Variable Rate Fertilization for Maize and its Effects Based on the Site-specific Soil Fertility and Yield

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ABSTRACT

The experiments of variable rate fertilization (VRF) for maize were carried out by using a VRF system that was designed and manufactured by us. In the studies, prescriptions of VRT were made for maize according to the nutrient levels in soil and the theory of yield goal. The results of this study have shown that VRF increased maize yield by 11% more in 2004 than that of conventional method of fertilization and 33% in 2005, and the application rate was saved by 32% in 2004 and 29% in 2005. In addition to higher yields, VRF also increased the cost-benefit ratio under the condition of reasonable rate of fertilizer application.

Keywords: Variable rate fertilization, soil fertility, yield goal, precision agriculture, USA

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1. INTRODUCTION

Variable rate fertilization (VRF) has a positive effect on the agricultural development and environmental- friendly application of fertilizer. Variable rate fertilization (VRF) is an important part of variable rate technology (VRT) in precision agriculture. VRT is based on the crop productivity differences across a field and varying the inputs to a specific area of a field based on the nutrition or fertility in the soil. The aim of VRT is to maximize the return in each part of a field by adjusting the rate of applying fertilizer to optimize productivity.

VRT has been investigated by many researchers and agricultural experts. During the 1997 and 1998 growing seasons, Yang et al. (2001) studied variable rates by applying nitrogenous (N) and phosphorus (P) fertilizer for grain sorghum. These results showed that VRT increased yield, reduce yield variability, and raised economic returns. At Kyoto University in 2000 (Mikio, 2001), VRT was effective in reducing the input of N fertilizer; however, the causes and effects were complex. Wittry et al. (2004) compared variable rate and uniform-rate (UR) by applying P fertilization for maize-soybean rotations .The fertilization method did not influence crop responses to P fertilizer. However, VRF resulted in better P fertilizer management because it applied 12 to 41% less fertilizer and reduced soil-test P variability compared with the conventional injection fertilization method. Koch (2004) assessed the economic feasibility of variable rate nitrogen application and found that variable-rate N application utilizing site-specific management zones were more economically feasible than conventional uniform N application. Huang et. al. (2008) developed a multi-spectral imaging system for use on agricultural aircraft to provide images of fields and help farmers and crop consultants manage agricultural lands. The results of this research indicate that the airborne MS4100 multi-spectral imaging system has a great potential for use in areawide pest management systems, such as weed control or detection of insect damage. Multi-spectral image processing produces NIR, red, green, NR, NG, NDVI and NDNG indices or images, which can be used to evaluate biomass, crop health, biotypes, and pest infestations in agricultural fields. The classified images identify the ground land cover clusters by differentiating the variation of spectral signatures in the image. The results of the image classification can provide critical input to generate prescription data for precision application of crop production and protection materials.

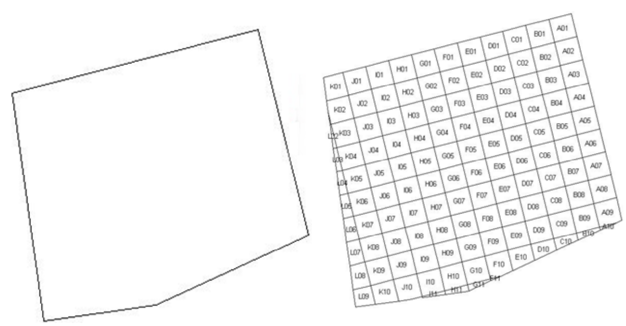
Xue et. al. (2004) studied the results of variable-rate nitrogen application for winter wheat in China. Compared to uniform nitrogen application, variable-rate nitrogen application caused slightly lower yield and higher coefficient of variance (CV) of yield. Wheat head density in variable-rate zone was approximately equal to that in the uniform fertilization zone, but its CV was lower. The number of grains per ear in the variable rate zone was less than that in the uniform fertilization zone, but its CV was higher. Both grain weight and its' CV in the variable rate zone were higher than those in the uniform fertilization zone. Grain protein concentration in the variable rate zone was slightly higher than that in the uniform fertilization zone, while its variability was also higher. Profitability of fertilization in the variable rate zone was smaller than those in the uniform zone. However, Potassium concentration in the variable rate zone after the wheat season was much lower than that in the uniform fertilization zone, and the risk of ground water pollution by soil K is reduced apparently.

The objective of this study was to investigate the impact on maize yield of variable rate fertilizer (VRF) applications of soil nutrients as compared to conventional applications, which apply uniform amounts of soil nutrients across the entire field. During 2004 and 2005, the field experiments of VRF for maize were carried out using the VRF system made by Jilin University.

2. MATERIALS AND METHODS

2.1 Experimental Field

The experimental field was located at GongPeng town (125°30′E, 44°96′N, 246m above sea level), Jilin province, P.R. China. The total area of the farm was 18 hm^2 with an annual average temperature of 4□ and annual precipitation of 591mm. The field was divided into 120 plots with sizes of 1600 m^2 (40 m X 40 m).The soil was classified as black soil and soil texture was recorded as loamy soil with 30.8 mg/kg of average contents of organic matter. The experimental field boundary map and grid map are shown in Figure 1.



a. Boundary Map b. Grid Map

Figure1. The field maps

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2.2 Instruments

2.2.1 Global Positioning System (GPS)

It is necessary to know the actual location of a fertilizer applicator as it moves through a field. The global positioning system (GPS) meets the positioning needs of VRF. Two AgGPS132 receivers were used for real-time differential positioning during the process of VRF in-fields. Here, AgGPS132 receivers can receive signals from the American satellites. Twelve satellites can be locked simultaneously. Observed signals are the coarse acquisition code (C/A) of pseudo-range. While operating in DGPS mode, the GPS's positioning error was less than one meter.

2.2.2 Geographical Information System (GIS)

GIS is a key part of the VRT system. With GIS, the databases of soil parameters, such as contents of N, P, K, organism and moisture contents of soil, were set up. MapInfo Professional 6.0, a tabletop geographical information system, was used to generate electronic maps of the fields. Information about soil type, soil quality, soil fertility, application rate, and the crop yields over the past several years was turned into application map layers using GIS. Then, the growing condition of crops was analyzed. The decision-making data for VRF was made according to the goal of soil nutrient content balance, and the data was written into the memory unit of the fertilizer applicator.

2.2.3 Control Unit

A one-chip computer was created and used as the control center on the board. After receiving the positional signals from the GPS receivers, the control unit applied the desired fertilizer rate based on decision-making data stored in the memory. At the same time, ground speed signals were read and pulses were output to control the rotational speed of the distribution shaft on the fertilizer applicator.

2.2.4 Seeder and Fertilizer Applicator

The tractor-driven seeder and fertilizer applicator developed by Jilin University is hitch-mounted and plants and fertilizes 6 rows at a time. The application rate of fertilizer can be adjusted by changing the rotational speed of the distribution shaft. The maize was planted and, at the same time, the fertilizer was applied into soil 15cm deep and 7cm away from the crop.

2.3 Method of decision-making

According to the theory of soil nutrient balance and the soil nutrient levels in every plot, the amount of input fertilizer (y) was calculated using the following formula:

$$y = \frac{x \times \theta - \tau \times 2.25 \times \xi}{\varphi \times \varepsilon} \qquad (1)$$

Where,

y——Amount of fertilizer required (kg/hm^2)

x——Yield goal (kg/hm^2)

θ——Amount of nutrient actually needed by every kilogram maize seeds

τ——Amount of nutrient measured in the soil (mg/kg)

ξ——Utilizing rate of soil nutrients

φ——Amount of nutrient in the fertilizer

ε——Efficiency of nutrient absorbed by the maize plant

Where, 2.25 is a conversion coefficient when value of measuring soil nutrient is expressed by using unit of kg/hm^2.

There are three important parameters: yield goal (x), the utilizing rate of soil nutrients (ξ) and the utilizing rate of the fertilizer (ε). These parameters are tightly correlated to soil type and fertility level, crop, amount of fertilizer input, fertilizer quality, climate, region, gradient, stability of soil, fertilizing method including fertilizing time, place, and dosage.

2.4 Experiments of VRF

Based on the results of VRF decision-making, the field experiment of VRF for maize was carried out using the VRT applicator integrated with GPS and GIS respectively on April 20th-21st, 2004 and on April 28th-29th, 2005.

The VRT is implemented in several steps. A field boundary map was obtained by using DGPS receivers and the data was processed and input into the GIS system. The field was divided into many small plots which are named operation units or grids. The soil nutrients and past yield information database was constructed in GIS. The decision-making data, provided by the Expert System, was then transmitted into the control unit. When the VRF applicator works in the fields, data involving position and velocity of the applicator are received by the GPS receiver fixed on the tractor; and the positioning signals are read and used as a trigger signal to adjust the rotational velocity of the applicator shaft.

2.5 Samples and Measure Methods

Georeferenced soil samples were analyzed for nutrient content before maize planting. In every operational unit of the field, soil samples were gathered as composites of five sub-samples from topsoil 0 to 20 cm deep, at a 3m radius from every plot center. These soil samples were sent to the lab for testing. In the lab, the quantities contained of available N, P and K were measured by standard wet chemistry methods (Rukun, 1999). The content of available N was measured by 1mol/L NaOH hydrolyzation diffusion method, the content of available P was measured by Olsen, and that of available K by 1mol/L NH_4OAc extraction flame photometric analysis.

Maize yields (y) in each operational unit were calculated using Equation 2. The weight of the harvested maize in each plot was measured by using a digital balance, and the moisture content in each plot was sampled by using the instrument of grain moisture content with 3 repetitions.

$$y = \frac{500 \times [m \times w(1 - \frac{t}{100})]}{m_1(1 - \frac{t_0}{100})} \quad (2)$$

Where, $$t = \{1 - \frac{m_2 \times (1 - \frac{t_1}{100})}{w_1}\} \times 100 \quad (3)$$

y——maize yield (kg/hm^2),

m ——Maize weight of 20 square meters (kg)

w ——Maize seeds weight of 5 ears (kg)

t ——Moisture of harvested maize (%)

m1——Maize weight of 5 ears (kg)

t0——Standard moisture 18% (%)

m2——Maize weight of 5 ears after drying (kg)

t1——Moisture of maize after drying (%)

w1——Maize seeds weight of 5 ears after drying (kg)

3. RESULTS AND DISCUSSION

3.1 Decision-making for VRF

Data from the VRF for the experimental field in 2004 and 2005 are shown in Figure 2. Yield goal was selected as 9735Kg/ hm^2, based on the contents of soil nutrients measured by standard wet chemistry methods. The fertilizer used in the experiment field was mixed fertilizer containing 15% of N, 15% of P, and 15% of K.

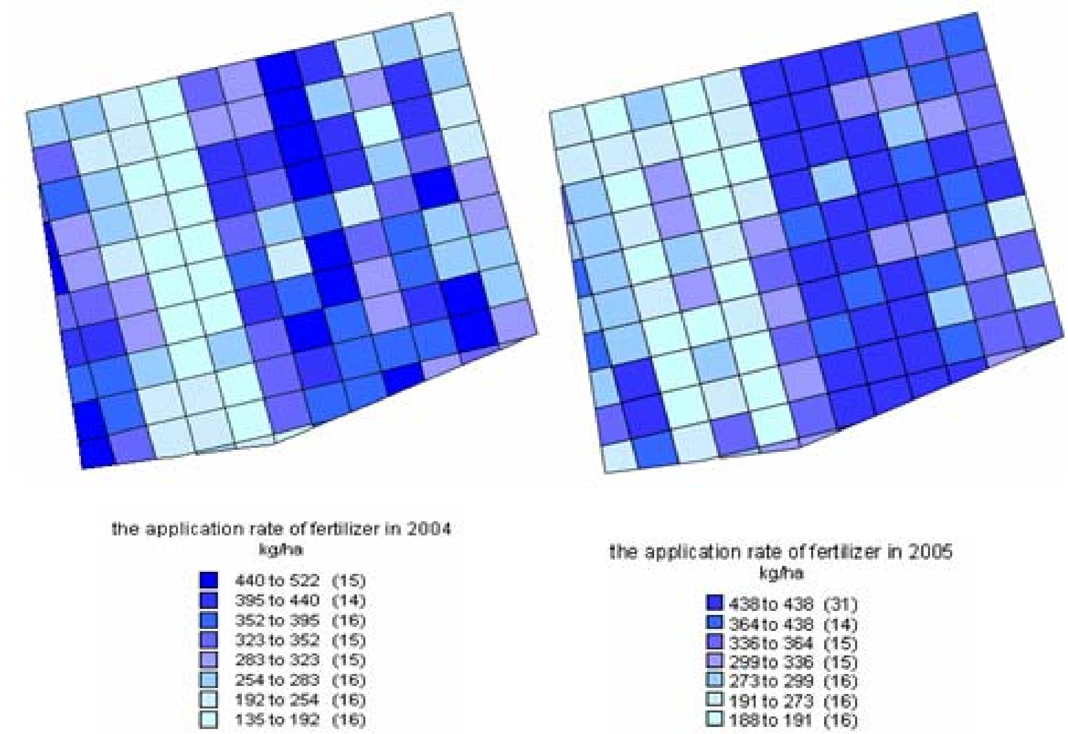

Figure 2.The application rate map of fertilizer in 2004 and 2005

3.2 Yield and Profitability Analysis

Spatial distributions of the yield in each plot in 2004 and 2005 are shown as in Figure 3. The profitability of VRF was analyzed (shown in table 1 and 2) according to the prices of selling fertilizer and purchasing maize in 2004 and 2005 in Jilin Province. Data in the tables is the average value of costs for fertilizer and yields in related plots, and the income is the earning by selling maize based on the native purchasing price(￥0.9/kg in 2004, ￥1.0/kg in 2005). The cost of basal fertilizer was only countered supposing that all other inputs are the same as those of the conventional method of fertilization. Ratio of output and input is the ratio between the income of selling maize and the cost of applying basal fertilizer.

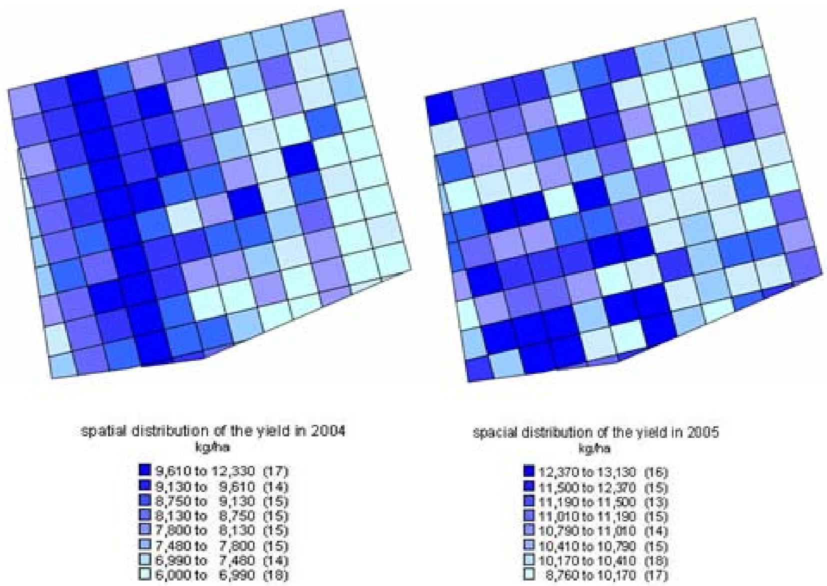

Figure3 Spatial distribution of the yield in 2004 and 2005

Table 1. The analysis of profitability in 2004

Method	Quantity of Applying Fertilizer /kg·(hm^2)$^{-1}$	Cost of Fertilizer /￥·(hm^2)$^{-1}$	Yield /kg·(hm^2)$^{-1}$	Income /￥·(hm^2)$^{-1}$	Ratio of Output and Input/%
VRF	238.5	400.7	9162.32	8246.1	20.60
Conventional method	350	588	8253.6	7428.2	12.63
Increment	-111.5	-187.3	908.7	817.9	7.97

In the VFR application plots in 2004, quantity of applied fertilizer was decreased on average by 111.5kg/ hm^2 resulting in a reduction in fertilizer cost of ￥187.3/ hm^2. The average yield was increased by 908.7kg/ hm^2 resulting in an increase in income of ￥817.9/ hm^2. Considering both decreasing quantity of applying fertilizer and increasing yield, the income is raised by ￥1005/ hm^2 by means of VRF.

Table 2. The analysis of profitability in 2005

Method	Quantity of Applying Fertilizer /kg·(hm^2)$^{-1}$	Cost in Fertilizer /￥·(hm^2)$^{-1}$	Yield /kg·(hm^2)$^{-1}$	Income /￥·(hm^2)$^{-1}$	Ratio of Output and Input/%
VRF	351.8	773.96	10490.8	10490.8	13.55
Conventional method	497.0	1093.4	7880.0	7880.0	7.21
Increment	-145.2	-319.44	2610.8	2610.8	6.35

In the VRF application plots in 2005, quantity of applying fertilizer is decreased on average by 145.2kg/ hm^2 reducing the cost of fertilizer by ￥319.44/ hm^2. The yield increased by 2610.8kg/ hm^2 in the VRF plots resulting in an increase in income of ￥2610.8/ hm^2. Considering decreasing the quantity of applying fertilizer and increasing yield simultaneously, the income is increased by ￥2930/ hm^2 with VRF. Therefore, VRF can improve fertilizer input efficiency so as to reduce cost in fertilizer and increase the yield for maize producers.

Descriptive statistics indicate that the maize yield in the plots with different rates of basal fertilizer application varied between 6005.8 and 12328.2 kg/ hm^2, with an average value of 8253.6 kg/hm^2 and a CV of 5.92 % in 2004; and 8759.5 to 13121 kg/hm^2, with an average value of 10490.8 kg/hm^2 and a CV of 5.50 % in 2005.

4. CONCLUSIONS

The studies on VRF for maize were carried out in an experimental field of about 36hm^2 during 2004 and 2005. The results of yield analysis show that VRF increased maize yield by 11% more in 2004 than that of conventional method and 33% more in 2005. Furthermore, the amount of applied fertilizer was reduced by 32% in 2004 and 29% in 2005. These results enhance the feasibility of using VRF in maize cultivation for maintaining high yields with minimum variability.

Crop yield is correlated to many factors. With further application of VRF, more abundant and robust data will be accumulated. The characteristics of VRF in precision agriculture determine that the effects are not easily shown in the short term. Therefore, further research needs to be done in order to evaluate the long-term profitability of and the ecological benefits of VRF.

5. REFERENCES

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