supply and protein content of rice grain, increasing crude protein content from 6.08% to 7.06%, and increasing pure protein content from 5.98% to 6.87% after an adequate Zn applied (Academy of

Agricultural Sciences of China, 1985). Zhang (1993) also found that there is positive correlation between Zn content and protein content of rice grain.

Concerning the nutritional value of protein of rice grain, Singh (Marschner, 1986) reported that an increasing zinc supply resulted in improving the tryptophan content in the grains of rice plants growing in zinc-deficient calcareous soil (Table 2.7).

Regarding the appearance quality of grain, it has been known that Zn supply has also been associated with the seed size and texture in cereal crops such as corn, wheat, and rice (Shi, 1988).

Table 2.7 Effect of zinc supplies as Zn-EDTA to a zinc-deficient calcareous soil on the tryptophan content of rice grains.

Zinc supplies (mg/kg soil)	Tryptophan content (mg/kg dry wt)
0	830
5	1476
10	2011

Source: Marschner, 1986.

It seems that the effects of Zn supply on Zn content of rice grain have not been documented, but it has been shown (Table 2.8) that the higher Zn supply of soil, the higher zinc content of rice plant at 35 days after transplanting (De Datta, 1981). Similarly, Shi (1988) indicated that the rice grain yield would not increase further after zinc supply exceeded a certain quantity level, while there was an increment of Zn content of plant with increasing Zn supply.

Table 2.8 Effects of Zn application on growth, yield and Zn concentration of rice plant growing on a calcareous soil, Philippine (Adapted from Yoshida 1975).

Treatment	Plant height	Tiller no./hill	Dry weigh g/hill	Zinc ppm	Grain yield t/ha	Relative yield
NPK	31	8	1.0	15	1.8	100
NPK+dipping in 1% ZnO	32	16	5.4	22	5.3	301
NPK+ZnCl 100 kg/ha	62	17	11.5	55	5.6	316
NP+ZnCl 100 kg/ha	58	18	10.8	60	5.1	288

Source: De Datta, 1981.

2.4.3 Interaction of P and Zn affecting plant growth and grain quality

P-Zn interaction remains complex. It involves many phenomena in both soil and plants. The most common and important interaction is that large applications of P fertilizers to soil low that is in available Zn may induce Zn deficiency and increase the Zn requirement of plants (Marschner, 1986). As summarized by Loneragan et al. (1979, 1993), three different factors may be responsible for "P induced Zn deficiency ": (a) dilution of Zn in plants by the increase in growth induced by P fertilizer, (b) inhibition of Zn uptake by cations (Ca^{2+} in particular) added with P fertilizer, and (c) P enhanced Zn adsorption in soil to hydroxides and oxides of iron and aluminum and to $CaCO_3$.

It does not necessarily indicate that high rate of P application is the cause of the Zn deficiency (Chinese Academy of Agricultural Sciences, 1985). However, the incident of Zn-deficiency because of increased use of P fertilizer, has become recognized as a widespread and important nutritional problem throughout the rice-growing world (De Datta, 1981).

Yang et al. (1986) confirmed that P induced-Zn deficiency often occur when grown rice in low Zn or Zn deficiency soils. It has also been pointed out that plant absorption and translocation of P and Zn were affected by the levels of P and Zn supplied. The levels of P causing Zn-deficiency were variable with various soils., and the higher the available Zn of soil, the greater the P level of induced-Zn deficiency (Table 2.9).

Table 2.9 Effects of P and Zn applications[a] on the total amount of plant uptake P and Zn in rice (Modified from Yang et al., 1986).

Soil[b]	amount of P uptake (μg/plot)					amount of Zn uptake (μg/plot)				
	CK	P5	P20	P30	P5+Zn	CK	P5	P20	P30	P5+Zn
1	4599	7147	9659	9819	9518	53.4	148.7	94.5	50.2	185.4
2	8980	17751	17536	19994	18002	91.1	235.1	151.5	82.6	291.6
3	6153	9530	12217	14073	12582	73.1	182.4	108.3	44.7	209.9
4	15195	22447	28843	32699	15195	204.1	388.7	337.8	223.0	407.4
5	8948	23143	25858	34740	8948	119.9	365.8	389.1	243.2	447.6
6	9960	17707	22742	25249	9960	141.8	289.4	274.8	179.2	311.4

[a] CK: without P and Zn application; P5, P20, P30: 37.5, 150, 225 kg P_2O_5 /ha application; and P5+Zn: 37.5 kg P_2O_5 / ha + 15 kg $ZnSO_4.7H_2O$ /ha application.

[b] For soil 1 2 3 4 5 and 6, the available Zn contents were 0.33, 0.46, 0.60, 0.85, 0.98, and 1.08 ppm; available P contents were 2.20, 3.76, 2.04, 7.85, 13.77, 5.40 ppm; and pH were 8.12, 7.99, 8.32, 8.19, 8.06, 7.92, respectively.

Effect of P-Zn interaction on grain yield has been found to be significant. Yang et al. (1986) reported that under soil conditions with low P and Zn-deficiency or low Zn, rice grain yield increased significantly with P and combined P and Zn applications (Table 2.10). Lian (1989) also found that P increased grain yield of barley by 80-143%, while the influence of Zn on grain yield was found to be associated with ratio of P/Zn of soil. It has been indicated that on the basis of soil available Zn below 0.44 ppm and P/Zn above 56.2, Zn application increased grain yield of barley significantly, and it tended that the greater the P/Zn of soil, the higher the potential of yield increasing.

Influences of P-Zn interaction on rice grain qualities (i.e. protein and amylose contents of rice grain, etc.) have not been well documented. However, it has been reported that the effect of P-Zn interaction on grain quality of barley was not pronounced. Lian (1989) also found that crude protein of barley was markedly reduced by increasing of P application, and Zn content of grain increased 15-15.6 ppm by Zn applied. However, Zn application showed no effect on crude protein content of grain in barley.

Table 2.10 Effects of P and Zn application[a] on vegetative and reproductive growth of rice (Modified from Yang et al., 1986).

Soil[b]	yield of biomass & grain (g/plot)					grain/straw				
	CK	P5	P20	P30	P5+Zn	CK	P5	P20	P30	P5+Zn
1	18.0	39.2	42.8	42.8	40.8	0.54	0.73	0.61	0.49	0.77
2	21.8	41.9	422.1	43.0	44.2	0.49	0.70	0.55	0.48	0.74
4	33.1	53.0	55.5	57.5	54.0	0.39	0.80	0.75	0.59	0.79
5	20.3	36.4	40.4	40.8	41.1	0.50	0.78	0.83	0.78	0.77
6	54.8	69.9	74.4	75.4	73.5	0.62	0.76	0.80	0.65	0.78

[a] CK: without P and Zn application; P5, P20, P30: 37.5, 150, 225 kg P_2O_5 /ha application; and P5+Zn: 37.5 kg P_2O_5 /ha + 15 kg $ZnSO_4.7H_2O$ /ha application.

[b] For soil 1 2 3 4 5 and 6, the available Zn contents were 0.33, 0.46, 0.60, 0.85, 0.98, and 1.08 ppm; available P contents were 2.20, 3.76, 2.04, 7.85, 13.77, 5.40 ppm; and pH were 8.12, 7.99, 8.32, 8.19, 8.06, 7.92, respectively.