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Full Length Research Paper

Effects of soil properties and agronomic practices on wheat yield variability in Fengqiu County of North China Plain

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To produce sufficient food with limited arable lands has been a challenging issue. Thus, identification of the main factors influencing crop productivity has attracted the attention of many researchers. Fengqiu County of Henan Province, located in North China was chosen as study area; soil property and agronomic practice data of 111 sites were collected during the 2009 growing season. Measurement on soil parameters were made on top-soil (0 to 20 cm) and sub-surface soil (20 to 40 cm) of sampling sites, while agronomic practices data were obtained through survey using questioner. The relative importance of soil parameters and agronomic practices in influencing yield variability was analyzed with step-wise linear regression analysis and classification and regression tree (CART) model. The results showed that the level of soil nutrient content in the study area was relatively low. Soil electrical conductivity (EC) was the most important parameter in determining wheat yield variability. Agronomic practices had great impact on wheat yield. Among the variables of agronomic practices, nitrogen fertilizer rates was the most crucial for wheat production. In order to increase local wheat yields in region scale, some management practices, such as scientific irrigation, manure application for improving soil fertility, should be implemented. The recommended quantity of nitrogen fertilizer ranged between 1.34 and 2.60 q/ha with higher wheat yields.

Key words: Wheat yield, soil properties, agronomic practices, nitrogen fertilizer, classification and regression tree (CART).

INTRODUCTION

The world population is expected to increase from its current 6.7 billion to 8 billion by about 2020. Since the area of arable land is limited, how to produce more food with limited land resources has been the research focus of domestic and international scholars. China faces serious challenges, confronted with high population pressure and small landholdings; the intensification of land use has been the major strategy adopted by the Chinese government to secure food self-sufficiency. North China Plain (NCP) contributes about 30% of China's total agricultural production. Winter wheat–maize double cropping is an important rotation system in the North China Plain (Zhu et al., 1994) and contributes 76 and 33% of the total wheat and maize production in China, respectively (http://www.stats.gov.cn/tjsj/ndsj/2009/indexch.htm).

Factors affecting crop production were generally classified as internal or genetic factors and external or environmental factors, such as soil, water, management and climate factors (De Wit, 1992; Tittonell et al., 2008). Soil properties such as soil organic matter, electrical conductivity and cation exchange capacity etc, are commonly defined as the inherent capacity of a soil to supply plant nutrients in adequate amounts, forms, and in suitable proportions required for maximum plant growth (Zhen, 2006). Agronomic management practices such as fertilization, irrigation, pest control, variety improvement and other measures varied with social, economic and

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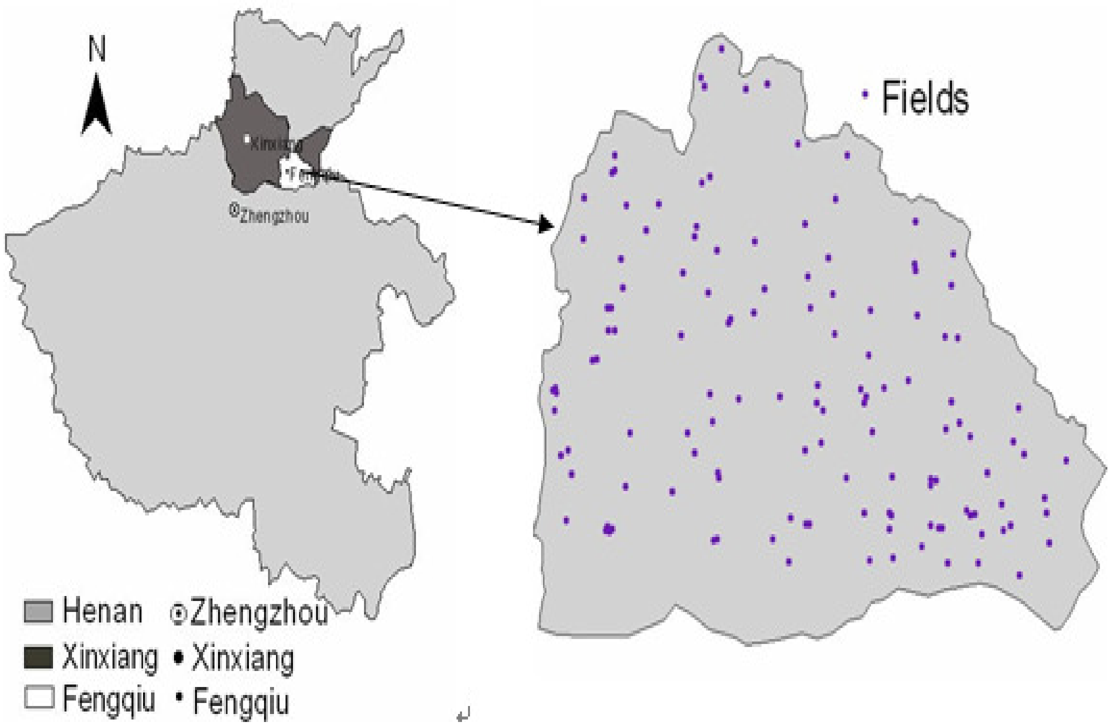


Figure 1. Location of study area and the distribution of sampling sites.

technical conditions. Some researchers suggested agronomic practice as a main reason for yield variation (Tittonell, 2008). Other studies (Wienhold et al., 1995; Norwood, 2000) underlined the essentiality of optimized management practices of irrigation and fertilization for the increase of crop yield. Sun et al. (2009) reported that the key point to achieve optimized practices was the high usage efficiency of water resource, fertilizers and soil nutrients. In North China Plain, large amounts of external mineral nitrogen fertilization has caused severe environmental problems and low N use efficiency since the 1990s (Liu and Diamond, 2008; Ju et al., 2009). However, yield growth rates of major crops have slowed down since 1995 (http://faostat.fao.org/default.aspx.). To achieve the goals of both higher crop yield and environmental protection in regional scale, it is important to explore main factors contributing to crop yields. In our study, all the variables of soil nutrients and agronomic practices during the 2009 growing season assumed to have a potential impact on wheat yield were measured in Fengqiu County, Henan Province located in the North China Plain.

The main objectives of this study were:

1) to compare the contribution of soil properties with that of agronomic practices to wheat yield variation;
2) to identify the most important variables for wheat yield variation; and
3) to propose effective measures for local farmers to increase wheat yield according to the results of 1) and 2).

METHODOLOGY

Study area

This study was conducted in Fengqiu County (Figure 1), Henan Province (35.18°N, 113.52°E). Fengqiu County is located in the North China Plain which thus has a semi-arid, semi-humid warm temperate monsoon climate with a mean annual precipitation of 615.1 mm and a mean annual temperature of 13.9°C. The dominant soil type is fluvo-aquic soil developed mainly from the Yellow River Sediments, as well as the saline, alkaline earth, wind sand and marsh land. Being one of the most fragile ecosystems of the North China Plain, crops in the studying area are vulnerable to frequent drought, flood, sandstorm and other natural disasters. Local climate permits two harvests of wheat or maize a year, with early crop planted in early October and late crop in June respectively.

Soil property analysis

Originally 133 sites were distributed across 111 villages or 19 towns of Fengqiu County. After removing 22 sites with incomplete data, 111 sampling sites were finally chosen for further analysis (Figure 1).

Top-soil (0 to 20 cm) and sub-surface soil (20 to 40 cm) samples were taken respectively by means of a manual coring tube from the selected sites. Basic properties of the top-soil and sub-surface soil samples were analyzed by the standard soil test methods (Lu, 1999). Soil pH was determined using a soil-to-water suspension of 1:2.5 ratio and soil electrical conductivity (EC) was measured using Mettler Toledo Delta-326 conductivity meter (Mettler Toledo, Shanghai, China). Soil total nitrogen (TN) was determined by the semi-micro Kjeldahl method, total phosphorus (TP) determined calorimetrically after wet digestion with H_2SO_4 plus $HClO_4$, and total potassium (TK) by atomic absorption spectrometer. Available

Table 1. Agronomic practice variables used in the CART analysis.

Variable	Unit	Description	Mean	Max	Min	S.D.
TERRAIN	None	Flat terrain (0=No, 1=Yes)	0.91	1	0	0.3
FYM	None	Farmyard manure (0=No, 1=Yes)	0.14	1	0	0.4
CROP	None	Crop planted last year (0=others, 1=corn)	0.94	1	0	0.2
STRAW	None	Straw returned to fields (0=No, 1=Yes)	0.95	1	0	0.2
DTPL	Days	Planting date (days after 1 October)	8.56	25	1	4.8
SEED	kg/ha	Seeding rate	223.78	337.5	120	43.6
N	kg/ha	Fertilizer N applied	257.59	556.8	67.5	86.4
P_2O_5	kg/ha	Fertilizer P_2O_5 applied	109.39	345	0	81.8
K_2O	kg/ha	Fertilizer K_2O applied	19.39	135	0	31.3
IRRIGATE	Times	Amount of irrigation	2.65	4	1	0.7
INSECTICIDE	Times	Amount of insecticide applications	1.05	3	0	0.6
HERBICIDE	Times	Amount of herbicide applications	0.78	3	0	0.5
IRRIGATEW	None	Irrigation water (0=river, 1= Well water)	0.91	1	0	0.3
LODGING	None	Lodging (0=No, 1=Yes)	0.05	1	0	0.2

phosphorus (AP) was extracted with 0.5 mol L^{-1} $NaHCO_3$ solution at pH 8.5 and available potassium (AK) was extracted with 1.0 mol L^{-1} CH_3COONH_4 solution. After filtering, the solution was measured by ICP-AES.

In late May, the plants were cut above the ground, separated into straw and grain, dried at 70°C to constant weight and got wheat yields for each sampling site.

Household interview

Data on agronomic practices were obtained through survey using questionnaire. Heads of households whose fields were chosen as sampling sites answered questions from the questionnaire and the information on agronomic practices is given in Table 1. The selected variables included TERRAIN (whether the terrain is flat or not), FYM (whether farmyard manure was applied to fields or not), CROP (crop rotations), STRAW (whether straw is return to fields or not), DTPL (planting date), SEED (seeding rate per hectare of field), N, P_2O_5, K_2O (total amount of fertilizer applied, which were calculated from their respective percentages as written on the fertilizer bags), IRRIGATE (amount of irrigation), INSECTICIDE (amount of insecticide applied), HERBICIDE (amount of herbicide applied), IRRIGATEW (source of irrigation water) and LODGING (whether crops are laid flat or not)applications.

Statistical analysis

Initial data of soil properties and agronomic practices were compared using descriptive statistics. Step-wise linear regression analysis and classification and regression tree (CART) analysis were performed using the software SYSTAT 13.

Summary and regression analysis

After summary statistics of soil property data, step-wise linear regression analysis in which soil properties are used as independent variables and the wheat yield as dependent variable was conducted to reveal the effects of soil properties on wheat yield, with the significance level of 5% (two sides).

Classification and regression tree (CART) analysis

In the SYSTAT 13 software, the TREES module computes classification and regression trees. Classification trees include models in which the dependent variable (the predicted variable) is categorical. Regression trees include those in which it is continuous. Within these types of trees, the TREES module can use categorical or continuous predictors, depending on whether a CATEGORY statement includes some or all of the predictors. For any of the models, a variety of loss functions is available. Each loss function is expressed in terms of a goodness-of-fit statistic - the proportion of reduction in error (PRE). For regression trees, this statistic is equivalent to the multiple R^2. It represents the proportion of the error in dependent that can be explained by the whole model, with each split contributing a part of the PRE. TREES module produces graphical trees called mobiles. At the end of each branch is a density display (box plot, dot plot, histogram, etc.) showing the distribution of observations at that point (SYSTAT 13 Statistics_I II_III_IV in the SYSTAT 13 Manuals. http://www.systat.com.).

In this study, CART analysis (Breiman et al., 1984; Reibneggeret al., 1991; De'ath et al., 2000) were used to clarify the relationships between wheat yield (dependent variable) and all kinds of soil and agronomic practice parameters (independent variables). Gini index was chosen for classification trees and the least squares method for regression trees as the loss function in the software running process. The stopping criteria allowed for stopping the programmer were set as 0.05 for the minimum proportion reduction in error and five for minimum counts at any nodes.

RESULTS AND DISCUSSION

Variability of soil properties and wheat yield

Soil properties

Results of soil properties of top soil and sub-surface soil (Table 2) indicated that EC for both the top soil and sub-surface soil showed the highest variability (56.9% for top soil and 51.8% for sub-surface soil, respectively), while

Table 2. Summary of soil properties in sampling sites.

0 - 20 cm	pH1	EC1 (μs/cm)	CEC1 (mmol/kg)	AP1 (mg/kg)	TN1 (g/kg)	AK1 (mg/kg)	TP1 (g/kg)	TK1 (g/kg)
Minimum	7.34	32.6	45.89	4.92	0.2	39.22	0.57	11.14
Maximum	8.76	362.2	246.41	26.66	1.212	315.46	1.91	22.11
Mean	8.316	85.587	103.083	8.083	0.572	73.23	1.377	16.023
S.D.	0.201	48.683	37.868	2.638	0.184	38.519	0.274	2.138
C.V.	0.024	0.569	0.367	0.326	0.322	0.526	0.199	0.133

20 - 40 cm	pH2	EC2 (μs/cm)	CEC2 (mmol/kg)	AP2 (mg/kg)	TN2 (g/kg)	AK2 (mg/kg)	TP2 (g/kg)	TK2 (g/kg)
Minimum	7.37	22.2	26.9	5.05	0.027	40.21	0.56	-2.05
Maximum	9.57	269	223.86	13.73	0.767	245.44	2.15	22.2
Mean	8.392	86.518	103.021	7.415	0.35	64.414	1.323	15.793
S.D.	0.271	44.808	43.181	1.689	0.166	28.941	0.285	2.602
C.V.	0.032	0.518	0.419	0.228	0.475	0.449	0.215	0.165

soil pH showed the lowest variability (2.4% for top soil and 3.2% for sub-surface soil, respectively).

The average content of TN was 572 mg/kg in the top soil (0 to 20 cm), which was much higher than that of 350 mg/kg in the sub-surface soil (20 to 40 cm). AP content and AK content were 8.08 and 73.23 mg/kg, respectively in the top soil, while in the sub-surface soil the values were 7.42 and 64.41 mg/kg, respectively.

Figure 2 showed the variability of soil nutrients in sampling sites. In spite of the diverse distribution of soil data sets, the mean value, standard deviation and coefficient of variation of soil properties in the top soil differed only slightly from those in the sub-surface soil. The content of TN, AK and AP for both of the two soil layers fell mainly in the range of 200 to 800 mg/kg, 50 to 90 mg/kg and 6 to 12 mg/kg, respectively. According to the national grading standards of soil nutrients (Table 3; Sun and Liu, 2009), the overall soil nutrient level in Fengqiu County are below the medium grade, with some properties even belonging to the lowest grade.

Wheat yield

The highest yield of sampling sites was 89.88 q/ha and the lowest 19.62 q/ha. Most of the sampling sites had a yield that ranged from 45.20 to 83.60 q/ha (Figure 3).

Effects of soil properties on wheat yield variability

Step-wise linear regression analysis

In the step-wise linear regression analysis, wheat yield was the dependent variable(y) while the top soil and sub-surface soil properties were used as independent variables, respectively. With the probability F for entry set between 0.05 and 0.1 only EC1 (EC for top soil) and EC2 (EC for sub-surface soil) were selected for regression parameters. For EC of the top soil the equation was

$$y = 6653.368 - 6.695EC1 \quad (R^2=0.052,\ P=0.016) \quad (1)$$

For EC of the sub-surface soil:

$$y = 6628.859 - 5.181EC2 \quad (R^2=0.026,\ P=0.088) \quad (2)$$

The coefficient of determination (R^2) of the two equations indicated that only 5.2 and 2.6% of the variability of wheat yield could be explained by soil EC in 0 to 20 cm and 20 to 40 cm soil layer, respectively.

Classification and regression tree (CART) analysis

The results of classification and regression tree models for wheat yield as a function of soil property variables in 0 to 20 cm and 20 to 40 cm soil layer were shown in Figure 4A and 4B, respectively. CART analysis indicated that 11.5 and 27.5% of the variability of wheat yield could be explained by soil EC, which confirmed the results of step-wise regression analysis that EC was the most important parameter in determining wheat yield variability. Zhao et al. (2009) claimed that soil EC, as a comprehensive index of soil physical and chemical properties, could serve as a guideline for soil productive potentiality, and thus be used as an important indicator to assess the variability of crop yield. The management practices should be adjusted according to soil EC so as to achieve precision agriculture. In order to attain a high wheat yield there would be a suitable range for the value of soil EC. If soil EC value drops to less than 114.2 μs/cm, it would have a positive effect on wheat yield (Figure 4A). But if the soil

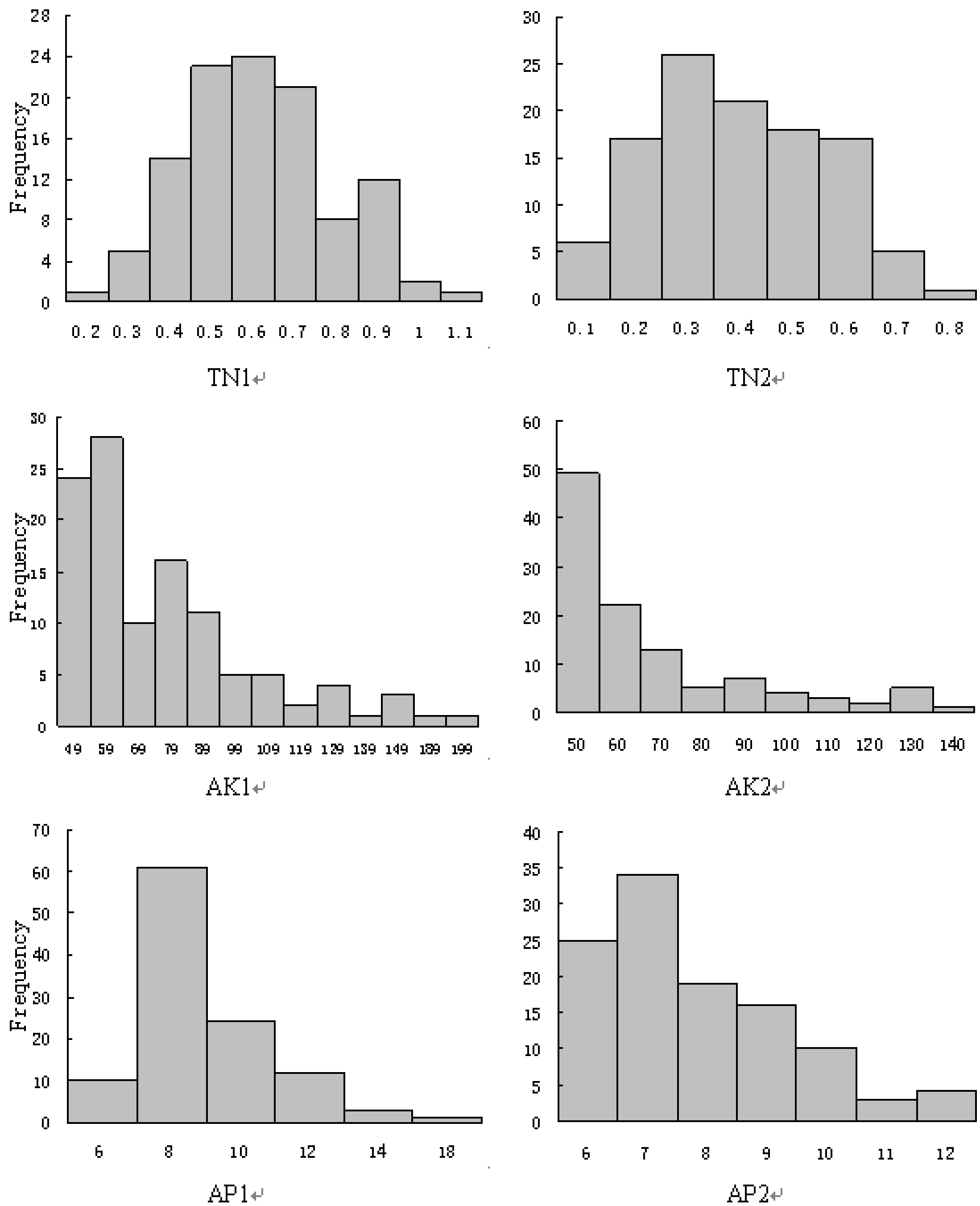


Figure 2. Variability of soil nutrients in all sampling sites.

EC value increases to more than 114.2 μs/cm, wheat yield would decrease the other way round.

Effects of agronomic practice on yield variability

Agronomic practices, such as irrigation, fertilization, weeding, pest management, variety improvement and so on, play an important role in crop yield (Lewis et al., 1997; Funk et al., 2007). Nitrogen is the main and most frequently yield-limiting nutrient for high yields of most field crops (Zhao et al., 2006; Fang et al., 2006). Through the regression tree analysis for wheat yield against all agronomic practice variables, we have identified that the amount of N application is the most important factor in determining wheat yield in the study region (Figure 5). The overall model roughly explained 19.4% of the variation in wheat yield was accounted to N fertilizer

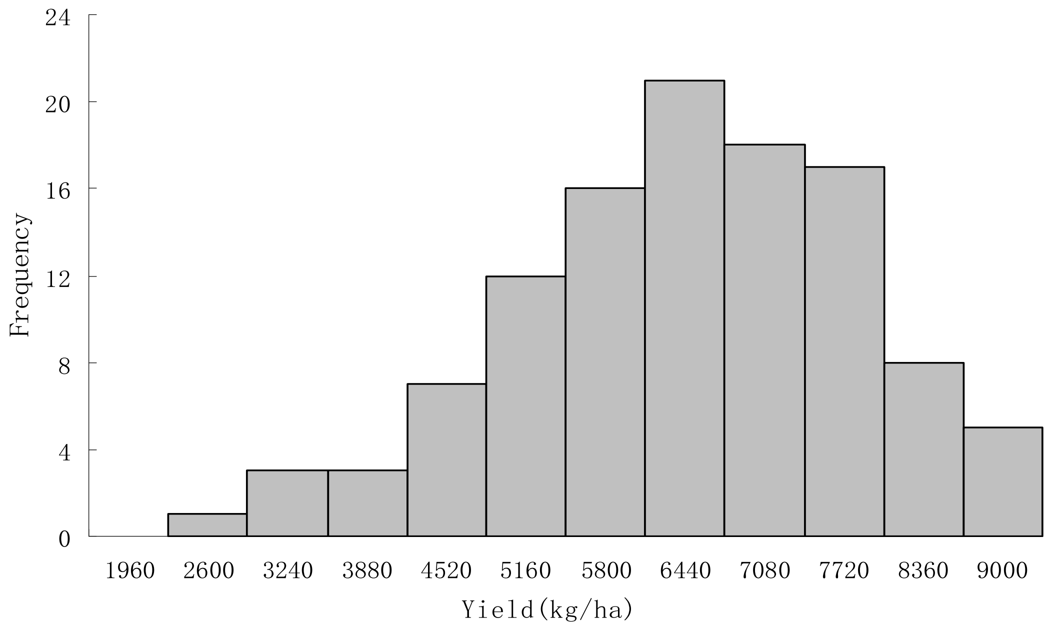


Figure 3. Histogram of wheat yield in all sampling sites.

application rate according to regression tree (Figure 5). In general, N deficient crops generally have much less tillers or no tillers at all. At the end of the growth period most of these crops matured early, leading to the reduction of yield. However, with over-application of N fertilizer crops grow excessive stems, which tampers crops' resistance to drought, cold and disease and causes yield reduction as well (Arnall et al., 2009). Nitrogen fertilizer applied in excess of crop requirements can also result in lower N recovery rates by crops and dramatic increases in non-point source pollution from agriculture (Ju et al., 2004; Zhou et al., 2008). Nitrogen fertilizer rates are determined by the crop to be grown, yield goal, and quantity of nitrogen that might be provided by the soil. Numerous field plot experiments revealed that the application of about 1.28 to 2.45 q/ha nitrogen could achieve high wheat yields without significant environmental risk (Ju et al., 2009; Chen et al., 2006; Zhao et al., 2006). In this study we found that the most suitable range of nitrogen fertilizer rates in Fengqiu County was 1.34 to 2.60 q/ha with higher wheat yields, which was surprisingly similar to the results of field plot experiments. N fertilizer rates of 54 samples sites fell in this range with the average wheat yield of 65.37 q/ha, which is much higher than the average yields (60.81 q/ha) of total 111 sites.

Effects of soil properties and agronomic practice variables on yield variability

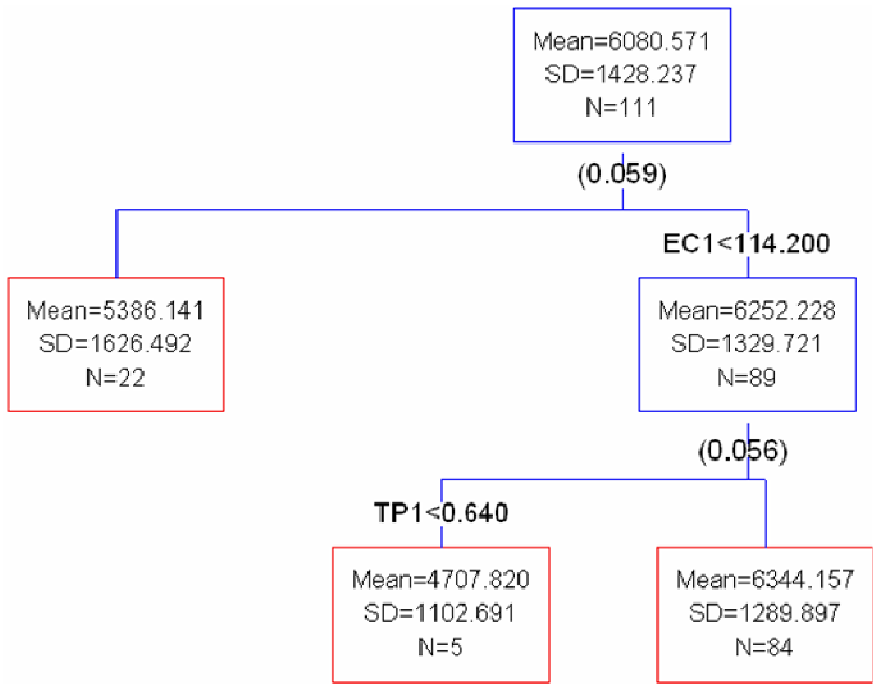
To further explore the importance of all variables on the variability of wheat yield, we combined soil properties and agronomic practice variables altogether to develop the regression tree, which identified four main parameters explaining nearly 25.1% of wheat yield variability (Figure 6). The right splits are the same as the right splits in the regression tree structure with only soil properties of 0 to 20 cm (Figure 4A). The left splits are all agronomic practice variables, and the result indicates that local wheat yield could increase if more phosphorus and less nitrogen fertilizer were applied. Agronomic practice exerted greater impact on wheat yield variability than soil properties did.

According to the result of summary statistics of soil nutrients, the overall level of soil nutrients in Fengqiu County is low. In order to increase local wheat yield, it is necessary to improve agronomic practice measures, especially to adjust the application ratio of different fertilizers accordingly. However, through our household interview farmers were found to be unwise in choosing suitable types of fertilizer for their fields due to their ignorance of fertilizer ratio labeled on the fertilizer bags (Zheng et al., 2009). So it is essential for farmers to understand the knowledge of fertilizer ratio so as to make the right fertilizer application decision.

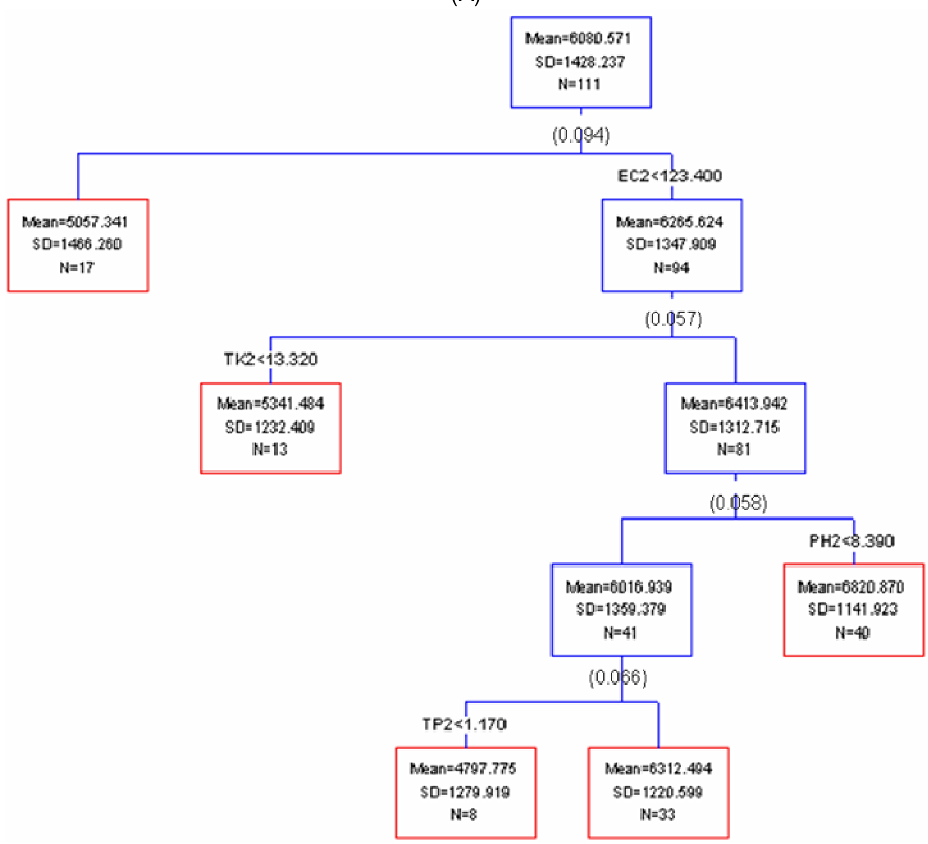
Our study was constrained to only one year's data, which might be inadequate to probe all the dimensions about factors influencing local wheat yield. Further analysis on wheat yield variability and its determining parameters could be conducted after the accumulation of perennial data.

Conclusions

Analysis of soil properties showed that the overall level of



(A)



(B)

Figure 4. Regression tree analysis of relationships between wheat yield (Dependent variable) and soil parameters (Independent variables). Each node (rectangle) is labeled with average yield (mean), standard deviation (S.D.) and the number of fields in that group (n). Single-factor PRE values are displayed in parentheses at each root node to split. (A) Soil properties in 0 to 20 cm soil layer (PRE = 0.115). (B) Soil properties in 20 to 40 cm soil layer (PRE = 0.275).

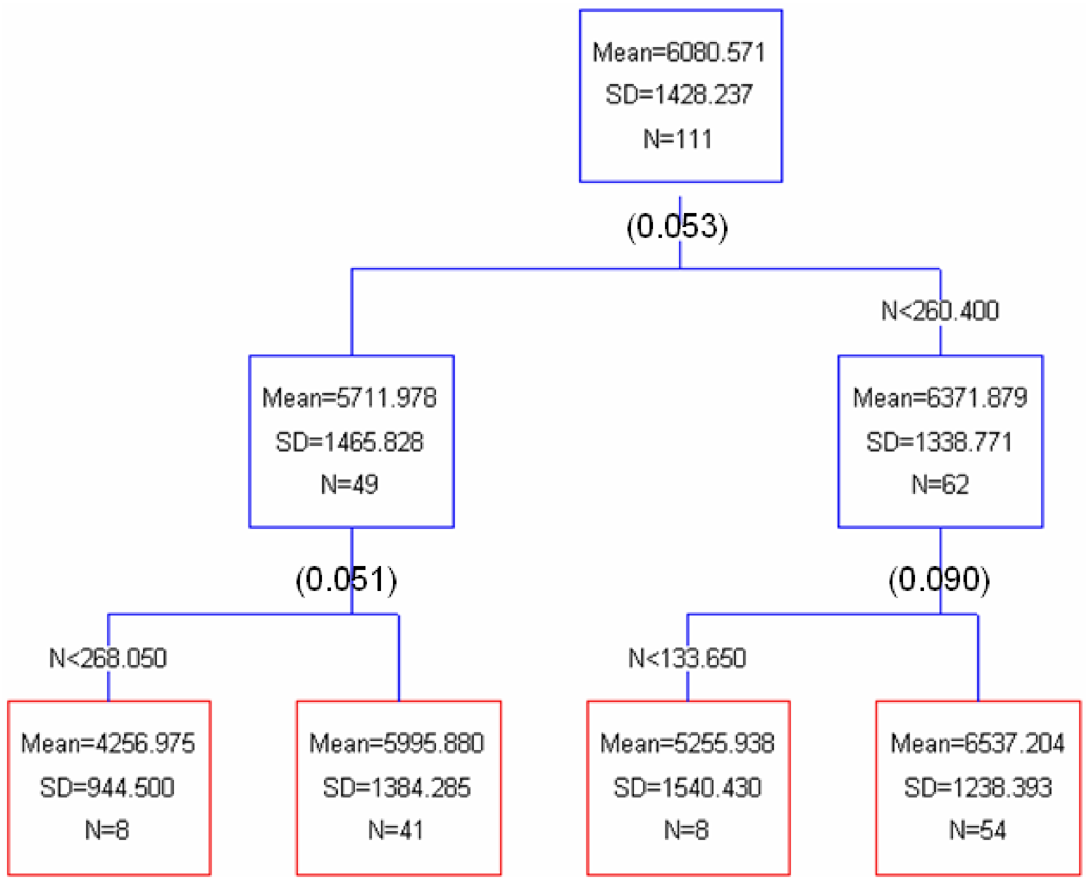


Figure 5. Regression tree analyses of relationships between wheat yield (Dependent variable) and agronomic practice variables (Independent variables) (PRE=0.194).

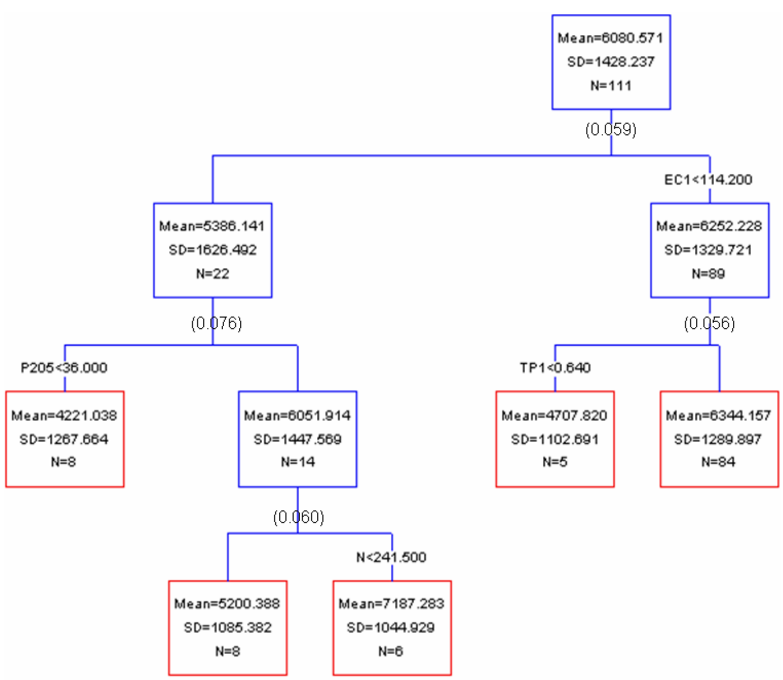


Figure 6. Regression tree analyses of relationships between wheat yield (Dependent variable) and soil parameters plus agronomic practice variables (Independent variables) (PRE=0.251).

soil nutrients in Fengqiu County is relatively low. Among them, soil EC was the most important parameter in determining wheat yield variability. Agronomic practices had great impact on wheat yield; among the variables of agronomic practices, nitrogen fertilizer rates was the most crucial for wheat production, which was 1.34 to 2.60 q/ha with higher wheat yields. In order to attain a high wheat yield in the region scale, some management practices, such as scientific irrigation, manure application for improving soil fertility should be implemented.

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