ECONOMIC EVALUATION OF N-P-K APPLICATION FOR POTATO PRODUCTION IN GUIZHOU

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Crop Science

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การประเมินผลทางเศรษฐศาสตร์ของการใช้ปุ๋ย N-P-K สำหรับการผลิตมันฝรั่งในมณฑลกุ้ยโจว

นางลี หลิว

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาปรัชญาดุษฎีบัณฑิต
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EECONOMIC EVALUATION OF N-P-K APPLICATION FOR POTATO PRODUCTION IN GUIZHOU

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ลี หลิว : การประเมินผลทางเศรษฐศาสตร์ของการใช้ปุ๋ย N-P-K สำหรับการผลิตมันฝรั่งในมณฑลกุ้ยโจว (ECONOMIC EVALUATION OF N-P-K APPLICATION FOR POTATO PRODUCTION IN GUIZHOU) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร. สุดชล วุ้นประเสริฐ, 119 หน้า.

วัตถุประสงค์ของงานวิจัยนี้คือการประเมินผลทางเศรษฐศาสตร์ของการใช้ปุ๋ย N-P-K ในการผลิตมันฝรั่ง โดยมี 4 การทดลอง ดำเนินการในดินที่มีความอุดมสมบูรณ์ของดินสูงและต่ำ ในมณฑลกุ้ยโจว ประเทศสาธารณะรัฐประชาชนจีน การทดลองที่ 1 การประเมินผลทางเศรษฐศาสตร์ของการจัดการ N สำหรับการผลิตมันฝรั่ง ผลการวิจัยพบว่าการจัดการ N ที่เหมาะสมเป็นปัจจัยที่สำคัญที่สุดประการหนึ่งที่ทำให้ได้ผลผลิตและคุณภาพของมันฝรั่งที่ดี การใส่ปุ๋ย N เพิ่มขึ้นทำให้ผลผลิตของมันฝรั่งเพิ่มมากขึ้นในระยะแรก แต่เมื่อให้ปุ๋ย N เพิ่มขึ้นต่อไปผลผลิตและน้ำหนักแห้งลดลง การเพิ่มขึ้นของอัตราปุ๋ย N ส่งผลให้ปริมาณแป้งของหัวมันฝรั่งลดลง แต่ปริมาณโปรตีนที่ละลายได้ และปริมาณน้ำตาลรีดิวซ์เพิ่มขึ้น ในพื้นที่นี้การให้ปุ๋ย N ที่เหมาะสมสำหรับดินที่มีความอุดมสมบูรณ์สูงคือ 193 กก.N/เฮกตาร์ และ 302 กก.N/เฮกตาร์ ในดินที่มีความอุดมสมบูรณ์ต่ำ

การทดลองที่ 2 การประเมินผลทางเศรษฐศาสตร์ของการจัดการปุ๋ย P สำหรับการผลิตมันฝรั่ง ผลการทดลองพบว่าการใส่ปุ๋ย P เพิ่มขึ้นส่งผลให้ผลผลิต ปริมาณแป้ง โปรตีนที่ละลายได้ และน้ำหนักแห้งของมันฝรั่งเพิ่มขึ้นในระยะแรก แต่เมื่ออัตราปุ๋ย P ยังคงเพิ่มขึ้นต่อไปทำให้ผลผลิต ปริมาณแป้ง โปรตีนที่ละลายได้ และน้ำหนักแห้ง ของมันฝรั่งลดลง และอัตรา P ที่เพิ่มขึ้นส่งผลให้ปริมาณน้ำตาลรีดิวซ์ของหัวมันฝรั่งลดลง อัตราการใส่ปุ๋ย P ที่เหมาะสมในดินที่มีความอุดมสมบูรณ์สูงคือ 151 กก.P_2O_5/เฮกตาร์ และ 192 กก. P_2O_5/เฮกตาร์ ในดินที่มีความอุดมสมบูรณ์ต่ำ

การทดลองที่ 3 การประเมินผลทางเศรษฐศาสตร์ของการจัดการปุ๋ย K สำหรับการผลิตมันฝรั่ง ผลการทดลองพบว่าการใส่ปุ๋ย K เพิ่มขึ้นทำให้ผลผลิต ปริมาณแป้ง โปรตีนที่ละลายได้ และน้ำหนักแห้ง ของหัวมันฝรั่งเพิ่มขึ้นในระยะแรก แต่ถ้าอัตราปุ๋ย K ยังคงสูงขึ้นต่อไปทำให้ผลผลิต ปริมาณแป้ง โปรตีนที่ละลายได้ และน้ำหนักแห้งลดลง ปริมาณ K ที่เพิ่มขึ้นส่งผลให้ปริมาณน้ำตาลรีดิวซ์ของหัวมันฝรั่งลดลง การใส่ปุ๋ย K ที่เหมาะสมในดินที่มีความอุดมสมบูรณ์สูงคือ 210 กก.K_2O/เฮกตาร์ และ 341 กก.K_2O/เฮกตาร์ ในดินที่มีความอุดมสมบูรณ์ต่ำ

การทดลองที่ 4 ผลของการใช้ปุ๋ย N P K ร่วมกันในการผลิตมันฝรั่ง จากการวิเคราะห์รีเกรซชันของ quadratic model พบว่าอัตราปุ๋ยที่เหมาะสมในดินที่มีความอุดมสมบูรณ์สูงคือ 228 กก.N/เฮกตาร์ 180 กก.P_2O_5/เฮกตาร์ และ 152 กก.K_2O/เฮกตาร์ ส่วนในดินที่มีความอุดมสมบูรณ์ต่ำคือ 253 กก.N/เฮกตาร์ 156 กก.P_2O_5/เฮกตาร์ 232 กก.K_2O/เฮกตาร์

จากผลการทดลองทั้ง 4 สรุปได้ว่าอัตราปุ๋ย N P และ K ที่แนะนำสำหรับดินที่มีความอุดมสมบูรณ์สูง คือ 193-228 กก.N/เฮกตาร์ 151-180 กก.P_2O_5/เฮกตาร์ 152-210 กก.K_2O/เฮกตาร์ ตามลำดับ ส่วนดินที่มีความอุดมสมบูรณ์ของต่ำไม่เหมาะสมสำหรับการปลูกมันฝรั่งภายใต้สภาวะปัจจุบันของดิน หากปลูกมันฝรั่งในดินที่มีความอุดมสมบูรณ์ต่ำควรมีการปรับปรุงความอุดมสมบูรณ์ของดินและโครงสร้างของดินโดยการใช้ปุ๋ยอินทรีย์และสารปรับปรุงดิน

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LI LIU : ECONOMIC EVALUATION OF N-P-K APPLICATION FOR POTATO PRODUCTION IN GUIZHOU. THESIS ADVISOR : ASST. PROF. SODCHOL WONPRASAID, Ph.D., 119 PP.

POTATO/N-P-K FERTILIZER/ECONOMIC EVALUATION/YIELD/QUALITY

The overall objective of this research was to evaluate the economics of N-P-K application for potato production in Guizhou. Four experiments were conducted in high and low soil fertility fields in Guizhou, China. The first experiment was the economic evaluation of N fertilizer management. Results showed that proper N management was one of the most important factors required to obtain high yield of excellent quality potatoes. Increasing N fertilizer resulted in increments of potato yield and dry matter, then as N rate continued to increase, the yield and dry matter decreased. Increased N rates resulted in reduced starch content. Increased N rates resulted in increased soluble protein and the reducing sugar content of potato tubers. In this area, the optimum N fertilizer application was 193 kg/ha in the high soil fertility field and 302 kg/ha in the low soil fertility field.

The second experiment was the economic evaluation of P fertilizer management. Results showed that increasing P fertilizer resulted in increments of potato yield, starch, soluble protein, and dry matter, then as the P rate continued to increase, the yield, starch, soluble protein, and dry matter decreased. Increased P rates resulted in the reduction of the reducing sugar content of potato tubers. The optimum P fertilizer application was 151 kg/ha in the high soil fertility field and 192 kg/ha in the low soil fertility field.

The third experiment was the economic evaluation of K fertilizer management. Results showed that increasing K fertilizer resulted in increments of potato yield, starch, soluble protein, and dry matter, then as the K rate continued to increase, the yield, starch, soluble protein, and dry matter decreased. Increased K rates resulted in the reduction of the reducing sugar content of potato tubers. The optimum K fertilizer application was 210 kg/ha in the high soil fertility field and 341 kg/ha in the low soil fertility field.

The fourth experiment was the effects of N, P, K combined application on potato production. From the regression analysis of the quadratic model, the results showed that: the optimum N P K rates were N 228 kg/ha, P 180 kg/ha, K 152 kg/ha in the high soil fertility field and N 253 kg/ha, P 156 kg/ha, K 232 kg/ha in the low soil fertility field.

From the results of all four experiments, the recommended amount of N-P-K fertilizer rates were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha in high soil fertility fields. For the low soil fertility field, from the overall results, the low soil fertility field was not suitable for planting potatoes under current soil conditions. In order to grow potatoes in low soil fertility fields, it should improve the soil fertility and soil structure by using organic fertilizers and soil amendments.

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LIST OF ABBREVIATIONS

AAS	=	Atomic Absorption Spectrophotometer
AAT	=	Active accumulate temperature
ATP	=	Adenosine Triphosphate
B	=	Boron
BCR	=	Benefit cost ratio in potato production
BD	=	Bulk density
C	=	Carbon
CEC	=	Cation exchange capacity
Ca	=	Carbon
Cost N	=	Cost of nitrogen fertilizer
Cost P	=	Cost of phosphorus fertilizer
Cost K	=	Cost of potassium fertilizer
Cu	=	Copper
Db	=	Double
FAO	=	Food and Agriculture Organization
FC	=	Iron
Fe	=	Electric conductivity
H	=	Hydrogen

LIST OF ABBREVIATIONS (Continued)

HF	=	High fertility
K	=	Potassium
LAI	=	Leaf area index
LF	=	Low fertility
Mg	=	Manganese
Mo	=	Molybdenum
MNP	=	Maximum net profit
N	=	Nitrogen
O	=	Oxygen
OM	=	Organic matter
OYP	=	Optimum yield price
P	=	Phosphorus
RCBD	=	Randomized complete block design
S	=	Sulphur
SPSS	=	Statistical Package for the Social Science
SS	=	Spring single
Sg	=	Single
SW	=	South west
T	=	Temperature

LIST OF ABBREVIATIONS (Continued)

TCP	=	Total cost of production
Total C	=	Total cost
T JAN	=	Temperature in January
T JUL	=	Temperature in July
TRT	=	Moisture content
Zn	=	Zinc

CHAPTER I

INTRODUCTION

1.1 Background of this study

Potato (*Solanum tuberosum*) is a plant belongs to Solanaceae family (also known as the nightshade) (Jackson, 1999; Huang et al., 2001). Recent publications have shown that potato is the fourth important crop in the world after rice, wheat, and corn (Liu et al., 2014; Zhang, 2015; Zhang et al., 2017; Lei, 2006).

Once harvested, potatoes are used for a variety of purposes. FAO estimates that just over two-thirds of the 320 million tons of potatoes produced in 2005 were consumed by people as food, fresh potatoes are baked, boiled or fried and used in a staggering range of recipes, such as mashed potatoes, potato pancakes, potato dumplings, potato soup, and potato salad (FAO, 2005). However the global consumption of potato as food is shifting from fresh potatoes to added-value processed food products. One of the main items in that category goes by the unappetizing name of frozen potatoes, but includes most of the French fries served in restaurants and fast food chains worldwide. The production process is fairly simple: peeled potatoes are shot through cutting blades, parboiled, air dried, par fried, frozen and packaged. The world's appetite for factory-made French fries has been put at more than 11 million tons a year (FAO, 2005). Potato starch is also widely used by the pharmaceutical, textile, wood and paper industries as an adhesive, binder, texture agent and filler, and by oil drilling firms to wash boreholes. Potato starch is a 100% biodegradable substitute for polystyrene and other plastics and used, for example, in disposable plates and dishes. Potato peel and other “zero value” wastes from potato processing are rich in starch that can be liquefied and fermented to produce fuel-grade ethanol. The rest are processed into potato food products and food ingredients, fed to cattle, pigs, and chickens, processed into starch for the industry, and re-used as seed tubers for growing the next season's potato crop. Because of the above reasons, more and more potatoes are planted in China.

Guizhou is in Southwestern China. Potato has long planting history in Guizhou since 1950-1960’s; planting areas were 67 thousand hectares (Xu et al., 2013; Wang et al., 2014). Varieties dominated by local variety Biandan and Hekan potato in Guizhou, and the yield was 6-7.5 tons/ha. Planting areas reached 180-210 thousand hectares in 1980’s ranked 7-8 in China, with 1.35-1.71 million tons of overall production. Planting areas were getting expanded in 1990’s and concentrated in Northwest of Guizhou in Bijie and Liupanshui districts. Only in Bijie district, the planting area was more than 80 thousand hectare. In 2006, the planting area in Guizhou was about 605.8 thousand hectare, and with about 7.5 million tons of overall yield. In Guizhou, it ranks 3rd just after rice and corn, and become the specialty and competitive industry; which is meaningful to develop the potato in Guizhou (Lei, 2006). Even though Guizhou has a large planting area and high overall production, but the yield per unit is still low compared to other areas. According to experts’ estimation, the theoretic productivity of potato is about 120 tons/ha (Lei, 2006). It means just intensive production could increase the potato productivity. The average yield in Holland is about 43 tons/ha. In Liaoning and main potato producing areas in China, the average yield already reached 25-30 tons/ha. In 2006, the average yield in Guizhou was about 12.4 tons/ha, average yield even did not reach the international average yield. The average yield in the world almost reached 17 tons/ha and in China reached about 14.6 tons/ha (Lei, 2006). It means Guizhou has the potential to improve the yield of potato.

There are many constraints for potato production in Guizhou. In general are socio-economic, biotic, and agronomic constraints. Socioeconomic include low commodity prices, poor input availability and poor marketing infrastructure. Biotic constraints include fungal diseases, bacterial diseases, viral diseases, insects, and nematodes. To solve these problems, potato research has been focusing on breeding, virus-free seed potato production, and cropping system (Jansky et al., 2009). Agronomic constraints in Guizhou are unfavorable climate conditions and unfavorable cropping system. Some of these constraints could be overcome or alleviated by fitting agronomic practices and managements such as intercropping, relay cropping, crop rotation, weeding, irrigation, as well as by breeding tolerant cultivars. Another main agronomic constraint is poor soil fertilizer management. The potato plant has one of the most massive production demands for fertilizer inputs of all vegetable crops, i.e., its nitrogen (N), phosphorus (P) and potassium (K) requirements are more significant than that required for tomato or pepper plant production (Maynard et al., 1997).

In Guizhou, there are some main problems in fertilization of potato production. First, in developed area, a lot of people went to the big city, so rural labor is very short. Farmers in these areas usually apply the compound fertilizer which is unscientific in fertilization. Second, in underdeveloped area, farmers focused on N fertilizer but ignore phosphorus fertilizer, potassium fertilizer. This leads to unbalance in fertilization. A lot of researchers focus on yield increasing, while economic evaluation of nutrient management for potato production always be ignored. It is hard to find any report about economics evaluation of nutrient management in Guizhou. The crop needs a given quantity and mix of nutrients to flourish. The higher the yield, the greater the nutrients required. One or more nutrients deficiency can inhibit or stunt plant growth, but excess nutrients, especially those provided by inorganic fertilizers can be wasteful, costly, and in some instances, harmful to the environment (Ladha et al., 2005; Raun et al., 2002).

The primary objective of commercial producers in applying fertilizers is to make a profit. The extent to which their use of fertilizers contributes to this objective depends not only upon the kinds and amounts of fertilizer applied, the way of application, and the crop responses that result, but also upon the costs of fertilization and the prices received for the crops. Both the physical and economic realities must be recognized. Effective and efficient management of the soil storehouse by the farmer is thus essential for maintaining soil fertility and sustaining high yields. So the soil and nutrient would be the key to solve the problems. High yield would be achieved with a high input of fertility. However, economic evaluate of fertilizer has to be done to find a suitable recommendation. To achieve healthy growth and optimal yield levels, nutrients must be available not only in the correct quantity and proportion, but in a usable form and at the right time. For the farmer, an economic optimum may differ from a physical optimum, depending on the added cost of inputs and the value of benefits derived from any increased output.

1.2 Objectives of the study

The overall objective of this research is to evaluate the economics of nutrient management for potato production in Guizhou.

(1) To study the effect of different levels of N P K on yield and quality of potato.

(2) To study the economic principles applied to responses function.

(3) To determine the maximum net profit from fertilizer and optimum applications of fertilizer, benefit cost ratio in potato production.

(4) Recommend the optimum amount of N P K fertilizer for potato production on different fertility soils in Guizhou.

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CHAPTER II

REVIEW OF THE LITERATURES

2.1 Potato production in the world

The homeland of potatoes is the western part of South America. The present territories are Peru Chile Bolivia and Ecuador. The international cultivation of potatoes in those countries has been traced back to several thousand years B.C. (Ugent, 1982). The tuber probably reached coastal China aboard ships from Europe during the 17th century and was introduced to central China by Russian traders around the same time. Potato originated from Andes Mountain in South America. It was spread to Europe in the 16th century, and brought to Taiwan by Hollander in the 17th century, and then to the mainland of China through Tianjin and littoral of Fujian province. So far, it has a planting history of about 400 years (Jansky et al., 2009).

Potatoes are grown worldwide under a broader range of altitude, latitude, and climatic conditions than any other major food crop from sea level to over 4000 m elevation. More than 100 countries planted potato with annual production of nearly 327 million tons and planted area of 19 million hectare. China, Russian, India, United States, Ukraine, and Germany are the main potato producing countries. The potato is also cultivated in Poland, Netherlands, France, United Kingdom, Iran, and Canada (FAO, 2005). In 2005, the developing countries' share of global potato output stood at 52 percent, surpassing that of the developed world. This is a remarkable achievement, considering that just 20 years ago the developing countries' share in global production was little more than 20 percent. Even so, world potato production and consumption are currently expanding more slowly than global population.

2.2 Potato production in China

As the biggest potato producing countries, China has the largest potato growing areas. In some arid areas or mountainous districts, potatoes are distributed in four agro-ecological zones (Figure 2.1). Most potato production occurs in the north single cropping zone (zone I) and the southwest mixed cropping zone (zone II). The south winter-cropping (zone III) and the southern portion of (zone IV) are characterized by high rainfall, while zone I is relatively dry (Anonymous, 1989). In addition, while elevations in zone II and III are low, zone II is mountainous, except in the east. The largest area of potato production is zone I, with favorable growth conditions such as cold temperatures, adequate sunlight, and a significant differential between day and night temperatures (Anonymous, 1989). Most potato cultivars grown in this region are round whites and oblong yellows with middle to late maturity, and include the Chinese selections in the numbered series Kexin, Jinshu, Longshu, Qingshu, Jiangshu, and Zhongshu; CIP 24, a clone from the International Potato Center; the American cv. Atlantic and the Canadian cv. Shepody (Wang and Zhang, 2004; Wu et al., 2008). In zone II, about 40% of China's potatoes are produced in these places. There are a lot of mountains and plateaus. Elevated regions (above 1,200 m) are best for potato production owing to cool summers and abundant rainfall. In Southwestern China, potatoes are planted in November to February and harvested from July to September. In more southern regions, potatoes are planted from January to April.

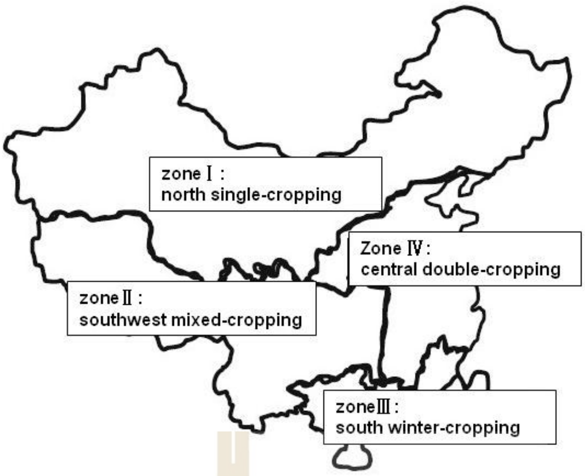

Figure 2.1 Potatoes distributed in four agro-ecological zones

China is the world's biggest potato producer and consumer. For the past three decades, the economy of China has grown tremendously owing to a liberalization of the economy and an increase in international trade (Wang and Zhang, 2004). Since 1990, potato planting area, yield, and total production have increased. In 1993, China has been the world's leading potato producer (Wang and Zhang, 2004). China contains 122 million ha of arable land, of which 4.9 million ha was used for potato production in 2006 (Jansky et al., 2009). It produced 70 million ton of potatoes. Which was 22% of the world's potato. In 2006, the total production, yield, and planting area were 2.20, 1.27, and 1.73 times greater than in 1990, respectively. Production doubled in 10 years, from 1990 to 2000, and continues to rise, owing to increases in both lands devoted to potato production and yield per hectare. In recent years, China has become an importer of processed potatoes and exporter of fresh potatoes (Wang and Zhang, 2004). However, the average yield in China is much lower than that of many countries. In 2006 it was 14.35 tons/ha, but it was 45.33 tons/ha in New Zealand, 43.67 tons/ha in the USA and 41.6 tons/ha in Holland (Jansky et al., 2009).

2.3 Potato production in Guizhou province

Guizhou province is located in Southwestern China, with the altitude of the 147.8-2906 m, between 24°37′-29°13′ N and 103°36′-109°35′ E. It is a mountainous province and covers an area of 176,100 square kilometers, or 1.8% of China's territory (Wu et al., 2008). The province's total area of 92.5% is characterized by mountains with the karst rock formations of special appeal. Because of its high altitude and relatively low latitude which means it is influenced by southeasterly monsoons, the climate in Guizhou varies greatly in different regions. Generally, the weather is mild and humid, sub-tropical monsoon climate with warm a winter, mild summer and unclear seasonal contrasts. It has a mean annual temperature of 14-16°C, with an average temperature of 5.2°C in January and 24.3°C in July, The annual rainfall is 1,100-1,400 mm with average relative humidity of 80%. It has more overcast days than any other part of the country (Wu et al., 2008). These eco-climatic conditions are suitable for potato growing. It is characterized by the largest natural open year-round planting potatoes. It can reduce the costs of storage and transportation which is very conducive to the development of industrial management.

Based on the temperature, the primary growing factor referred to the radiation and rainfall, and combined with variety types, cropping system, and the homogeneity and specificity of the planting areas, Guizhou is divided into several subareas in terms of potato planting. The temperature 21°C in July was the critical temperature point, regions colder than 21°C are main spring planting single harvesting areas, and regions hotter than 21°C are areas for both spring planting and autumn planting (double harvesting).

I. Spring planting single harvesting areas

These areas are in the northwest of Guizhou which includes Weining, Bijie and Hezhang counties, and Shuicheng district. Their altitudes are from 1537-1813 m, with low average annual temperature in winter and January, even summer (Table 2.1). The active accumulate temperature ≥10°C is 2171-2801°C There are more than 90 days of frosting days which early frost came earlier, and late frost came late. Precipitation in these areas varies from 850-1300 mm, and radiation is 4300 MJ/m^2. They are suitable areas for spring planting one crop potato (Wu et al., 2008).

Table 2.1 Areas of potato planting in Guizhou* (Adapted from Wu et al., (2008))

Altitude and temperature					
Areas	**Altitude**	**T**	**T JUL**	**T JAN**	**AAT**
	(m)	**(°C)**	**(°C)**	**(°C)**	**(≥°C)**
SS	1500-1500	12-13	20-21	3	2100-2800
SW	470-1500	>15	22-23	5-6	>4500
Mid-east	450-1300	15-16	24-26	3-5	3000-4500
Low-hot	<450	>18	>27	>7	6500

Frost and rainfall				
Areas	**Early frost**	**Late frost**	**Rainfall**	**Radiation**
	(10 d/Month)	**(10d/Month)**	**(mm)**	**(MJ/m^2)**
SS	Early, Mid/11	Mid, late/3	800-1300	4300
SW	late/11-late/12	Early, Mid/2	1200-1400	3600-4100
Mid-east	Mid, late/11	Mid, late/2	1200-1400	3700
Low-hot	Mid, late/12	Mid, late/1	1286.8	3694.0

II Spring planting and autumn plating double harvesting areas

These areas have diversified agro-ecology and complex cropping system. They were also divided into southwest, mid-east, and low-hot subareas according to average temperature in January and July, time of early and late frost, and homogeneity and specificity of the areas.

(1) Southwest areas including Anlong, Zhenning, Xingyi counties in southwest Guizhou.

(2) Mid-east areas including Zunyi, Guiyang, Douyun, Kaili, and Tongren district in meddle and east of Guizhou.

(3) Low-hot areas including Chishui, Luodian, Congjiang counties

Varieties can be divided into 4 types according to their growing period:

(1) Early maturing variety

Growing period is less than 80 days, such as Favorita, Zhongshu 2 3 4 Kexin 4 9. The active accumulate temperature is required to be 1100˚C, among them 250˚C for planting to germination, 320˚C for germination to budding, 360˚C for budding to flowering, 450˚C flowering to maturing.

(2) Mid-maturing variety

Growing period is less than 90 days, such as Atlantic, Kexin 1 3 Bashu 9 Jinguan. The active accumulate temperature is required to be 1200˚C among them 300˚C for planting to germination 350˚C for germination to budding 400˚C for budding to flowering 470˚C flowering to maturing.

(3) Mid-late maturing variety

Growing period is less than 100 days, such as Weiyu 3, Shepody. The active accumulate temperature is required to be 1300°C among them 300°C for planting to germination 400°C for germination to budding 410°C for budding to flowering 500°C flowering to maturing.

(4) Late maturing variety

Growing period is less than 110 days, such as Hezuo 88, Yibuqie. The active accumulate temperature is required to be 1500°C among them 330°C for planting to germination 480°C for germination to budding 500°C for budding to flowering 600°C flowering to maturing.

2.3.1 Seeding time

The seeding time is decided by the temperature during the potato growing period (Table 2.2). The temperature for tuber forming should be between 15-25°C spring planting potato should be planted 30 days before the late frost and germinated after the late frost. The temperature for autumn planting potato should be less than 25°C and harvested before the early frost (Wu et al., 2008).

Table 2.2 Potato seeding time in different planting areas* (Adapted from Wu et al (2008))

Area	**Spring (10 days/Month）**	**Autumn (10 days/Month）**
SS	late/2~Early/3	-
SW	Early/1~Early/2	Early-Mid/8
Mid-east	Early/2~Mid/2	Mid/8
Low- hot	Mid/12~Late/12	Mid/9

Density

Density depends on variety seeding time soil fertility density and production purpose, such as low density for extended growing period variety high for short growing variety (Table 2.3).

Table 2.3 Potato density in different planting areas (Adapted from Wu et al., (2008)).

Area	**Spring**		**Autumn**	
	Density ($pl/667m^2$)	**Spacing (cm)**	**Density ($pl/667m^2$)**	**Spacing (cm)**
SS	4000	60×26.67	-	-
SW	4000-5000	60×(26.7-23.3)	7000	40×(23.3-26.7)
ME	4000-5000	60×(26.7-23.3)	7000	-
LH (Sg)	4000-5000	66.7×(26.7-23.3)	7000	(53.3-60)×20
LH (Db)	4000-5000	100×(33.3-30)	7000	(83.3-100)×(20-23.3)

Nutrient should be enough for stem and leaves forming aboveground and tubers and roots system underground. Seventy percent of organic fertilizer should be applied for one crop spring planting potato, 80% for both spring and autumn planting 2 harvest potatoes. Generally, yield with 1.5 ton/ha of potato uptake 1.5 kg N 2.2 kg P_2O_5 and 10.2 kg K_2O. Take N as sample, N as same as 1250 kg compost, if 80% is applied as base fertilizer, others use chemical fertilizer, should apply 2.2 kg urea 10 kg superphosphate and 20 kg potassium sulphate. Urea and potassium sulphate are always used as top dressing (Wu et al., 2008).

2.4 Nutritional requirements of the potato

There are sixteen essential elements required by plants for growth and development including C H O N P K Ca Mg S Fe Mn Zn Cu B Mo and Cl (Westermann, 2005). C H and O are supplied by air and soil water, other nutrients from the soil and manure. Among them, N P and K are primary nutrients (Westermann, 2005). When insufficient, these primary nutrients are most often responsible for limiting crop growth. In addition to the primary nutrients, less intensively used secondary nutrients (S Ca and Mg) are necessary as well. A number of micronutrients such as Fe Mn Zn and Cu also influence plant growth. These micronutrients are required in small amounts (ranging from a few grams to a few hundred grams per hectare) for the proper functioning of plant metabolism. The absolute or relative absence of any of these nutrients can hamper plant growth; alternatively, too high concentration can be toxic to the plant or to humans.

Effects of fertilization on potato production

During the growing season, plants absorb certain amounts of nutrients indispensable to their growth. Most nutrients are removed from the field together with harvested crops which, consequently, impoverish the soil. This requires a supplementary supply of nutrients to the soil, in the form of organic and mineral fertilization. Mineral fertilization (application of compounds comparatively readily available to plants) aims also to improve the yields. Potato demand for nutrient and fertilizers is to a large extent, determined by soil fertility. Application of fertilizers and progressive increase in the rates result in improved potato yield. Mineral fertilizers in the form of readily available salts intensify potato plant growth, but they also influence chemical composition of potato tubers. Potato response to fertilizers depends chiefly on varietal traits and the type of soil under potato cultivation. Mineral fertilization, especially in high dosage, may have an adverse effect on the quality of potato tubers.

Fertilization is one of the most important factors required to obtain high yields. Researcher did some experiment in Qinghai (Zhang, 2013). The result showed that proper N (113.9 kg/hm^2) and K (90.3 kg/hm^2) can get the high yield, at the same time, affected the chemical composition and quality of potato tubers. Higher application rates resulted in decreased specific gravity and dry matter content (Neeteson, 1986). Increased N rates reduced sugar content of potato tubers (Swuniarski and Ladenberger, 1970).

Phosphorus reduced harmful effects of potassium and potassium-N fertilizers on starch in potato tubers (Mondy et al., 1986). Phosphorus fertilizers affect changes in mineral substance, especially those present in potatoes in trace amounts. It increases starch content in potato tubers. Increased rate of phosphorus also increase vitamin C and protein content as well as non-protein N but decrease the phospholipids content of potato tubers (Mondy et al., 1986).

Potassium has a crucial role in the energy status of the plant, translocation and storage of assimilates and maintenance of tissue water relations. Potassium is not an incorporated component of plant molecules; in opposite to N and P which are constituents of proteins, nucleic acids, phospholipids, ATP etc. Potassium predominantly exists as a free or absorptive bound cation, and can therefore be displaced very easily on the cellular level as well as in the whole plant. This high mobility in the plant explains the major functional characteristics of K: as the main cation involved in the neutralization of charges and as the most important inorganic osmotic active substance.

More than 50 enzymes are reported to be dependent on this element for their activities (Suelter, 1970). Studies on potassium for potato fertilizers have been conducted in many potato areas of the world and over long periods of time. Potatoes are heavy uptake of potassium in comparison with some crops. Potassium plays a pivotal role in influencing potato yield and quality. Potassium is primarily supplied to potato roots through diffusion over short distances, so K is generally considered a relatively immobile nutrient in most soils. It was reported that increased rates of potassium can reduce the specific gravity of potato tubers as well as dry matter, calcium and magnesium contents.

Mulder (1949) was among the first to show that potassium deficient tubers had a tendency to discolor more than those receiving an adequate supply of the element. Increasing the amount of potash fertilizer significantly reduced the black spot formation of potatoes (Scudder et al., 1950).

Apart from the three basic fertilizers used in potato cultivation, there are other mineral substances used depending on the requirements, mainly soil demand. They include calcium, magnesium and microelements. All of them affect plant growth, potato yield and quality.

2.5 Nutrient supplies and crop yields response curves

Characteristically, yield of a crop plot against the quantity of an essential nutrient added to the soil may be represented by a curve. At first the yield increases, eventually it reaches a maximum value. In some instances, there is a broad plateau region in which the yield remains about the same over a wide range of quantities of nutrient. In other instances, the plateau region is very narrow. Beyond the plateau, the yield decreases with increasing additions of the nutrient.

Russell (1973) has presented a schematic picture of what is widely accepted by agronomists to be the general relationship for a single-nutrient response function (Figure 2.2). This relationship can be interpreted as a continuous function with up to six well-defined stages. Some of the stages may be negligible in certain cases, but plant behavior resembles the curve shown in Figure 2.2 when the growing medium initially has a limiting nutrient at extremely low levels of availability, and the remaining essential nutrient exist in sufficient amounts to produce the maximum yield.

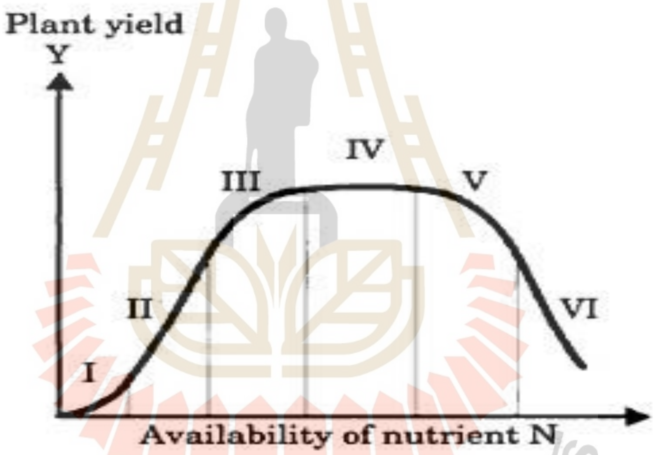

Figure 2.2 General relation between any particular nutrient and plant yield (Adapted from Russell, 1973).

Table 2.4 summarize the first and the second derivatives of the function Y=f (N), f_n and f_{nn}, which characterize the different portions of the general fertilizer response curve.

In agriculture there is a strong need for advice on fertilizer application rate that is specific for individual site and crop type. A traditional approach (Kamprath and

Watson, 1980; Cornforth and Sinclair, 1984; Wood et al., 1984) has been identified“optimum” or target soil test values in order to produce maximum yield, and then to estimate how much fertilizer is needed to bring the actual soil test results up to these targets. That approach does not indicate the most profitable rate of fertilizer to apply. However, growers need to know the marginal returns on fertilizer use to make the best decisions. In field investigations, there is also a need for method of estimating the degree to which nutrient availability is limiting yields. For instance, interpretation of results from surveys or experiments to determine the optimum plant populations, irrigation strategies or even weed control methods can be confounded by variations in soil fertility within and between sampling areas. A simple analytical model of crop response to nutrient supply could greatly increase the confidence with which generalizations can be made from experimental results. Researchers have studied to determine energy and economic analysis.

Table 2.4 First and second derivatives which characterize the different segments of the general fertilizer response curve depicted in Figure 2.2 (Adapted from Jauregui and Sain, 1992)).

Stage	f_n	f_{nn}
I Increasing response	>0	>0
II Linear response	>0	=0
III Decreasing response	>0	<0
IV No response	=0	=0
V Decreasing response	<0	<0
VI Linear negative response	<0	=0

Among four alternative functions forms: quadratic, square root, transcendental and translog, the quadratic function has been widely used (Heady, 1952; Mead and Pike, 1975; Nelson et al., 1985) because it is easily generalized to models with more than one nutrient and it allows for easy interpretation of linear, curvilinear and interaction effect.

The square root model frequently has been favored as a reasonable choice which does not have the undesirable features of the quadratic function (Heady et al., 1961). In some two-nutrient case, however, the square root model does not work well.

The translog function is a promising alternative because of its flexibility, although the economic optima must be estimated numerically, which should not pose a major problem if the appropriate computer hardware and software are available.

The transcendental response function also displays a high degree of flexibility, especially if, as suggested by Debertin (1986), an interaction term is include in the two-nutrient case. With this function, numerical methods are also used to estimate economic optima. Four functional forms are presented in Table 2.5.

Table 2.5 Marginal physical productivity (MPP) of four functional farms (for the one-nutrient case (Adapted from Jauregui and Sain, 1992)).

Functional Form	Equation Y=f(N)	MPP
Quadratic	$\beta_0 + \beta_1 N + \beta_2 N^2$	$\beta_1 + 2\beta_2 N$
Square root	$\beta_0 + \beta_1 N^{0.5} + \beta_2 N$	$\beta_2 + 0.5\beta_1 N^{-0.5}$
Transcendental	$\beta_0 N^{\beta_1} e^{\beta_2 N}$	$[\beta_2 + (\beta_1/N)]Y$
Translog	$\beta_0 N^{\beta_1} e^{\beta_2 (\ln N)^2}$	$(\beta_1 + 2\beta_2 \ln N)(Y/N)$

Numerous studies have compared response functions. A study considers different functions, which are fitted to data from several N and P factorial experiments on rice in India. The economic analysis gave optimum N and P levels that were relatively similar from one model to another for some experiments but differed substantially for others. The quadratic polynomial function estimated the highest optimum doses in some cases, and the Mitscherlich equation gave the second highest estimate. But for other experiments the highest does of N and P were derived from the Mischerlich function rather than the quadratic polynomial (Jauregui and Sain, 1992).

Tronstad and Taylor (1989) performed an economic and statistical evaluation of 15 functional forms (including the quadratic square root transcendental generalized Cobb-Douglas and Liebig functions) and three estimation procedures (sum of squared errors generalized least squares and minimum absolute deviations). They examined the error structure of each functional form and could not assert that any single functional form was superior. However, these authors observe that the forms conventionally used in agricultural production economics studies-especially the quadratic seem to fit forms that allow for a yield plateau or an asymptotic plateau.

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CHAPTER III

ECONOMIC EVALUATION OF N MANAGEMENT FOR POTATO PRODUCTION IN GUIZHOU

3.1 Abstract

Two field experiments were conducted to study the effects of N rates on yield and quality of potato in different soil fertility fields in Huishui County, Guizhou, China. Ten rates of N (0-405 kg/ha) were applied with the fixed amount of P and K. The N rates that give the maximum and optimum yield were evaluated. Results showed that proper N management was one of the most important factors required to obtain high yield of excellent quality potatoes. Increasing N fertilizer resulted in increments of potato yield and dry matter, then as N rate still increased yield and dry matter did decreasing trend. Increased N rates resulted in increased plant height, LAI, soluble protein and the reducing sugar content of potato tubers. Increased N rates resulted in reduced starch content.

In high soil fertility field, when applied N reached 197 kg/ha, yield reached maximum at 32,784 kg/ha while in low soil fertility field, when applied N reached 319 kg/ha, yield reached maximum at 9,117 kg/ha. However, the N rate that produced the maximum yield did not give the maximum net profit. In high soil fertility field, applied optimum N 193 kg/ha, resulted in the optimum yield price of 78,659 Yuan/ha while in low soil fertility field, applied optimum N 302 kg/ha, resulted in the optimum yield price of 21,825 Yuan/ha. The maximum net profit was 54,347 Yuan/ha in high

soil fertility field and 1,543Yuan in low soil fertility field. The results also indicated that the benefit cost ratio in potato production was 2.24 Yuan in high soil fertility field while in low soil fertility field it was 0.076 Yuan.

3.2 Introduction

N is an essential nutrient required for plant growth and production. Field studies showed that insufficient amounts might result in yield losses, excessive apply of N not only reduced yield but it also harmed the environment (Shen, 1990; Chen and Zhang, 1996; Zhang et al., 2002). However, farmers often tend to apply a large excess of N fertilizer to ensure high yields. They often apply a higher amount of N fertilizer than the amount required for maximum crop yield (Peng et al., 2006). Further increases in N application are unlikely to be as effective toward increasing crop yields because of diminishing returns (Tilman et al., 2002). Furthermore, this practice might decrease economic returns from crop production, damage water quality and aquatic ecosystems (Fischer et al., 2010) and cause emissions of N_2O to the atmosphere (Huang and Tang, 2010). Therefore, selecting an appropriate rate of N fertilization is a major decision affecting the profitability of crop production and the impact of agriculture on the environment (Cerrato and Blackmer, 1990). However, the reports on the application amount of N on the basis of balancing production and farmers' economic benefit was relatively few. This study explored the optimum amount of N fertilizer in different soil fertility fields in Huishui County Guizhou province, to provide quantitative methods of economic evaluation, as well as a scientific basis for potato production.

In this chapter, potato was evaluated to investigate the effect of different N rates on yield formation and quality. The objectives of this experiment were: (1) To study the relationship between N fertilizer and potato production. (2) To determine the optimum quantity of N fertilizer application. (3) To determine the maximum net profit from N fertilization. (4) To evaluate the benefit cost ratio in potato production.

3.3 Materials and methods

3.3.1 Plant seed

Favorita, an early maturing high yield potato variety introduced from Holland in 1980 by Chinese Agriculture Ministry was used in these two experiments. Its planting area in Guizhou was growing recently, especially in the mid-low altitude areas in autumn season. The growing period of Favorita was around 60 days from germination to maturity. Plant height was around 65 cm. The average yield in Guizhou from 2003-2005 was about 18,750 kg/ha (Lei, 2006; Huang et al., 2001; Jiang, et al., 2008).

3.3.2 Fertilizer

Urea (46 % N) was used as N source, K_2SO_4 (50 %K_2O) was used as K source and ordinary superphosphate (12 % P_2O_5) was used as P source in these two experiments.

3.3.3 Experimental site

Experiments were conducted at Huishui County, Guizhou, China, from January 2011 to June 2011. Two different soil fertility fields: low soil fertility and high soil fertility, and the areas were selected after the soil samples were analyzed for fertility base on the standard requirement of potato (Appendix: Table 1). Both soils belong to the ferrallitic soil order, moist warm ferralsol soil suborder, and yellow soil group (Yi, 1994). The soil genus, texture, BD, CEC and soil analysis results were shown in Table3.1.

Table 3.1 Soil series, texture, and chemical properties (0-30cm).

Soil series texture and traits					
Field	**Soil genus**	**Soil texture**	**BD**	**CEC**	**pH**
			(g/cm^3)	**(cmol/kg)**	
HF	Yellow upland soil	Loamy soil	1.18	16.4	5.68
LF	Sandy yellow upland soil	Sandy soil	1.11	13.5	5.42
Chemical properties of soil (0-30cm)					
Field	**OM**	**Total N**	**Available N**	**Available P**	**Available K**
	(g/kg)	**(g/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
HF	28.9	1.624	182.1	42.7	107.4
LF	17.7	0.787	39.4	10.6	27.9

3.3.4 Experimental Design:

Ten treatments of N application rates were arranged in randomized complete block design (RCBD), with 3 replications. Two experiments (Table 3.2) were carried out in two different soil fertility areas (low and high soil fertility). The amount of P_2O_5 was applied at 56 kg/ha and K_2O was 158 kg/ha which were the rates recommended in Guizhou (Fan et al., 2008). Forty percent of N was used as basal fertilizer by row application at the seeding time. Thirty percent of N was used as the first top dressing during the budding stage. Thirty percent of N was used as the second top dressing during the flowering stage. Individual plots were 2 m wide and 6 m long and were separated from adjacent plots by 0.5m. Seeding was completed at a hill spacing of 0.375m×0.5m with one seed per hill, 64 hills per plot. During the growing period, the pesticide was used twice when insect incidence occurred. Supplement irrigation was done once due to less rainfall and weeding was done twice.

Table 3.2 Ten treatments of N application rates.

TRT	**Total fertilizer**	**Base N fertilizer**	**Top dressing N**	
			First time	**Second time**
		(kg/ha)		
N0	0	0	0	0
N1	45	18	13.5	13.5
N2	90	36	27	27
N3	135	54	40.5	40.5
N4	180	72	54	54
N5	225	90	67.5	67.5
N6	270	108	81	81
N7	315	126	94.5	94.5
N8	360	144	108	108
N9	405	162	121.5	121.5

3.3.5 Data collection and analysis

Climate data: Precipitation, radiation and temperature during the growing period were obtained from the closest weather station.

Soil data: OM, pH, total N, available N, available P and available K were analyzed before the experiment.

Plant data: During harvest, tubers were counted and measured for fresh weight in each plot.

Plant height, leaf area index, yield, starch, soluble protein and reducing sugar were determined.

Investigation data: Potato price, fertilizer price and cost of production were collected (Table 3.3)

Table 3.3 Unit price of input and production cost.

Materials	**Unit Price**
N	4.3(Yuan/kg)
P_2O_5	5.8 (Yuan/kg)
K_2O	6.8 (Yuan/kg)
Potato seed	3.0 (Yuan/kg)
Fresh potato	2.4 (Yuan/kg)
Pesticide	485 (Yuan/ha)
Land rent of high fertility field	10500 (Yuan/ha)
Land rent of low fertility field	6000 (Yuan/ha)
Cost of labor	7500 (Yuan/ha)

3.3.5.1 Methods of soil and plant analysis

For soil analysis, methods recommended by the Soil Science Society of China (1999) were adopted as follow:

Methods of soil analysis:

pH: (Distilled Water Method)

OM: (Walkley-Black Acid Digestion Method ($K_2Cr_2O_7$-AFS Method))

Total N: (Kjeldahl Method)

Available N: (Alkali Diffusion Method)

Available P: (Sodium bicarbonate Method)

Available K: (Ammonium acetate extraction Method)

Methods of plant agronomic traits and tuber analysis

During harvest, tubers were counted, weighed and ranked for their marketability and size. Tubers were collected from each plot to measure the fresh and dry weight.

Plant height was recorded from 10 representative plants in each treatment by measure stem length (from the cotyledon node to the top of plant).

Leaf area index: (Coordinate Paper Method)

Yield: Yield of the potato was measured in each whole plot.

Starch: (Colorimetric Method)

Soluble protein: (Bradford Method (Coomassie brilliant blue G-250)) Reducing sugar: (Colorimetric Method (3, 5-Dinitrosalicylic acid)).

Dry matter: (Weighing method)

3.3.6 Data analysis:

Analysis of variance was performed using Statistical Package for the Social Sciences (SPSS) for Window (version 16). Regression analysis was used to determine the yield response curve to fertilizer rates. The response to N was studied by fitting quadratic response equations for total tuber yield. The quadratic response equation had the best fit of the relationship between x and y as shown below:

$$y=a+bx+cx^2$$

In which, y was total tuber yield (kg/ha); x was the rate of N fertilization (kg/ha); a, b and c were constants.

By setting the derivative of the yield equation equal to zero (y'=0) the quantity of N fertilizer to produce the maximum yield could be calculated.

The economic response to N was studied by fitting quadratic equations for monetary value as shown below:

$$y_1=a_1+b_1x+c_1x^2$$

In which y_1 was total value (Yuan/ha); x was N rate (kg/ha); a_1 b_1 and c_1 were constants.

With N fertilizer at 4.3 Yuan per kilogram, the total costs of N fertilizer in Yuan per hectare thus were

$$C=4.3x.$$

The quantity of N to produce the maximum profit from fertilization is then estimated by setting the derivative of the crop value equation equal to the derivative of the cost equation($y_1'=4.3$) and solving the resulting equation for the quantity of N (optimum N).

From the optimum N rate, optimum yield price can be calculated. The following economic parameters can be calculated as follow:

Maximum net profit from the production:

$$P_p = y_1 - C_p.$$

In which P_p was the maximum net profit from the production; y_1 was the total value (Yuan/ha); C_p was the total cost of potato production.

Benefit cost ratio in potato production (BCR):

$$BCR = P_p / C_p.$$

In which BCR was the benefit cost ratio in crop production; P_p was the maximum net profit from the production (Yuan/ha); C_p was the total cost of potato production.

3.4 Results and discussion

3.4.1 Growing Condition

Average daily temperature data for the 2011 January to May growing seasons are shown in figures (Appendix: Attached figure 1 and 2). The precipitation for the growing period was 143.7 mm. However, the drought period occurred from January to February. Early growing season temperatures were lower in January. The average daily temperature for that period in January 2011 (5.5°C) was notably lower than usual which cause the delay in maturity.

3.4.2 The growth of potato

3.4.2.1 Plant height

Analysis of variance (Table 3.4) showed that plant height was significantly different at 5% probability level among N treatments. Plant height in high soil fertility field was much taller than that in low soil fertility field. The maximum plant height was found at the application N rate of 405 kg/ha in both fields. The result indicated that increasing N rate resulted in increased plant height. The result was supported by that of Sriom, et al. (2017) who reported that increasing levels of N fertilizer significantly increased the height of the plant. Because of the supply of nitrogen is related to carbohydrate utilization. When N supply is adequate and conditions are favorable for growth, proteins are formed from the manufactured carbohydrates. This extra protein allows the plants to grow faster. Thus, plant height was significantly increased by increasing levels of N application. These results were also supported by Anabousi et al. (1997), Ramirez et al. (2004) and Gupta (1992).

3.4.2.2 Leaf area index

Analysis of variance (Table3.4) showed that leaf area index was significantly different at 5% probability level among N treatments. The maximum leaf area index was found at the application of N 405 kg /ha in both soil fertility fields. The results were similar to the result from other studies. For example, Li et al. (2010) reported that the plant height and leaf area index increased with the increase of N level. It is in agreement that N is the most important plant macronutrient which required in high amount than other plant nutrients for most plant species. These results were also supported by Sriom, et al. (2017).

Table 3.4 The effect of N application on potato growth.

TRT	Plant height (cm)		LAI	
	HF	LF	HF	LF
N_0	40.4i	22.7i	2.07 g	1.13 g
N_{45}	44.9h	26.7h	2.31 f	1.37f
N_{90}	48.7g	29.2g	2.57 e	1.45e
N_{135}	49.3fg	30.3f	2.74 d	1.48de
N_{180}	50.4ef	31.1e	3.01 c	1.54cd
N_{225}	51.0de	32.8d	3.09 c	1.60 c
N_{270}	51.8 cd	33.6c	3.21 b	1.68 b
N_{315}	52.4bc	34.4b	3.22 b	1.70 b
N_{360}	53.3b	35.1b	3.34 b	1.75 b
N_{405}	54.9a	37.1a	3.46a	1.88a
Cv(%)	1.8	1.7	2.4	2.9

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

3.4.3 Yield and quality

3.4.3.1 Fresh tuber yield

Analysis of variance (Table 3.5) showed that tuber yields were significantly different among N rates at 5% probability level. Fresh tuber yields in high soil fertility field were much more than those in low soil fertility field. Among fertilizer levels, the fertilizer level of 180 kg/ha in high soil fertility produced the highest yield (32,583 kg/ha). While in low fertility field the highest yield (9,166 kg/ha) was obtained at the N rate of 315 kg/ha. The result indicated that increase in the application of N fertilizer up to a certain level increased the potato yield, but above that, it had an adverse effect on yield. The result was similar to the report of Wang et al. (2012). According to the results, not only the excessive application of N was not useful for the crop, but also it is not cost-effective and even it may impose some injuries to crop and affects to the environment. Li (2006) reported that if the amount of applied fertilizer was greater than 210 kg/ha, the yield decreased. Therefore, the recommendation regarding fertilizer type and level for a crop and field must be based upon genuine and delicate experiments.

3.4.3.2 Starch content

Analysis of variance (Table 3.5) showed that starch was significantly different among N rates at 5% probability level. Starch in treatment N0 ranked in the superior group with the highest starch content. Starch content decreased with the increasing N fertilizer indicated that an excess of N fertilizer promoted the growth of excess aboveground vegetative organs which would limit the amount of photosynthate translocate to produce starch for underground tubers. This result was supported by that of Wang (1994) who reported starch content decreased with the increasing N fertilizer application. Some researchers had different findings, such as Yaghbani and Mohammadzadeh (2005) reported that there was a significant difference between starch contents of different cultivars and N levels, too high or too low would reduce tuber starch content.

3.4.3.3 Soluble protein content

Analysis of variance (Table 3.5) showed that soluble protein was significantly different among N rates at 5% probability level. The result showed that the soluble protein content in the tubers of both soil fertility fields increased significantly under the influence of N fertilization. The increased in the soluble protein content after the application of the N fertilizer (N 405kg/ha) was 1.624 g/100g for high fertility soil and 1.599 g/100g for low fertility soil. These results have been proved by

Li (2006), who concluded that the increase of N doses regularly increased the soluble protein content in potato. These results were also supported by Swuniarski and Ladenberger (1970).

3.4.3.4 Reducing sugar content

Analysis of variance (Table 3.5) showed that reducing sugar was significantly different among N rates at 5% probability level. The means comparison showed that among fertilizer levels, the level of N 405 kg/ha producing the highest reducing sugar in both soil fertility fields. N fertilizer increased the reducing sugar in potato tubers. The result of this study was supported by that of Zhang et al. (2002) who reported that with the increase of N application rate, the reducing sugar content increased. Because N fertilizer can promote the growth of stems and leaves, photosynthetic organs produce a large number of photosynthetic products and transport them to the tubers. Especially in the late growth stage, sufficient nitrogen can delay aging and increase the reducing sugar content of tubers. These results were also supported by Li (2006).

3.4.3.5 Dry matter content

Dry matter percentage of tuber was significant differences between N rates at 5% probability level (Table 3.5). Dry matter percentage in high fertility soil was much more than those in low fertility soil. Among fertilizer levels, the fertilizer level of 180 kg/ha in high soil fertility produced the highest dry matter percentage (19%). While in low fertility field the highest dry matter percentage (17.4 %) was obtained at the N rate of 315 kg/ha. The results were in agreement with the finding of Wang et al. (2014) in which dry matter accumulation of fleshy roots all increased firstly and then decreased with the increase of N application rates. Similar results were reported by Beukema and van der Zaag (1990). The results were not in agreement with Moosavi et al. (2001) who reported that the N fertilizer was positively on dry matter content. Other researchers, such as Krijthe (1982) and He et al. (2016) reported that the excessive level of available N fertilizer stimulates reformation of tubers and may lead to the lengthening of tuber formation period and the difference in tubers maturity which in turn, leads to the difference in tubers dry matter content.

Table 3.5 The effect of N application on potato yield and quality.

TRT	Yield (kg/ha)		Starch (%)		Soluble protein (g/100g)		Reducing sugar (%)		Dry matter (%)	
	HF	LF	HF	LF	HF	LF	HF	LF	HF	LF
N_0	20,417f	3,417h	69.2a	65.9a	0.966i	0.806j	0.314g	0558g	14.2e	11.2c
N_{45}	27,917d	5,000g	67.4b	65.3b	0.979gh	0.826i	0.346g	0.590fg	15.3de	12.4fbc
N_{90}	30,667c	6,000f	65.4c	60.7c	1.008gh	0.926h	0.385fg	0.646ef	16.7bcd	13.3b
N_{135}	32,333a	7,333e	56.4d	54.7d	1.173f	0.994g	0.419de	0.658def	17.3abcd	15.7a
N_{180}	32,583a	8,167d	47.5e	49.5e	1.203ef	1.017f	0.441cde	0.668cde	19.0a	16.8a
N_{225}	32,250a	8,500c	47.3f	39.4f	1.227de	1.029e	0.478bcd	0.691cde	18.9ab	16.9a
N_{270}	31,667b	9,000ab	41.4g	35.0g	1.260d	1.053d	0.484bcd	0.729bcd	17.7abc	17.1a
N_{315}	27,667d	9,167a	40.6h	34.4h	1.334c	1.185c	0.496abc	0.737bc	17.5abcd	17.4a
N_{360}	23,417e	8,917ab	37.5i	34.2i	1.547b	1.444b	0.522ab	0.757b	17.2abcd	16.7a
N_{405}	23,083e	8,750bc	35.8j	32.2j	1.624a	1.599a	0.559a	0.824a	16.1cde	15.8a
Cv(%)	0.76	2.51	0.30	2.21	2.79	0.49	10.0	6.5	6.8	6.7

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

3.4.4 Economic evaluation of N management for potato production

3.4.4.1 Maximum yield and N fertilizer rate

In this experiment with the fixed P and K application, we have obtained a response of potato yield to N rates. A quadratic equation was well fitted for the relationship between potato yield and N application (Figure 3.1).

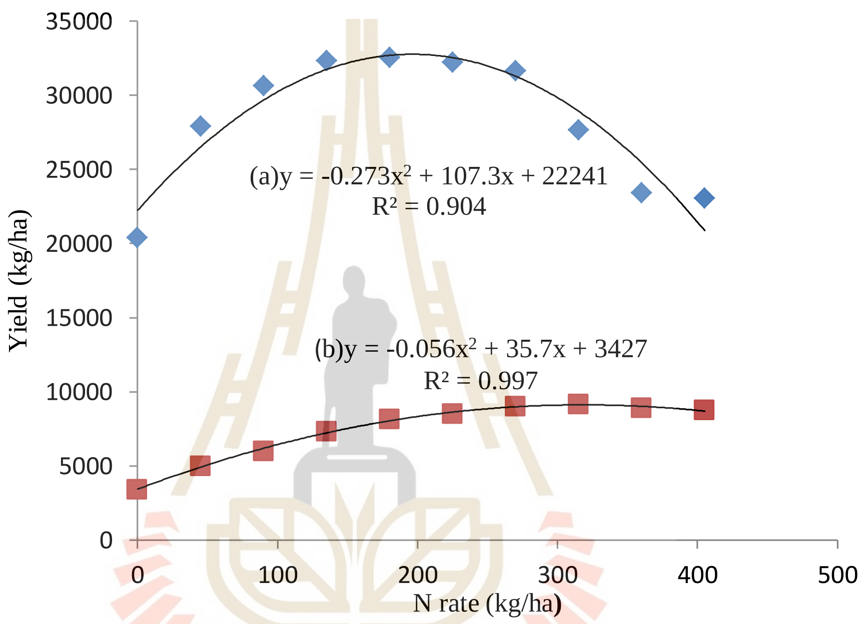

Figure 3.1 Relationship between the yield and the application of N fertilizer in high fertility soil field (a) and low soil fertility field (b).

The response function used for the experiment in high soil fertility field was:

$$y= 22,241+107.3x-0.273x^2,\ R^2=0.904 \quad (a)$$

The response function used for the experiment in low soil fertility field was

$$y = 3,427+35.7\ x-0.056x^2,\ R^2=0.997 \quad (b)$$

Where y is the yield of potato (kg/ha) and x is the application of N fertilizer (kg/ha). The results (Figure 3.1) showed that at low N level in both fields potato yield positively responded to N rate and reached the maximum at certain levels of N. After reaching the maximum, yield then gradually decreased with the increased N rate.

From the regression analysis of quadratic model, the result showed that in high fertility soil maximum potato yield (32,784 kg/ha) was obtained at N rate of 197 kg/ha. While in low soil fertility field maximum yield (9,117 kg/ha) was obtained at N rate of 319 kg/ha. These results reflected the limitation of available N in both fields but the N limitation was more in low fertility field. This indicated that the proportion of N fertilizer in high soil fertility field was high. The application of N fertilizer caused excessive N in the soil, and the potato plant grew very high, which consumes too much photosynthetic products and reduced the yield of potato tubers. The result was proved by Dou, et al. (2017). They also showed that in low soil fertility field, when the N application level was gradually increased, the corresponding increased production occurred. When the N consumption reaches a certain level, for the increase of N resulted in decreased production. It might be because in the low soil fertility field appropriate application of N fertilizer can increase the number of potatoes and single potato weight, while excessive application of nitrogen fertilizer may cause delayed single potato number and single potato weight decrease, and potato yield decrease.

3.4.4.2 Optimum N fertilizer application and optimum yield price

The application of economic principles to fertilizer use is usually illustrated by the relatively uncomplicated situation in which the supply of capital is ample and no other investment possibilities would yield more profitable return. The optimum application of fertilizer is then the quantity that will return the maximum net profit.

The optimum yield price from fertilization is returned by the fertilizer application at which the monetary value of the optimum N fertilizer rate (Figure 3.2).

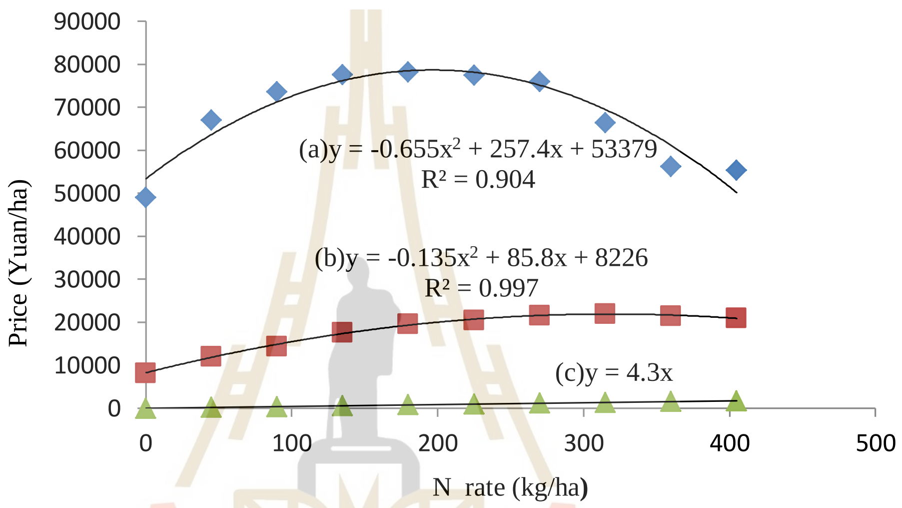

Figure 3.2 Relationship between the monetary value and the application of N fertilizer and monetary values in high fertility field (a), low fertility field (b) and fertilizer price (c).

Where the response curve is represented by a mathematical function, the quantity of fertilizer that returns the optimum yield price is estimated mathematically. The process perhaps can be understood most easily if the yield response function is first multiplied by the price per unit of the crop to convert the function to monetary units. Then the procedure can be visualized in terms (Fig.3.2).

In these two experiments, the N fertilizer was side-dressed alone in different quantities, and the response function used for these two experiments was

Quadratic function $y = a + bx + cx^2$

Where y is the monetary value of potato per hectare and x is the application of fertilizer N in kilograms per hectare.

$$y = 53{,}379 + 257.4x - 0.655x^2 \text{(high fertility soil)} \quad \text{(a)}$$

and

$$y = 8{,}226 + 85.8x - 0.135x^2 \text{(low fertility soil)} \quad \text{(b)}$$

With N fertilizer at 4.3 Yuan per kilogram, the total costs of N fertilizer in Yuan per hectare thus were

$$y = 4.3x \quad \text{(b)}$$

Where y is the cost of N fertilizer and x is N rate.

On the economic benefits, mainly due to economic output and overall performance, value, cost and other aspects increasing N fertilizer can increase yield and production value, however the corresponding costs are also increased. Therefore, the process does not represent the maximum yield can produce the highest economic benefits. The maximum benefits can be obtained when marginal costs are equal marginal output and profit margin is zero. By calculation of these two equations as described in section 3.3.6, the optimum N fertilizer application in high fertility soil was 193 kg/ha and optimum yield price was 78,659 Yuan/ha; and the optimum N fertilizer application in low fertility soil was 302 kg/ha with the optimum yield price of 21,825 Yuan/ha.

3.4.4.3 Maximum net profit

From the result (Table 3.6) obtained the maximum net profit was 54,347 Yuan/ha in high soil fertility field and 1,543 Yuan in low soil fertility field.

Table 3.6 Maximum net profit and benefit cost ratio in potato production.

Field	Cost N	FC	Total C	OYP	MNP	BCR
			(Yuan/ha)			
HF	830	23,482	24,312	78,659	54,347	2.24
LF	1,299	18,982	20,282	21,825	1,543	0.076

3.4.4.4 Benefit cost ratio in potato production

Benefit cost ratio is directly proportional to the net return, higher the benefit cost ratio will result in the higher net return (Naeem, et al., 2015). Total costs of production, including the cost of all fertilizers, seed, pesticide, labor and land rent. In high fertility soil field total cost were estimated at 24,312 Yuan/ha and it was 20,282 Yuan/ha in low fertility soil field. In high soil fertility field, the benefit cost ratio in crop production was 2.24 Yuan, in low soil fertility field the Benefit cost ratio in crop production was 0.076 Yuan. The results indicated that it was economic to invest in high fertility soil than in low fertility soil.

The overall results indicated that application of N fertilizer is one of the main measures to improve potato yield, but an unreasonable application of N fertilizer is not only difficult to achieve high yield but also causes N fertilizer waste and pollutes the environment. Over the years, many researchers have done a lot of research on the application of N fertilizer, the rational application of N fertilizer and the utilization of N, which has played an important guiding role in realizing the high yield, high quality, high efficiency and reducing the loss of N fertilizer. Almost all of the researchers conducted the experiments in the same soil under the conditions of soil fertility. However, for the analysis of economic information must be determined in various soil conditions. In Guizhou, very few researches have been done for determine the appropriate N application rate. The results of this study could contribute to the recommendation of N macronutrient for production in Guizhou.

3.5 Conclusion

Proper N management is one of the most important factors required to obtain high yield of excellent quality potatoes. Increasing N fertilizer resulted in increments of potato yield and dry matter, then as N rate still increased yield and dry matter did decreasing trend. Increased N rates resulted in increased plant height, LAI, soluble protein and the reducing sugar content of potato tubers. Increased N rates resulted in reduced starch content.

In high fertility soil, when applied N reached 197 kg/ha, yield reached maximum at 32,784 kg/ha; in low fertility soil, when applied N reached 319 kg/ha, yield reached maximum at 9,117 kg/ha. However, N rate for the maximum yield did not produce the maximum net profit. In two different soil fertility fields, the result showed that: in high soil fertility field, N rate of 193 kg/ha, resulted to optimum yield price of 78,659 Yuan/ha; In low soil fertility field, N rate of 302 kg/ha, produced the optimum yield price of 21,825 Yuan/ha. The maximum net profit was 54,347 Yuan/ha in high soil fertility field and 1,543Yuan in low soil fertility field. Benefit cost ratio in potato production was 2.24 in high soil fertility field while in low soil fertility field it was 0.076.

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CHAPTER IV

ECONOMIC EVALUATION OF NUTRIENT P MANAGEMENT FOR POTATO PRODUCTION IN GUIZHOU

4.1 Abstract

Two field experiments were conducted to study the effects of P rates on yield and quality of potato in different soil fertility fields in Huishui County, Guizhou, China. Ten rates of P (0-225 kg/ha) were applied with the fixed amount of N and K. The P rates that give the maximum and optimum yield were evaluated. Results showed that increasing P fertilizer resulted in increments of potato yield plant height LAI starch soluble protein and dry matter, then as P rate still increased potato yield plant height LAI starch soluble protein and dry matter did decreasing trend. Increased P rates resulted in reduced the reducing sugar content of potato tubers.

In high soil fertility field, when applied P reached 156 kg/ha, yield reached the maximum at 27,117 kg/ha; in low fertility soil, when applied P reached 208 kg/ha, yield reached the maximum at 5,879 kg/ha. However, P application rate for the maximum yield did not produce the maximum profit. In high soil fertility field, applied optimum P rate of 151 kg/ha resulted in the optimum yield price of 65,058 Yuan/ha while in low soil fertility field, applied optimum P rate of 192 kg/ha, resulted in the optimum yield price of 14,101 Yuan/ha. The maximum net profit was 40,542

Yuan/ha in high soil fertility field and -6,153 Yuan/ha in low soil fertility field. Benefit cost ratio in potato production was 1.71 in high soil fertility field while in low soil fertility field it was -0.30.

4.2 Introduction

P plays an essential role in plant health and root development (Mehrvarz and Chai 2008). The P requirement of potato is frequently higher than the P required for many field crops due to the high nutrient demand of potato and their relatively shallow root system. Therefore, some fertilizer P is commonly recommended for potato grown in a crop rotation. Potato plants require an adequate supply of P throughout the growing season to achieve high yield and quality. However, excessive uses of mineral and organic P strongly enhanced P losses through surface runoff (Sharpley et al., 2000), and soil P accumulation also accelerated the enrichment of P in surface water (Zhang et al., 2004; Sharpley et al., 2004; Sharpley et al., 2001).

The recent development of studies indicated the potential impact of P fertilization in crop production on the environment. However, most of the studies focused on the water pollution of P fertilizer (Bang et al., 2004; Zhang et al., 2004; Sharpley and Tunney, 2000). Little information is available on the proper P fertilization rate, which can meet the requirement of crop production without significant environmental impact.

P is generally broadcasted as a basal dressing before transplanting; therefore, top dressing is usually not necessary (Chen and Zhang, 1996). Although the response of numerous crops to P has been characterized (Wang, 2004; Wells et al., 2004), little information is available on recommended levels of P fertilizer for nutrient management in Guizhou. Thus, in this study, potato was evaluated to investigate the effect of yield formation and quality under different P application rates.

Objectives of this study were: (1) To get the relationship between P fertilizer and potato production. (2) To determine the optimum quantity of P fertilizer application. (3) To determine the maximum net profit from P fertilization. (4) To evaluate the benefit cost ratio in potato production.

4.3 Materials and methods

4.3.1 Plant seed

Favorita, an early maturing high- yield potato variety was used in this study. The details of this variety have been given in section 3.3.1. (Chapter III)

4.3.2 Fertilizer

Urea (46% N) was used as N source. K_2SO_4 (50% K_2O) was used as K source. Ordinary superphosphate (12% P_2O_5) was used as P source in these two experiments.

4.3.3 Experiments site

Experiments were conducted at Huishui County, Guizhou, China, from January 2011 to June 2011. Two different soil fertility areas (low and high), and the areas were selected after the soil samples were analyzed for fertility base on the standard requirement of potato. The soil analysis results were performed as chapter III (section 3.3.3).

4.3.4 Experimental Design

Ten treatments of P application rates were arranged in the randomized complete block design (RCBD), with 3 replications. Two experiments (Table 4.1) were carried out in two different soil fertility areas (low and high soil fertility). The amount of the N fertilizer was designed to be 113 kg/ha and the amount of K (K_2O) fertilizer was 158 kg/ha. 40% of N fertilizer was used as basal fertilizer by row application at the seeding time, 30% of N was used as the first top dressing during the budding stage and 30% of N was used as the second top dressing during the flowering stage. Individual plots were 2 m in width and 6 m in length and were separated from adjacent plots by a 0.5 m wide plant-free border. Each plot consisted 4 rows. Seeding was completed at a hill spacing of 0.375 m×0.5 m with one seed per hill, 64 hills in one plot. During the growing period, the pesticide was used twice when insect incidence occurred. Supplement irrigation was done once due to less rainfall. Weeding was done twice.

Table 4.1 Ten treatments of P fertilizer application rates.

Treatment	Total P fertilizer (kg/ha)
P_0 (CK)	0
P_1	15
P_2	45
P_3	75
P_4	105
P_5	135
P_6	165
P_7	195
P_8	225
P_9	255

4.3.5 Data collection and analysis

Data collection and analysis were performed as the same as the chapter III (section 3.3.5 and 3.3.6)

4.4 Results and discussion

4.4.1 Growing condition

Average daily temperature data for the 2011 January to May growing seasons are shown in (Appendix: Attached figure 1 and 2). The details have been given in section 3.4.1. (Chapter III)

4.4.2 The growth of potato

4.4.2.1 Plant height

Analysis of variance (Table 4.2) showed that P fertilizer rates were significant on the mean of plant height at 5% probability level. It can be seen (Table 4.2) that the height of the potato in the high-fertility field was much higher than that of the low-fertility field, which indicates that the high-fertility soil was favorable for the potato growth. In two fertility soils, the plant height increased first and then decreased with the increase of P application rate. The highest plant height (48.6cm) in high fertility soil and (34.3 cm) in low fertility soil were recorded at rate application of P 165 kg/ha in high fertility soil and P 225 kg/ha in low fertility soil. However, the minimum plant height was recorded (45.8cm and 23.7cm) in control in both fertility soils. It could be concluded that increasing the application of P fertilizer was conducive to improving the plant height of potato. However, when the fertilizer increased to a certain extent, plant height did not increase but tended to decrease, indicating that P fertilizer should be appropriate. The highest rate of P application at the study site had no effect on plant height. This might due to a high dose of P fertilizer tends to form nutrient interaction and may affect the availability of other nutrients which are essential for growth of the potato. A study by Prosper I and Jerome (2017) reported a similar effect of P fertilizer on plant height. They also reported that plants grown without P fertilizer produced the shortest plant irrespective of growth stages. De Datta (1981) reported stunted plant height due to deficiency of phosphorus. The result of this study was supported by that of Li and Zhang (2012) who reported an appropriate increase of P fertilizer is conducive to increase the plant height of potato.

4.4.2.2 Leaf area index

As the same with plant height, the leaf area index of potato in high-fertility soil was higher than that of low-fertility soil. In two fertility soils, the leaf area index increased first and then decreased with the increase of P application rate. Analysis of variance (Table 4.2) showed that P fertilizer rates were significant on the mean of Leaf area index at 5% probability level. Among P fertilizer levels, application of P 165 kg /ha gave rise to the greatest mean leaf area index of 3.42 in high soil fertility field. In low soil fertility field, application of 225 kg/ha gave the greatest mean of 1.49. The result of this study was supported by that of Li and Zhang (2012) who reported an appropriate increase of P fertilizer is conducive to increase the leaf area index of potato. Similar results were found by other researchers (Dong et al., 2007; Delourme et al., 2006).

Table 4.2 The effect of P application on potato growth.

TRT	Plant height (cm)		LAI	
	HF	**LF**	**HF**	**LF**
P_0 (CK)	45.8c	23.7h	2.11 g	0.97g
P_{15}	46.3c	24.5g	2.15g	1.12f
P_{45}	46.2c	26.9f	2.37f	1.16ef
P_{75}	47.6b	26.9f	2.51e	1.23de
P_{105}	48.1ab	27.6f	2.90d	1.24de
P_{135}	48.3ab	29.4e	3.12c	1.31cd
P_{165}	48.6 a	30.3d	3.42a	1.35bc
P_{195}	48.5a	32.1c	3.28b	1.43ab
P_{225}	48.5a	34.3a	3.31b	1.49a
P_{255}	48.3ab	33.4b	3.23b	1.46a
Cv (%)	1.6	2.9	1.9	4.3

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

4.4.3 Yield and quality

4.4.3.1 Fresh Tuber Yield

Analysis of variance (Table 4.3) showed that the P fertilizer rates were significant on fresh tuber yield at 5% probability level. Fresh tuber yield in high soil fertility field was much more than that in low soil fertility field. Among fertilizer levels, the P fertilizer level of 165 kg/ha in high fertility soil produced the highest yield (27,639 kg/ha). While in low fertility field the highest yield (6,001kg/ha) was obtained at the P rate of 225 kg/ha. It could be concluded that increasing the application of P fertilizer up to a certain level, the yield increased, but since then, the yield decreased. The result of this study was supported by that of Meseret and Amin (2014) who studied the influence of different levels of P fertilizer (0 10 20 30 and 40 kg/ha) on yield attributes of common bean. The results revealed that P fertilizer 20 kg/ha gave the highest seed yield. It could be concluding that an appropriate increase of P fertilizer is conducive to increase the yield of potato. According to Shuler and Hochmuth (1995), experiments, excessive application of P fertilizer was not always lead to higher yields which were confirmed in this study.

4.4.3.2 Starch content

The P fertilizer rates were significant on starch percentage at 5% probability level. According to means comparison (Table 4.3), among fertilizer levels, the P fertilizer level of 165 kg/ha in high fertility soil produced the starch (69.9%). While in low fertility field the highest starch content (65.6%) was obtained at the P rate of 225 kg/ha. It could be concluded that increasing the application of P fertilizer up to a certain level, the starch percentage increases, since then, the starch percentage decreased. The results were in agreement with the recent observation of Tang, et.al. (2011), who reported that an excessive amount of P is not conducive to the accumulation of sweet potato starch, other researchers such as Cai et.al. (2007), Wu et al. (2011) also found similar results with other crops. This result was similar to Li and Zhang (2012).

4.4.3.3 Soluble protein content

Analysis of variance (Table 4.3) showed that the P fertilizer rates were significant on soluble protein at 5% probability level. According to means comparison, among fertilizer rates, firstly, tuber soluble protein content increased with the P fertilizer, after a certain rate then showed a decreasing trend. The P fertilizer level of 165 kg/ha in high fertility soil produced the soluble protein (1.212 g/100g). While in low fertility soil the highest soluble protein content (1.105g/100g) was obtained at the P rate of 225 kg/ha. This study showed that the appropriate amount of P fertilizer was conducive to the accumulation of soluble protein when the amount of P fertilizer was greater than a certain extent, the soluble protein was no longer increased or even reduced. The results were in agreement with the recent observation of Tang, et.al. (2011), who reported that an excessive amount of phosphorus is not conducive to the accumulation of sweet potato soluble protein, other researchers such as Cai et.al. (2007), Wu et al. (2011) also found similar results with other crops.

4.4.3.4 Reducing sugar content

Analysis of variance (Table 4.3) showed that the P fertilizer rates were significant on the mean of reducing sugar at 5% probability level. According to means comparison, the results showed that among fertilizer rates, with the increasing of P application the reducing sugar decreased. This was in agreement with Tang et al. (2015) who reported that increases of P rates led to a lower amount of reducing sugars. The result of this study was also supported by that of Xu, et al. (2005). Sun et al. (2013) also had similar findings.

4.4.3.5 Dry matter content

P fertilizer rates were significant on dry matter percentage at 5% probability level. Among fertilizer rates, firstly, tuber dry matter percentage increased with the P fertilizer application, after a certain rate then showed a decreasing trend. Among the ten levels P fertilizer rates, the maximum (19.2%) dry matter percentage was recorded at the application of P 165 kg/ha in high fertility soil. While the maximum (17.5%) dry matter yield was recorded at the application of P 225 kg/ha in low fertility soil. The minimum was recorded on control in both soils. This result was similar to Meseret and Amin (2014) who reported that the appropriate amount of P fertilizer was conducive to the accumulation of dry matter percentage when the amount of P fertilizer was greater than a certain extent, the dry matter percentage was no longer increased or even reduced. This was in agreement with the study conducted on potato indicated that increasing the phosphorus concentration in the soil increased the whole plant dry matter accumulation (Li and Zhang, 2001). This increment in dry matter yield with application of P fertilizer might be due to the adequate supply of P could be attributed to an increase in the number of branches per plant and leaf area. This, in turn, increased photosynthetic area and number of per plant, which demonstrates a strong correlation with dry matter accumulation and yield (Meseret and Amin, 2014).

Table 4.3 The effect of P application on potato yield and quality.

TRT	Yield (kg/ha)		Starch (%)		Soluble protein (g/100g)		Reducing sugar (%)		Dry matter (%)	
	HF	LF	HF	LF	HF	LF	HF	LF	HF	LF
P_0	20,583 d	2,456f	46.1j	36.6j	0.981b	0.812e	0.601a	0.845a	14.7f	11.9f
P_{15}	22,083cd	3,414 e	51.6h	41.8i	1.012b	0.843e	0.572a	0.761b	15.5ef	12.5ef
P_{45}	23,194bcd	4,303d	57.7e	45.4h	1.158a	0.861de	0.566ab	0.743b	15.9de	13.6e
P_{75}	24,861abc	4,778c	61.5d	49.1g	1.176a	0.918cd	0.521bc	0.721b	16.8cd	14.8d
P_{105}	26,194ab	5,024c	63.4c	52.9f	1.185a	0.945c	0.486cd	0665c	17.4c	15.2cd
P_{135}	27,250a	5,436b	64.3b	54.4e	1.197a	0.967bc	0.471d	0.639c	18.3b	15.7bcd
P_{165}	27,639a	5,673ab	69.9a	58.5d	1.212a	0.983bc	0.463d	0.583d	19.2a	16.3abc
P_{195}	27,361a	5,703ab	56.2f	63.2c	1.182a	1.023b	0.442de	0.552d	17.2bc	16.8ab
P_{225}	24,722abc	6,001a	53.5g	65.6a	1.173a	1.105a	0.405ef	0.513e	16.8cd	17.5a
P_{255}	24,583abc	5,812a	48.6i	64.6b	1.154a	1.031b	0.391f	0.501e	16.5cd	16.2bc
Cv	7.4	3.9	0.5	0.7	2.8	4.7	6.4	4.8	2.9	4.6

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

4.4.4 Economic evaluation of P management for potato production

4.4.4.1 Maximum yield and P fertilizer rate application

In this experiment with the fixed N and K application, a response of potato yield to P rates was performed. A quadratic equation was well fitted for the relationship between potato yield and P application (Figure 4.1)

The response function used for the experiment in high soil fertility field was:

$$y=20{,}433+85.9x -0.276x^2,\ R^2=0.946 \quad (1)$$

The response function used for the experiment in low soil fertility field was:

$$y=2{,}815+29.5x -0.071\,x^2,\ R^2=0.971 \quad (b)$$

Where y is the yield of potato (kg/ha) and x is the application of P fertilizer (kg/ha). The results (Figure 4.1) showed that at low P level in both fields potato yield positively responded to P rate and reached the maximum at certain levels of P. After reaching the maximum, yield then gradually decreased with the increased P rate.

From the regression analysis of the quadratic model, the result showed that in high fertility soil maximum potato yield (27,117 kg/ha) was obtained at P rate of 156 kg/ha. While in low fertility soil maximum yield (5,879 kg/ha) was obtained at P rate of 208 kg/ha. These results reflected the limitation of available P in both fields but the P limitation was more in low fertility field.

The result was similar to Liu (2000) who reported that when the P application level was gradually increased, the corresponding increased production occurred. When the P consumption reached a certain level, for the increase of P resulted in stable or decreased production.

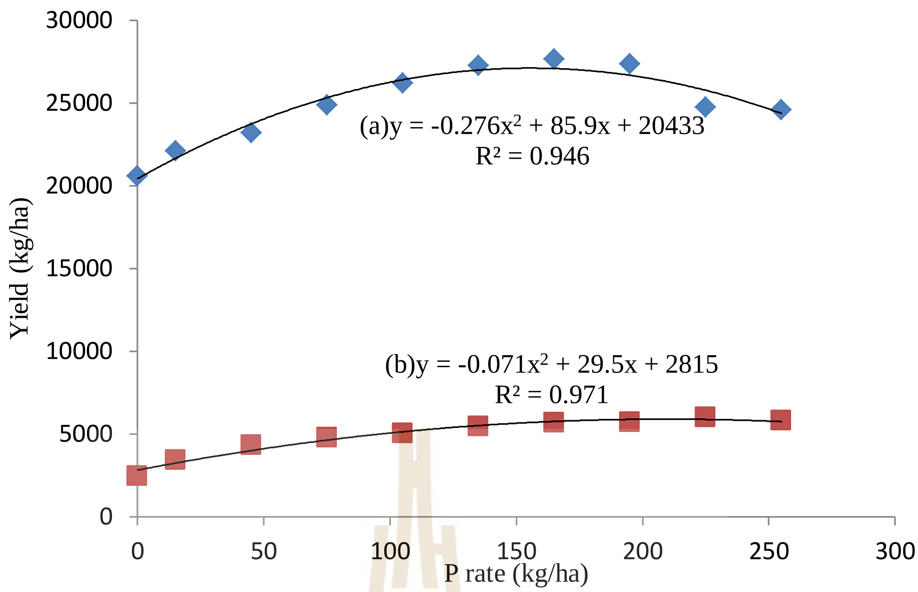

Figure 4.1 Relationship between the yield and the application of P fertilizer in high (a) and low (b) soil fertility fields.

4.4.4.2 The optimum P fertilizer rate and optimum yield price

The optimum application of fertilizer is then the quantity that will return the maximum net profit. The optimum yield price from fertilization is returned by the fertilizer application at which the monetary value of the optimum P fertilizer rate (Figure 4.2).

Where the response curve was represented by a mathematical function, the quantity of fertilizer that returns the optimum yield price was estimated mathematically. The process perhaps can be understood most easily if the yield response function is first multiplied by the price per unit of the crop to convert the function to monetary units. Then the procedure can be visualized in terms (Fig.4.2).

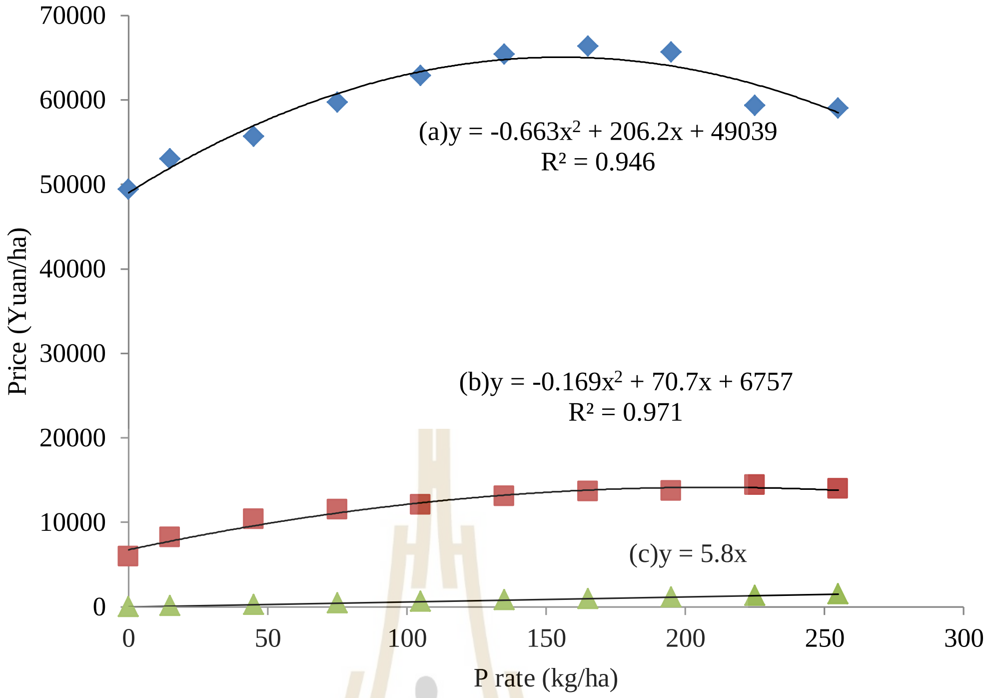

Figure 4.2 Relationship between the monetary value and the application of P fertilizer and monetary values in high (a), low (b) fertility fields and fertilizer price (c).

In these two experiments the P fertilizer was side dressed alone in different quantities, and the response function used for these two experiments was

$$\text{Quadratic function } y=a+bx+cx^2$$

Where y is the monetary value of potato per hectare and x is the application of fertilizer P in kilograms per hectare.

$$y=49{,}039+206x-0.663x^2,\ R^2=0.946 \text{ (high fertility soil)} \qquad (1)$$

and

$$y=6{,}757+70.7x-0.169x^2,\ R^2=0.971 \text{ (low fertility soil)} \qquad (b)$$

With P fertilizer at 5.8 Yuan per kilogram, the total costs of P fertilizer in Yuan per hectare thus were

$$y=5.8x \quad \text{(c)}$$

Where y is the cost of P fertilizer and x is P rate.

On the economic benefits, mainly due to economic output and overall performance, value, cost, and other aspects increasing P fertilizer can increase yield and production value, but the corresponding costs are also increased. Therefore, the process does not represent the maximum yield can produce the highest economic benefits. The maximum benefits can be obtained when marginal costs are equal marginal output and profit margin is zero. By calculation of these two equations as described in section 3.3.6, the optimum P fertilizer application in high fertility soil was 151 kg/ha and the optimum yield price was 65,058 Yuan/ha; and the most economical P fertilizer application in low fertility soil was 192 kg/ha with the optimum yield price of 14,101 Yuan/ha.

4.4.4.3 Maximum net profit

From the calculated result, the maximum net profit was 40,542 Yuan/ha in high soil fertility field while it was -6,153 Yuan/ha in low soil fertility field (Table 4.4). There was a negative value in the low fertility soil, probably due to the limitation of N and K in this soil and the amount of N and K fertility application was too low to get the optimum yield. This result also showed that it was not suitable for investment in low fertility soils. A similar result was reported by Qi et al. (2001). However, other researchers (Krzymanski, 1970; Zhou and Liu, 1987; Mou and Liu,

1990) have not found the negative profit of P application as they did not include all cost in their calculation. In this study, all cost including labor coat and land rent was included in the analysis.

Table 4.4 Maximum net profit and benefit cost ratio in potato production.

Field	P Cost	Fixed C	Total C	OYP	MNP	BCR
			(Yuan/ha)			
HF	876	23,640	24,516	65,058	40,542	1.71
LF	1,114	19,140	20,254	14,101	-6,153	-0.30

4.4.4.4 Benefit cost ratio in potato production

Total costs of production, including the cost of all fertilizers, seed, pesticide, labor, and land rent were estimated. In high fertility soil field, total cost was 24,516 Yuan/ha and it was 20,254 Yuan/ha in low fertility soil field (Table 4.4). In high soil fertility field, the benefit cost ratio in potato production was 1.71 and in low soil fertility field it was -0.3. The results indicated that it was economic to invest only in high fertility soil. In the low fertility soil field, improve production by fertilization was not enough. It was more important to improve soil fertility which has been reported by Li (2010).

The overall results indicated that application of P fertilizer is one of the main measures to improve potato yield, but an unreasonable application of P fertilizer is not only difficult to achieve high yield but also causes P fertilizer waste, pollutes the environment. Over the years, many researchers have done a lot of research on the application of P fertilizer, the rational application of P fertilizer and the utilization of P, which has played an important guiding role in realizing the high yield, high quality, high efficiency and reducing the loss of P fertilizer. Almost all of the researchers conducted the experiments in the same soil under some conditions of soil fertility. However, for the analysis of economic information must be determined in various soil conditions. In Guizhou, very few researches have been done for determining the appropriate P application rate. The results of this study could contribute to the recommendation of P fertilization for production in Guizhou.

4.5 Conclusion

Proper P management was one of the most important factors required to obtain high yield of excellent quality potatoes. The P rates that give the maximum and optimum yield were evaluated. Results showed proper P management is one of the most important factors required to obtain high yield of excellent quality potatoes. Increasing P fertilizer resulted in increments of potato yield starch soluble protein and dry matter, then as P rate still increased yield, starch, soluble protein, and dry matter did decreasing trend. Increased P rates resulted in reduced the reducing sugar content of potato tubers.

In high fertility soil, when applied P reached 156 kg/ha, yield reached maximum at 27,117 kg/ha; in low fertility soil, when applied P reached 208 kg/ha, yield reached maximum at 5,879 kg/ha. However, P rate for the maximum yield did not produce the maximum profit. In two different soil fertility fields, the result showed that: in high soil fertility field, P rate of 151 kg/ha, resulted to the optimum yield price of 65,058 Yuan/ha; In low soil fertility field, P rate of 192 kg/ha, produced the optimum yield price of 14,101Yuan/ha. The maximum net profit was 40,542 Yuan/ha in high soil fertility field and -6,153 Yuan/ha in low soil fertility field. Benefit cost ratio in potato production was 1.71 in high soil fertility field while in low soil fertility field it was -0.30.

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CHAPTER V

ECONOMIC EVALUATION OF NUTRIENT K MANAGEMENT FOR POTATO PRODUCTION IN GUIZHOU

5.1 Abstract

In this chapter, two field experiments were conducted to study the effects of K rates on yield and quality of potato in different soil fertility fields in Huishui County, Guizhou, China. Ten rates of K (0-405 kg/ha) were applied with the fixed amount of N and P. The K rates that give the maximum and optimum yield were evaluated. Results showed that increasing K fertilizer resulted in increments of potato yield, plant height, LAI, starch, soluble protein, and dry matter, then as K rate still increased, potato yield, plant height, LAI, starch, soluble protein, and dry matter did decreasing trend. Increased K rates resulted in reduced the reducing sugar content of potato tubers.

In high soil fertility field, when applied K reached 218 kg/ha, yield reached the maximum at 27,689 kg/ha; in low soil fertility field, when applied K reached 443 kg/ha, yield reached the maximum at 5,814 kg/ha. However, K rate for the maximum yield did not produce the maximum profit. In two different soil fertility fields, the result showed that: in high soil fertility field, K rate of 210 kg/ha, resulted in the optimum yield price of 66,423 Yuan/ha; In low soil fertility field, K rate of 341 kg/ha, resulted in the optimum yield price of 13,489 Yuan/ha. The maximum net profit was 42,100 Yuan/ha in high soil fertility field and -6,740 Yuan/ha in low soil fertility field.

Benefit cost ratio in potato production was 1.73 in high soil fertility field while in low soil fertility field it was -0.33.

5.2 Introduction

Potato plants require much more potassium than many other vegetable crops. An adequate supply of potassium strengthens stems to prevent lodging, increases yield and improves tuber quality (Ibrahim et al., 1987; Omran et al., 1991).

Excess K fertilizer was reported to reduce dry matter or specific gravity (Schippers, 1968; Westermann et al., 1994). There is a general belief among farming communities that a higher and a better quality yield of potato crop is always obtained when K is added in quantities. Although the potato crop requires a heavy input of K for high yields (Errebhi et al., 1998), adequate levels should be established for economic yields and sustainable productivity. It is well documented that K affects potato quality and yield. Insufficient K results in reduced potato yield and smaller-sized tubers (McDole, 1978; Satyanarayana and Arora, 1985). Other workers found that a significant tuber yield responses to K fertilization (Westermann et al., 1994; Panique et al., 1997).

In China, there were numerous studies about K fertilizer application on potato. Most of them reported that add K can increase potato quality and yield, but fewer information reported the optimum K fertilizer application (Lu, 2005; Li, 1999; Yin et al., 2005; Liu et al., 2008; Guo, 2007; Guo, 2008; Xu, 2007;). Xia (2008) reported that when K_2O application amount in 150 kg/ha to 225 kg/ha plants growing well, and to obtain better yield and the large tubers. Applied 375 kg/ha K_2O can significantly improve the vitality of the root; It can also increase the amount of dry matter percentage, K content, and protein content. But it could not promote high yield.

Objectives of this experiment were: (1) To get the relationship between K fertilizer and potato production. (2) To determine the optimum quantity of K fertilizer application. (3) To determine the maximum net profit from K fertilization. (4) To evaluate the benefit cost ratio in potato production.

5.3 Materials and Methods

5.3.1 Plant seed

Favorita, an early maturing high- yield potato variety was used in this study. The details of this variety have been given in section 3.3.1. (Chapter III)

5.3.2 Fertilizer

Urea (46% N) was used as N source. K_2SO_4 (50% K_2O) was used as K source. Ordinary superphosphate (12% P_2O_5) was used as P source in these two experiments.

5.3.3 Experiments site

Experiments were conducted at Huishui County, Guizhou, China, from January 2011 to June 2011. Two different soil fertility areas (low and high), and the areas were selected after the soil samples were analyzed for fertility base on the standard requirement of potato. The soil analysis results were performed as chapter III (section 3.3.3).

5.3.4 Experimental Design:

Ten treatments of K application rates were arranged in the randomized complete block design (RCBD), with 3 replications. Two experiments (Table 5.1) were carried out in two different soil fertility areas (low and high soil fertility fields). The amount of the N fertilizer was designed to be 113 kg/ha and the amount of P fertilizer was 56 kg/ha. 40% of N fertilizer was used as basal fertilizer by row application at the seeding time, 30% of N was used as the first top dressing during the budding stage and 30% of N was used as the second top dressing during the flowering stage. Individual plots were 2 m in width and 6 m in length and were separated from adjacent plots by a 0.5 m wide plant-free border. Each plot consisted 4 rows. Seeding was completed at a hill spacing of 0.375 m×0.5 m with one seed in per hill, 64 hills in one plot. During the growing period, the pesticide was used for twice when insect incidence occurred. Supplement irrigation was done once due to less rainfall. Weeding was done for twice.

Table 5.1 Ten treatments of K fertilizer application rates.

Treatment	**Total K fertilizer (kg/ha)**
K_0 (ck)	0
K_1	45
K_2	90
K_3	135
K_4	180
K_5	225
K_6	270
K_7	315
K_8	360
K_9	405

5.3.5 Data collection and analysis

Data collection and analysis were performed as the chapter III (section 3.3.5 and 3.3.6)

5.4. Results and Discussion

5.4.1 Growing Condition

Average daily temperature data for the 2011 January to May growing seasons are shown in (Appendix: Attached figure 1 and 2). The details have been given in section 3.4.1. (Chapter III)

5.4.2 The growth of potato

5.4.2.1 Plant height

It can be seen (Table 5.2) that the plant height of the potato in the high-fertility field was much higher than that of the low-fertility field, which indicates that the high-fertility soil is favorable for the potato growth. In two fertility soils, the plant height increased first and then decreased with the increase of K application rate. Analysis of variance (Table 5.2) showed that K fertilizer rates were significant on mean plant height at 5% probability level. Application of 225 kg/ha gave rise to the greatest mean plant height of 50.1 cm in high fertility soil. In low fertility soil, application of 360 kg/ha gave rise to the greatest mean plant height of 33.7 cm. It could be concluded that increasing the application of phosphate fertilizer is conducive to improving the plant height of potato when the fertilizer increased to a certain extent, plant height will not increase but decreased, indicating that K fertilizer should be appropriate. A study by Al-Moshileh and Errebi (2004) reported a similar effect of K fertilizer on plant height. De Datta (1981) reported that plants grown without K fertilizer produced the shortest plant. He also reported stunted plant height due to deficiency of K fertilizer. The result of this study was supported by that of Li and Zhang (2012) who reported an appropriate increase of K fertilizer is conducive to increase the plant height of potato.

5.4.2.2 Leaf area index

As the same with plant height, the leaf area index of potato in high-fertility soil was higher than that of low-fertility soil. In two fertility soils, the leaf area index increased first and then decreased with the increase of K application rate. Analysis of variance (Table 5.2) showed that K fertilizer rates were significant on the mean of Leaf area index at 5% probability level. Among K fertilizer levels, the highest leaf area index (3.44) in high fertility soil and (1.51) in low fertility soil were recorded at rate application of K 225 kg/ha in high fertility soil and 360 kg/ha in low fertility soil. It might be due to K response dependence on available K in the study site and when it is above the optimum level it may interrupt other nutrients, which in turn can bring a decrease in growth of potato. Similar results were found by other researchers (Dong et al., 2007; Delourme et al., 2006).

5.4.3 Yield and quality

5.4.3.1 Fresh Tuber Yield

Analysis of variance (Table 5.3) showed that the K fertilizer rates were significant on fresh tuber yield at 5% probability level. Fresh tuber yield in high soil fertility field was much more than that in low soil fertility field. Among fertilizer levels, the K fertilizer level of 225 kg/ha in high fertility soil produced the highest yield (29,630 kg/ha). While in low fertility field the highest yield (6,333 kg/ha) was obtained at the K rate of 360 kg/ha. It could be concluded that increasing the application of K fertilizer up to a certain level, the yield increased, but since then, the yield decreased. The result of this study was supported by that of Al-Moshileh and Errebi (2004) who studied the influence of different levels of K fertilizer on yield attributes of potato. The results showed that an appropriate increase of K fertilizer is conducive to increase the yield of potato. According to Xu and Guo (2010) experiments, excessive application of K fertilizer was not always lead to higher yields which were confirmed in this study.

Table 5.2 The effect of K application on potato growth.

TRT	Plant height (cm)		LAI	
	HF	LF	HF	LF
K_0	46.1f	24.1h	2.13d	1.05 f
K_{45}	46.5ef	24.8g	2.21d	1.17e
K_{90}	46.7e	26.8f	2.49c	1.23de
K_{135}	47.7d	27.3f	2.54c	1.25d
K_{180}	48.4c	28.9e	2.97b	1.34c
K_{225}	50.1a	29.5d	3.44a	1.39bc
K_{270}	49.3b	30.7c	3.39a	1.44ab
K_{315}	48.6c	32.5b	3.32a	1.48a
K_{360}	48.5c	33.7a	3.28a	1.51a
K_{405}	48.3c	32.8b	3.24a	1.48a
Cv(%)	1.2	2.2	4.6	3.4

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

5.4.3.2 Starch content

Starch percentage showed a similar trend as yield. Analysis of variance (Table 5.3) showed that the K fertilizer rates were significant on the mean of starch percentage at 5% probability level. According to means comparison table, among fertilizer rates, starch percentage, the maximum (70.8%) starch percentage was recorded at the application of K 225 kg/ha in high soil fertility field. While the maximum (62.1%) starch was recorded at the application of K 360 kg/ha in low soil fertility field. It could be concluded that increasing the application of K fertilizer up to a certain level, the starch percentage increases, since then, the starch percentage decreased. This result was supported by that of Xu and Guo (2010) who reported that the appropriate amount of K fertilizer was conducive to the accumulation of starch percentage when the amount of K fertilizer was greater than a certain extent, the starch percentage was no longer increased or even reduced. Lu (2007) also had a similar finding.

5.4.3.3 Soluble protein content

Analysis of variance (Table 5.3) showed that the K fertilizer rates were significant on soluble protein at 5% probability level. According to means comparison table, among fertilizer rates, firstly, tuber soluble protein content increased with the K fertilizer, after a certain rate then showed a decreasing trend. In the high soil fertility field, the soluble protein content in treatment K 225 was the highest. In the low soil fertility field, the soluble protein content in treatment K 360 was the highest. This study showed that the appropriate amount of K is conducive to the accumulation of protein, when the amount of K fertilizer was greater than a certain extent, the protein was no longer increased or even reduced, The results were in agreement with the recent observation of Tang, et al. (2011), who reported that an excessive amount of K is not conducive to the accumulation of sweet potato protein content. Other researchers such as Cai, et al. (2007), Wu, et al. (2011) did experiments on soybeans and got similar results.

5.4.3.4 Reducing sugar content

Analysis of variance (Table 5.3) showed that the K fertilizer rates were significant on the mean of reducing sugar at 5% probability level. According to means comparison, among fertilizer rates, the results showed that among fertilizer rates, with the increasing of K application the reducing sugar decreased. This was in agreement with Bansali and Trehan (2011) who reported that a higher dose of K leads to a lower amount of reducing sugars content. The result of this study was also supported by that of Gerendas et al. (2007) who reported that increases of K rates leaded to a lower amount of reducing sugars. Westermann et al. (1994), Nikolova and Blagoeva (2000) also had similar findings.

5.4.3.5 Dry matter content

K fertilizer rates were significant on dry matter percentage at 5% probability level. According to means comparison, among fertilizer rates, firstly, tuber dry matter percentage on the tent increased with the K fertilizer, after a certain rate then showed a decreasing trend. Among ten levels K fertilizer rates, the maximum (18.9%) dry matter percentage was recorded at the application of K 225 kg/ha in high soil fertility field. While the maximum (16.2%) dry matter yield was recorded at the application of K 360 kg/ha in soil fertility field. The minimum was recorded on control in both soils. This result was similar to Xu and Guo (2010) who reported that the appropriate amount of K fertilizer was conducive to the accumulation of dry matter percentage when the amount of K fertilizer was greater than a certain extent, the dry matter percentage was no longer increased or even reduced.

5.4.4 Economic evaluation of K management for Potato Production

5.4.4.1 Maximum yield and K fertilizer rate application

In this experiment with the fixed N and P application, a response of potato yield to K rates was performed. A quadratic equation was well fitted for the relationship between potato yield and K application (Figure 5.1)

The response function used for the experiment in high soil fertility field was:

$$y=19{,}473+75.4x -0.173x^2,\ R^2=0.887 \quad \text{(a)}$$

The response function used for the experiment in low soil fertility field was:

$$y=2{,}866+13.3x -0.015x^2,\ R^2=0.920 \quad \text{(b)}$$

Where y is the yield of potato (kg/ha) and x is the application of K fertilizer (kg/ha). The results (Figure 5.1) showed that at low K level in both fields potato yield positively responded to K rate and reached the maximum at certain levels of K. After reaching the maximum, yield then gradually decreased with the increased K rate.

From the regression analysis of the quadratic model, the result showed that in high fertility soil maximum potato yield (27,689 kg/ha) was obtained at K rate of 218 kg/ha. While in low fertility soil maximum yield (5,814 kg/ha) was obtained at K rate of 443 kg/ha. These results reflected the limitation of available K in both fields but the K limitation was more in low fertility field.

Table 5.3 The effect of K application on potato yield and quality.

TRT	Yield (kg/ha)		Starch (%)		Soluble Protein (g/100g)		Reducing Sugar (%)		Dry matter (%)	
	HF	**LF**	**HF**	**LF**	**HF**	**LF**	**HF**	**LF**	**HF**	**LF**
K_{0}	19,444e	2,667h	42.5 h	35.5 g	0.789d	0.675d	0.652a	0.852a	16.9c	13.3d
K_{45}	21,852de	3,667g	48.2g	36.7f	0.932c	0.872c	0.583b	0.783b	17.7b	13.9cd
K_{135}	26,301abc	4,417ef	52.8e	43.6d	1.034bc	0.935bc	0.534cd	0.732c	18.4ab	14.9abc
K_{180}	26,482ab	4,667def	56.2d	44.7d	1.051bc	1.012ab	0.498de	0.683d	18.6a	15.1abc
K_{225}	29,630a	4,917cde	70.8 a	56.9 c	1.245a	1.023a	0.483e	0.652d	18.9a	15.3abc
K_{270}	26,851abc	5,083bcd	69.3 b	57.8 c	1.136ab	1.045a	0.475 ef	0.591e	18.7a	15.6ab
K_{315}	25,185bc	5,583b	61.3c	61.5 a	1.102b	1.055a	0.468ef	0.564ef	18.6a	15.9ab
K_{360}	23,333bcd	6,333a	57.2 d	62.1a	1.053bc	1.102a	0.432fg	0.526fg	18.3ab	16.2a
K_{405}	22,592cde	5,389bc	56.3d	60.3b	1.014bc	1.035a	0.411g	0.517g	18.2ab	15.5ab
Cv(%)	8.2	7.0	1.2	1.3	6.8	4.6	6.2	4.7	2.1	5.4

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

The result was similar to Liu (2000) and other studies. They also showed that when the K application level was gradually increased, the corresponding increased production occurred. When the K consumption reaches a certain level, for the increase of K resulted in stable or decreased production.

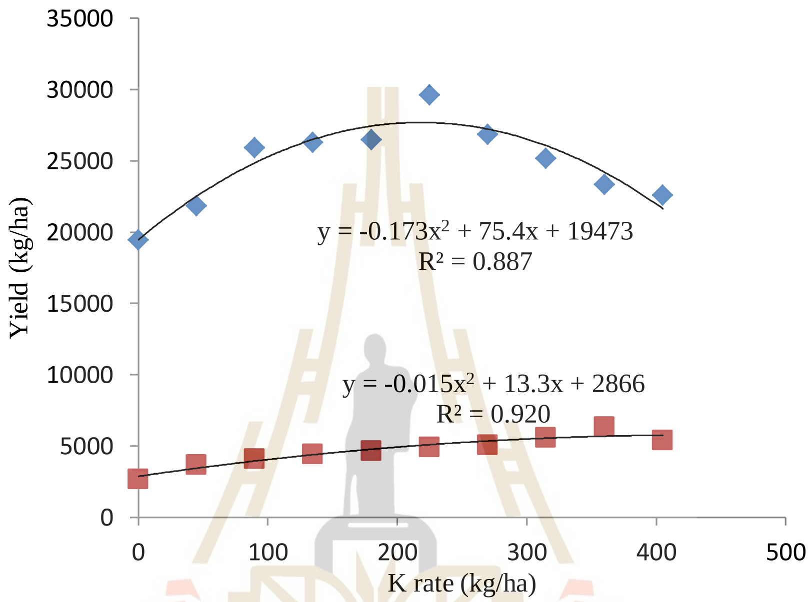

Figure 5.1 Relationship between the yield and the application of K fertilizer in high (a) and low (b) soil fertility fields.

5.4.3.2 Optimum K application and optimum yield price

The application of economic principles to fertilizer use is usually illustrated by the relatively uncomplicated situation in which the supply of capital is ample and no other investment possibilities would yield a more profitable return. The optimum application of fertilizer is then the quantity that will return the maximum net profit.

The optimum yield price from fertilization is returned by the fertilizer application at which the monetary value of the optimum K fertilizer rate (Figure 5.2)

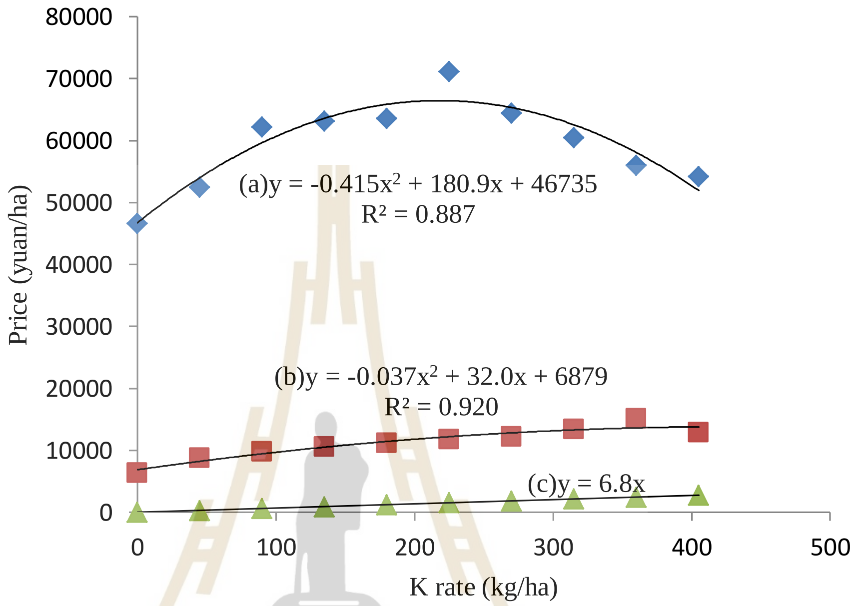

Figure 5.2 Relationship between the monetary value and the application of P fertilizer and monetary values in high (a), low (b) fertility fields and fertilizer price (c).

Where the response curve was represented by a mathematical function, the quantity of fertilizer that returns the optimum yield price was estimated mathematically. The process perhaps can be understood most easily if the yield response function is first multiplied by the price per unit of the crop to convert the function to monetary units. Then the procedure can be visualized in terms (Figure 5.2).

In these two experiments the K fertilizer was side dressed alone in different quantities, and the response function used for these two experiments was

Quadratic function $y=a +bx +cx^2$

Where y is the monetary value of potato per hectare and x is the application of fertilizer K in kilograms per hectare.

$$y=46,375 +181x-0.415x^2 , R^2=0.887 \text{ (high fertility soil)} \qquad (a)$$

and

$$y=6,879 +32.0x-0.037x^2, R^2=0.920 \text{ (low fertility soil)} \qquad (b)$$

With K fertilizer at 6.8 Yuan per kilogram, the total costs of K fertilizer in Yuan per hectare thus were

$$y=6.8x \qquad (c)$$

Where y is the cost of K fertilizer and x is K rate.

On the economic benefits, mainly due to economic output and overall performance, value, cost, and other aspects increasing K fertilizer can increase yield and production value, but the corresponding costs are also increased. Therefore, the process does not represent the maximum yield can produce the highest economic benefits. The maximum benefits can be obtained when marginal costs are equal marginal output and profit margin is zero. By calculation of these two equations as described in section 3.3.6, the optimum K fertilizer application in high soil fertility field was 210 kg/ha and the optimum yield price was 66,423 Yuan/ha; and the optimum K fertilizer application in soil fertility field was 341 kg/ha with the optimum yield price of 13,489 Yuan/ha.

5.4.3.3 Maximum net profit

From the calculated result, the maximum net profit was 42,100 Yuan/ha in high soil fertility field while it was -6,740 Yuan/ha in low soil fertility field. There was a negative value in the low fertility soil field, probably due to the limitation of N and P in this soil and the amount of N and P fertility application was too low to get the optimum yield. This result also showed that it was not suitable for investment in low fertility soil fields. Some researchers (Krzymanski, 1970; Zhou and Liu, 1987; Mou and Liu, 1990) have not found the negative profit of K application as they did not include all cost in their calculation. In this study, all cost including labor coat and the land rent was included in the analysis.

Table 5.4 Maximum net profit and benefit cost ratio in potato production.

Field	Cost K	Fixed C	Total C	OYP	MNP	BCR
			Yuan/ha			
HF	1,428	22,895	24,323	66,423	42,100	1.73
LF	2,319	18,395	20,229	13,489	-6,740	-0.33

5.4.3.4 Benefit cost ratio in potato production

Total costs of production, including the cost of all fertilizers, seed, pesticide, labor and land rent. In high soil fertility field, total cost was estimated at 24,323 Yuan/ha and it was 20,229 Yuan/ha in low soil fertility field (Table 5.4). In high soil fertility field the maximum the benefit cost ratio in potato production was 1.73 Yuan, in low soil fertility field the benefit cost ratio in potato production was

-0.33 Yuan. The results indicated that it was economic to invest in high soil fertility field than in low soil fertility field.

The overall results indicated that application of K fertilizer is one of the main measures to improve potato yield, but an unreasonable application of K fertilizer is not only difficult to achieve high yield but also causes K fertilizer waste, pollutes the environment. Over the years, many researchers have done a lot of research on the application of K fertilizer, the rational application of K fertilizer and the utilization of K, which has played an important guiding role in realizing the high yield, high quality, high efficiency and reducing the loss of K fertilizer. Almost all of the researchers conducted the experiments in the same soil under the conditions of soil fertility. However, for the analysis of economic information must be determined in various soil condition. In Guizhou, very few researches have been done for determining the appropriate K application rate. The results of this study could contribute to the recommendation of K macronutrient for production in Guizhou.

5.5 Conclusion

Proper K management is one of the most important factors required to obtain high yield of excellent quality potatoes. The K rates that give the maximum and optimum yield were evaluated. Results showed that increasing K fertilizer resulted in increments of potato yield, starch, soluble protein, and dry matter, then as K rate still increased yield, starch, soluble protein, and dry matter did decreasing trend. Increased K rates resulted in the reduction of the reducing sugar content of potato tubers.

In high soil fertility field, when applied K reached 218 kg/ha, yield reached the maximum at 27,689 kg/ha; in low soil fertility field, when applied K reached 443 kg/ha, yield reached the maximum at 5,814 kg/ha. However, K rate for the maximum yield did not produce the maximum profit. The result showed that: in high soil fertility field, applied the optimum K rate of 210 kg/ha, resulted in the optimum yield price of 66,423 Yuan/ha; In low soil fertility field, applied the optimum K rate of 341 kg/ha, resulted in the optimum yield price of 13,489 Yuan/ha. The maximum net profit was 42,100 Yuan/ha in high soil fertility field and -6,740 Yuan/ha in low soil fertility field. Benefit cost ratio in potato production was 1.73 in high soil fertility field while in low soil fertility field it was -0.33.

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CHAPTER VI

EFFECTS OF NPK COMBINED APPLICATION ON POTATO PRODUCTION

6.1 Abstract

The objective of this section was to study the effects of N P K combined application on potato. Two field experiments were conducted to study the effects of N, P, and K rates on yield and quality of potato in different soil fertility fields in Huishui County, Guizhou, China. Ministry of Agriculture, recommended the use of "3414" optimal regression design, a total of three factors 4 level 14 treatments of N P K application rates were arranged in the randomized complete block design (RCBD), with 3 replications. The N P K rates that give the maximum and optimum yield were evaluated. From the regression analysis of the quadratic model, the result showed that in high fertility soil maximum potato yield (31,863 kg/ha) was obtained at the rate of N 233 kg/ha, P180 kg/ha, and K171 kg/ha. While in low soil fertility field maximum yield (10,293 kg/ha) was obtained at N 270 kg/ha, P170 kg/ha, and K259 kg/ha. The optimum N P K fertilizer application in high fertility soil was N 228 kg/ha, P 180 kg/ha, K 152 kg/ha and net profit from fertilization was 48,199 Yuan/ha. While in low fertility was N 253 kg/ha, P156 kg/ha, K 232 kg/ha and net profit from fertilization was -248 Yuan/ha.

Comparing the results of all four experiments, the recommended amount of N P K fertilizer rates were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha in high soil

fertility field. From the overall results, the low soil fertility field was not suitable for planting potatoes under current soil conditions. In order to grow potatoes in low soil fertility fields, it should improve the soil fertility and soil structure by using organic fertilizers and soil amendments.

6.2 Introduction

Due to the low level of potato fertilization in Guizhou and the unreasonable fertilization structure, the yield of potato has been seriously affected. Therefore, according to the characteristics of potato growth and development and nutrient demand characteristics and soil characteristics and nutrient supply capacity, the use of scientific fertilization method is to obtain high quality, high yield of important technical measures. According to the Chinese Academy of Agricultural Sciences crop breeding and cultivation, the institute reported that the optimum fertilization rate is N 147 kg/ha, P 100.5 kg/ha, K 375 kg/ha and the yield is 26094 kg/ha (Chen and Zhang, 2009). There are many studies on potato balanced fertilization, because of the differences in natural cultivation and management (Chen et al., 2000; Li et al., 1999; Lou et al., 2008; Zhang et al., 2007; Zhang et al., 2004). However, there were fewer reports about the optimum N P K fertilization rate in Guizhou. Therefore, it was necessary to carry a study to evaluate the optimum N P K rate in this area.

“3414” fertilizer effect test program is the Ministry of Agriculture, "Fertilization technical specification (Trial) Revised" recommended design adopted is a quadratic regression D~optimal design refers to N P and K three factors, four levels, 14 processing. The program designed to absorb the best regression designed to handle small, high-efficiency advantages, in line with the requirements of professional testing and fertilizer making fertilizer (Wang et al., 1998; Wang et al., 2002; Yan et al., 2008; Ling et al., 2010). By now, the "3414" test is the main method in fertilization experiments, and it is suitable for most plants (Lv et al., 2013). The "3414" test refers to the fertilizer experiments including 3 factors (N, P, K), 4 levels and 14 treatments of fertilizers. The scheme is designed to take advantage of optimal regression design of little treatments and high efficiency. The meaning of the four levels is as follows. The zero level means no fertilizer. The second level is the best fertilizer level for the local approximation. The standard level = second level, first level = second level×0.5, third level = second level×1.5 (this level is over-fertilization). The test field is divided into 14 treatments blocks, and each level in these treatments has a different NPK fertilization amount (Cheng and Zhang, 2006).

In this chapter, potato was evaluated to investigate the effect of different N P K rates on yield formation and quality. The objectives of this experiment were: (1) To study the relationship between N P K fertilizer and potato production. (2) To determine the optimum quantity of N P K fertilizer application (3) To determine the maximum net profit from N P K fertilization. (4) To evaluate the benefit cost ratio in potato production. (5) Recommended N P K fertilizer application rate for potato production.

6.3 Materials and Methods

6.3.1 Plant seed

Favorita, an early maturing high- yield potato variety was used in this study. The details of this variety have been given in section 3.3.1. (Chapter III)

6.3.2 Fertilizer

Urea (46% N) was used as N source. K_2SO_4 (50% K_2O) was used as K source, and ordinary superphosphate (12% P_2O_5) was used as P source in these two experiments.

6.3.3 Experiments site

Experiments were conducted at Huishui County, Guizhou, China, from January 2011 to June 2011. Two different soil fertility areas (low and high), and the areas were selected after the soil samples were analyzed for fertility base on the standard requirement of potato. The soil analysis results were performed as chapter III (section 3.3.3).

6.3.4 Experimental Design:

Ministry of Agriculture, recommended the use of "3414" optimal regression design, a total of three factors 4 level 14 treatments of N P K application rates were arranged in the randomized complete block design (RCBD), with 3 replications. Two experiments (Table 6.1) were carried out in two different soil fertility areas (low and high soil fertility). Testing and treatment factors that level, as shown in Table 6.1 and Table 6.2. All P and K were used as basal fertilizer, 40% of N fertilizer was used as basal fertilizer by row application at the seeding time, 30% of N was used as the first top dressing during the budding stage and 30% of N was used as the second top dressing during the flowering stage. Individual plots were 2 m in width and 6 m in length and were separated from adjacent plots by a 0.5 m wide plant-free border. Each plot consisted of 4 rows. Seeding was completed at a hill spacing of 0.375 m×0.5 m with one seed per hill, 64 hills in one plot. During the growing period, the pesticide was used twice when insect incidence occurred. Supplement irrigation was done once due to less rainfall. Weeding was done twice.

Table 6.1 Treatments of potato fertilization trial based on the"3414"design.

Fertilizer level	N	P_2O_5	K_2O
	(kg/ha)		
0	0	0	0
1	90	60	120
2	180	120	240
3	270	180	360

Table 6.2 14 treatments of NPK fertilizer application rates.

No.	Treatment	Level			Fertilization (kg/ha)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	$N_0P_0K_0$	0	0	0	0	0	0
2	$N_0P_2K_2$	0	2	2	0	120	240
3	$N_1P_2K_2$	1	2	2	90	120	240
4	$N_2P_0K_2$	2	0	2	180	0	240
5	$N_2P_1K_2$	2	1	2	180	60	240
6	$N_2P_2K_2$	2	2	2	180	120	240
7	$N_2P_3K_2$	2	3	2	180	180	240
8	$N_2P_2K_0$	2	2	0	180	120	0
9	$N_2P_2K_1$	2	2	1	180	120	120
10	$N_2P_2K_3$	2	2	3	180	120	360
11	$N_3P_2K_2$	3	2	2	270	120	240
12	$N_1P_1K_2$	1	1	2	90	60	240
13	$N_1P_2K_1$	1	2	1	90	120	120
14	$N_2P_1K_1$	2	1	1	180	60	120

Note: 0 means CK, without fertilization; 2 normal fertilization amount; 1 half of normal fertilization amount; 3 one and a half times of normal fertilization amount.

6.3.5 Data collection and analysis

Data collection was performed as the same as the chapter III (section 3.3.5 and 3.3.6)

Data analysis: Analysis of variance was performed using Statistical Package for the Social Sciences (SPSS) for Window (version 16). Regression analysis was used to determine the yield response curve to fertilizer rates. The response to N P K was studied by fitting quadratic response equations for total tuber yield as shown below.

$$y = b_0 + b_1N + b_2P + b_3K + b_4N^2 + b_5P^2 + b_6K^2 + b_7NP + b_8NK + b_9PK$$

In which y was total tuber yield (kg/ha); N, P, and K were the rate of N, P, and K fertilization (kg/ha); b_0 to b_9 were constants. Analysis of 3414 test was performed using Data Processing System (DPS) for Window (version 13.0) and Excel 2010.

6.4. Results and Discussion

6.4.1 Growing condition

Average daily temperature data for the 2011 January to May growing seasons are shown in (Appendix: Attached figure 1 and 2). The details have been given in section 3.4.1. (Chapter III)

6.4.2 The growth of potato

6.4.2.1 Plant height

It can be seen (Table 6.3) that the height of the potato in the high soil fertility field was much higher than that of the low soil fertility field, which indicated that the high-fertility soil was favorable for the potato growth. In both fertility soils, analysis of variance (Table 6.3) showed that N P K fertilizer rates were significant on the mean of plant height at 5% probability level. Application of N180 kg/ha, P 120 kg/ha, K 240 kg/ha gave the highest mean plant height of 48.6 cm in high soil fertility field. In low soil fertility field, application of N 270 kg/ha, P 120 kg/ha, K 240 kg/ha gave the highest mean plant height of 39.1 cm. It could be concluded that increasing the application of N P and K fertilizer was conducive to improving the plant height of potato. However, when the fertilizer increased to a certain extent, plant height did not increase but tended to decrease, indicating that N P and K fertilizer should be appropriate. It was agreed with Ling et al. (2010) who reported that potato height in high-fertility soil was higher than that in the low-fertility soil. They also reported that appropriate N P K application was conducive to the improvement of plant height.

6.4.2.2 Leaf area index

The leaf area index of potato in high soil fertility field was higher than that of low soil fertility field. In two fertility soils, analysis of variance (Table 6.3) showed that N, P and K fertilizer rates were significant on the mean of leaf area index at 5% probability level. Among N P K fertilizer levels, application of N 180 kg/ha, P 120 kg/ha, K 240 kg/ha gave the highest mean leaf area index of 3.35 in high soil fertility field. In low soil fertility field, application of N 270 kg/ha, P 120 kg/ha, K 240 kg/ha gave the highest mean of 1.73. Similar results were found by Ling et al. (2010) who reported that potato leaf area index in high-fertility soil was higher than that in the low-fertility soil. It might be because of that the basic fertility was higher and was more conducive to plant growth.

Table 6.3 The effect of N P K application on potato plant height and LAI.

No.	TRT	Plant height (cm)		LAI	
		HF	LF	HF	LF
1	$N_0P_0K_0$	35.8i	25.6f	2.03f	1.14g
2	$N_0P_2K_2$	44.7h	29.0e	2.25e	1.35def
3	$N_1P_2K_2$	47.3ef	33.4b	2.58cd	1.43cd
4	$N_2P_0K_2$	45.7gh	30.5cd	2.23ef	1.31ef
5	$N_2P_1K_2$	49.3abc	33.9b	2.54cd	1.37de
6	$N_2P_2K_2$	50.2a	38.3a	3.35a	1.53bc
7	$N_2P_3K_2$	49abcd	38.5a	3.16ab	1.54b
8	$N_2P_2K_0$	49.5abc	28.9d	2.19ef	1.32ef
9	$N_2P_2K_1$	49.8ab	32.2bc	2.45d	1.38de
10	$N_2P_2K_3$	49.5abc	30.5cd	3.05b	1.51bc
11	$N_3P_2K_2$	48.4cde	39.1a	3.26a	1.73a
12	$N_1P_1K_2$	48.5bcde	32.5bc	2.71c	1.45bcd
13	$N_1P_2K_1$	47.8de	29.5d	2.67c	1.37de
14	$N_2P_1K_1$	46.5fg	28.4de	2.65cd	1.26f
Cv (%)		1.5	2.6	4.5	4.0

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

6.4.3 Yield and quality

6.4.3.1 Fresh Tuber Yield

Analysis of variance (Table 6.4) showed that the N P K fertilizer rates were significant on fresh tuber yield at 5% probability level. Fresh tuber yield in high soil fertility field was much more than that in low soil fertility field. Among 14 treatments, the N P K fertilizer rate of N 180 kg/ha, P 120 kg/ha, K 240 kg/ha in high soil fertility field had the most substantial effect on fresh tuber yield and produced the highest yield of 33,054 kg/ha. It could be concluded that increasing the application of N P K fertilizer up to a certain level, the yield increased, but since then, the yield decreased. According to Sun et al. (1996) experiments, excessive application of N P K fertilizer was not always lead to higher yields which were confirmed in this study. While in low fertility field the highest yield (9,605 kg/ha) was obtained at the N 270 kg/ha, P 120 kg/ha, K 240 kg/ha. The results also showed that the effect of increasing fertilizer production on low fertility soils was higher than that of high fertility soils. In both fertility soils, the effects of increasing yield, and contribution to yield were all expressed as N>P>K. The yield-increasing effects and economic benefits of N, P and K fertilizers on potato were similar to those of Zhang et al. (2004) who reported that the impact on potato yield was affected the most by N, followed by P and K. The result different from Zhou (1985) who reported the impact on potato yield was affected the most by N, followed by K and P. This might be related to the difference in the potato cultivars and soil fertility at the test sites.

Table 6.4 The effect of N P K application on yield of potato.

No.	**TRT**	**Yield (kg/ha)**	
		HF	**LF**
1	$N_0P_0K_0$	19,417h	3,649l
2	$N_0P_2K_2$	21,476g	3,828k
3	$N_1P_2K_2$	27,759e	5,682h
4	$N_2P_0K_2$	26,195f	4,187j
5	$N_2P_1K_2$	29,673cd	7,473e
6	$N_2P_2K_2$	33,054a	9,504b
7	$N_2P_3K_2$	30,200bc	9,517b
8	$N_2P_2K_0$	27,500e	5,297i
9	$N_2P_2K_1$	30,638b	8,546c
10	$N_2P_2K_3$	29,283d	6,987f
11	$N_3P_2K_2$	29,052d	9,605a
12	$N_1P_1K_2$	28,895d	6,810g
13	$N_1P_2K_1$	27,897e	8,406d
14	$N_2P_1K_1$	27,318e	8,574c
Cv(%)		1.8	0.4

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT.

6.4.3.2 Starch content

The N P K fertilizer rates were significant on the mean of starch percentage at 5% probability level (Table 6.5). The results showed that the different ratios of N P and K made the starch content different. In both soil fertility fields, the treatment with the highest starch content was recorded at $N_0P_2K_2$, which were 86.8% in the high soil fertility field and 67.3% and in the low soil fertility field. This result was agreed with Zhang (2013) who reported that that low N and appropriate P and K can improve the content of potato starch. This result was also supported by that of Wang (1994) who reported high N fertilization is not conducive to starch accumulation.

6.4.3.3 Soluble protein content

The N P K fertilizer rates were significant on the mean of soluble protein at 5% probability level (Table 6.5). The results showed that the different ratios of N P and K made the soluble protein different. In both soil fertility fields, the highest soluble protein was recorded at $N_3P_2K_2$, which were 1.651g/100g in the high soil fertility field and 1.302 g/100g in the low soil fertility field. These results have been proved by Li (2006), who reported that the high N application doses increased the soluble protein content in potato. Zhang (2013) also had a similar finding.

6.4.3.4 Reducing sugar content

The N P K fertilizer rates were significant on the mean of reducing sugar percentage at 5% probability level (Table 6.5). The results showed that the different ratios of N P and K made the reducing sugar percentage different. The treatment with the maximum reducing sugar percentage was recorded at $N_0P_0K_0$ in both soil fertility fields. However, the minimum sugar percentage was recorded at $N_2P_2K_2$, which were 0.34% in high soil fertility field. While the minimum sugar percentage was recorded at $N_2P_2K_3$, which were 0.652% in low soil fertility field. This result was proved by Zhang (2013) who reported that the appropriate amount of N P and K can reduce the reducing sugar percentage.

6.4.3.5 Dry matter content

The N P K fertilizer rates were significant on the mean of dry matter percentage at 5% probability level (Table 6.5). The results showed that the different ratios of N, P, and K made the dry matter percentage different. The treatment with the maximum dry matter percentage was recorded at $N_2P_2K_2$, which were 18.5% in high soil fertility field. While the maximum dry matter percentage was recorded at $N_3P_2K_2$ which was 16.9% in low soil fertility field. This result was proved by Zhang (2013) who reported that the appropriate amount of N, P, and K can dry matter percentage. The results were not agreement with Li and Zhang (2001) who reported that the effect of different N, P, and K fertilizer levels were insignificant on dry matter content. This difference may be contributed to the different soil fertility between this experiment and their experiments.

Table 6.5 The effect of N P K application on potato yield and quality.

No.	TRT	Starch (%)		Soluble protein (%)		Reducing sugar (g/100g)		Dry matter (%)	
		HF	LF	HF	LF	HF	LF	HF	LF
1	$N_0P_0K_0$	41.6j	38.1h	0.963b	0.675f	0.595a	0.835a	13.6g	11.3g
2	$N_0P_2K_2$	86.8a	67.3a	1.056b	0.701f	0.435fgh	0.754cde	14.9def	12.6def
3	$N_1P_2K_2$	74.1d	63.4bc	1.173b	0.820e	0.475def	0.701fg	15.3de	13.5cd
4	$N_2P_0K_2$	40.8j	40.8g	1.523a	0.702f	0.465ef	0.821ab	14.5f	11.8fg
5	$N_2P_1K_2$	71.8e	45.0f	1.565a	0.985d	0.442fg	0.773bcd	16.7bc	12.6def
6	$N_2P_2K_2$	83.5b	62.3c	1.632a	1.203b	0.398g	0.687fg	18.5a	14.9b
7	$N_2P_3K_2$	78.6c	63.5bc	1.601a	1.205b	0.415gh	0.721ef	17.2bc	13.8c
8	$N_2P_2K_0$	41.9j	38.0h	1.032b	0.811e	0.512bcd	0.786bc	14.6ef	12.0fg
9	$N_2P_2K_1$	64.9fg	36.9h	1.298ab	1.052cd	0.432fgh	0.732def	15.6d	13.2cde
10	$N_2P_2K_3$	84.4b	65.5ab	1.588a	0.981d	0.411gh	0.652g	17.4b	13.5cd
11	$N_3P_2K_2$	60.2h	51.8e	1.651a	1.302a	0.532b	0.691fg	16.5c	16.9a
12	$N_1P_1K_2$	63.0g	58.3d	1.583a	0.843e	0.487cde	0.657g	14.7ef	12.8cdef
13	$N_1P_2K_1$	65.3f	59.5d	1.622a	1.011cd	0.503bcde	0.667g	14.3f	12.3efg
14	$N_2P_1K_1$	46.2i	42.3g	1.601a	1.103c	0.521bc	0.702fg	15.3de	12.5def
	CV (%)	1.9	2.5	13.3	5.7	6.7	4.4	2.6	4.4

Mean in a column followed by the same letters are not significant difference at 5% level by DMRT

6.4.4 Maximum yield and N P K fertilizer rate application

The yield was taken as the objective variable y, N, P, K fertilizer as the independent variable x, and the ternary quadratic model was used to fit the "3414" test. The ternary secondary fertilizer model is

$$y = b_0+b_1N+b_2P+b_3K+b_4N^2+b_5P^2+b_6K^2+ b_7NP+b_8NK+b_9PK,$$

the regression equation of the fertility equation was shown in Table 6.6. The regression equation was significantly different among N P K rates at 5% probability level. The response function in high soil fertility field used for the experiment was:

$$y_1=19{,}315+37.6N+41.0P+46.1K-0.275N^2-0.304P^2-0.083K^2+ 0.447NP+0.059NK-0.176PK$$

The response function in low soil fertility field used for the experiment was:

$$y_2=3{,}794+15.6N+27.5P+13.3K-0.102N^2-0.243P^2-0.106K^2+ 0.108NP+0.092NK+0.099PK$$

Where y is the yield of potato (kg/ha), and N P K is the application of N P K fertilizer (kg/ha).

From the regression analysis of the quadratic model, the result showed that in high fertility soil maximum potato yield (31,863 kg/ha) was obtained at the rate of N 233 kg/ha, P 180 kg/ha, and K 171 kg/ha (Table 6.7). While in low fertility soil maximum yield (10,293 kg/ha) was obtained at N 270 kg/ha, P 170 kg/ha, and K 259 kg/ha. The result was similar to Lou et al. (2008) who found that when the N P K application level was gradually increased, the corresponding increased production occurred. When the N P K consumption reached a certain level, for the increase of N P K resulted in stable or decreased production.

Table 6.6 NPK fertilizer effect quadratic function.

Field	Fertilizer effect equation	F	R^2
HF	y_1=19,315+37.6N+41.0P+46.1K-0.275N^2-0.304P^2-0.083K^2+0.447NP+0.059NK-0.176PK	14.1*	0.970
LF	y_2=3,794+15.6N+27.5P+13.3K-0.102N^2-0.243P^2 -0.106K^2+0.108NP+0.092NK+0.099PK	12.7*	0.966

Table 6.7 Maximum yield and N P K fertilizer application rate.

Field	N	P_2O_5	K_2O	Yield
		(kg/ha)		
HF	233	180	171	31,863
LF	270	170	259	10,293

6.4.5 The optimum N P K fertilizer rate and net profit

On the economic benefits, mainly due to economic output and overall performance, value, cost, and other aspects increasing N P K fertilizer can increase yield and production value, but the corresponding costs are also increased. Therefore, the process does not represent the maximum yield can produce the highest economic benefits. The optimum N P K fertilizer application in high soil fertility field was N 228 kg/ha, P180 kg/ha, K152 kg/ha (Table 6.8) and the optimum price was 73,342 Yuan/ha, maximum net profit was 49,699 Yuan/ha; While in low soil fertility field was N 253, P

156, K 232 kg/ha and the optimum price was 20,912 Yuan/ha, maximum net profit was -248 Yuan/ha.

Table 6.8 Optimum N P K fertilizer application rate and economic benefit.

Field	Optimum N P K			CF	FC	Total C	OYP	MNP	BCR
	N	P_2O_5	K_2O						
	(kg/ha)			(Yuan/ha)					
HF	228	180	152	3,058	22,085	25,143	73,342	48,199	1.92
LF	253	156	232	3,575	17,585	21,160	20,912	-248	-0.01

6.5 Discussion

The main advantage of the ternary quadruple fertilization model is that the interaction of fertilizers was considered (Wang et al. 2002). However, from the results of the whole study, the model had the following disadvantages when fitting the "3414" test and calculating the recommended amount of fertilizer: (1) The 3414 test is more complicated than using the quadratic equation in one-element model. Sometimes the recommended high fertilization amount in the experiment not only causes the economic benefit of fertilization to decrease but also was likely to cause environmental problems. (2) At the same time, the ternary quadratic model fitting often ignored some of the tests that did not require fertilization. Therefore, the application of the ternary fertilizer effect model was poorly representative when analyzing the multi-point test. The results were also reported by Wang et al. (2002).

Yan (2008) and Wang et al. (2002) have shown that using the quadratic equation in one-element model to calculate the optimum recommended fertilizer application rate, the success rate of fitting is high, and information resources that cannot be used in the ternary quadratic model can be developed. The results are more comprehensive and reasonable. The inadequacy of the quadratic equation was that the interaction cannot be quantified. It can be said that in the calculation process of the "3414" test results, the fitting of the one-element fertilizer effect model was a supplement and optimization of the ternary secondary fertilizer model fitting.

Compared to the results of all four experiments (Table 6.9), through the analysis of the ternary fertilizer effect of the “3414” trial design, a large amount of fertilizer information can be obtained. The ternary fertilizer effect function is a full-factor model and can be used for recommended fertilization either from a statistical point of view or from an agricultural production practice. In high fertility soils, the optimal application rates of N and P fertilizers simulated by the ternary quadratic fertilizer effect model in this study were higher than the one-element quadric fertilizer effect model, while the optimal application rate of K fertilizer was lower than that of the one-element quadratic fertilizer effect. The model and research results were similar to those obtained by Chen (2006) who found that optimum K fertilizer was lower than that of the one-element quadratic. It might be because of different soil nutrients are different; fertilization in different soils varies greatly. This study refers to the routine fertilization measures of local farmers.

From the results of the four experiments, in the high soil fertility field (Table 6.9), the N P K fertilization rates were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha can produce a large net profit. Therefore, it was recommended that the potato N P K fertilization rates in high soil fertility field in Guizhou were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha.

For low soil fertility field (Table 6.9), from the four experiments, the net profits in the low soil fertility field were very low, even negative. From the overall results, the low soil fertility field was not suitable for planting potatoes under current soil conditions. In order to grow potatoes in low soil fertility fields, it should improve the soil fertility and soil structure by using organic fertilizers and soil amendments.

Table 6.9 The net profit and optimum N P K rate in different experiments.

ERT	HF Net profit	HF Optimum			LF Net Profit	LF Optimum		
		N	P_2O_5	K_2O		N	P_2O_5	K_2O
	(Yuan/ha)	(kg/ha)			(Yuan/ha)	(kg/ha)		
N	53,347	193			1,543	302		
P	40,542		151		-6,153		192	
K	42,100			210	-6,740			341
NPK	48,199	228	180	152	-248	253	156	232

Since the available soil nutrients vary among different soil types, there is a certain difference in the optimal fertilization amount. Therefore, it was recommended that the appropriate amount of fertilizer applied to the potato should be different from soil to soil. It was more practical to recommend the soil fertilization amount by combining the soil test results with the fertilizer effect function method.

It should be pointed out that due to the limitations of experimental conditions; tests are needed to obtain an accurate indicator system for fertilization. In addition, this study, only Favorite variety was used as a test material, whether the model of this study can be used for other varieties needs further validation.

6.6 Conclusions

(1) The results showed that the effect of increasing fertilizer production on low fertility soils was higher than that of high fertility soils, and the application of N, P and K fertilizers significantly increased potato yield. In both fertility soils, the effects of increasing yield, and contribution to yield were all expressed as N>P >K.

(2) From the regression analysis of the quadratic model, the result showed that in high fertility soil maximum potato yield (31,863 kg/ha) was obtained at the rate of N 233 kg/ha, P180 kg/ha, and K171 kg/ha. While in low fertility soil maximum yield (10,292 kg/ha) was obtained at N 270 kg/ha, P170 kg/ha, and K 259 kg/ha.

(3) The optimum N P K fertilizer application in high soil fertility field was N 228 kg/ha, P 180 kg/ha, K 152 kg/ha and net profit from fertilization was 48,199 Yuan/ha; While in low soil fertility field was N 253 kg/ha, P156 kg/ha, K 232 kg/ha and net profit from fertilization was -248 Yuan/ha.

(4) Comparing the results of all four experiments, the recommended amount of N P K fertilizer rates were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha in high soil fertility field. From the overall results, the low soil fertility field was not suitable for planting potatoes under current soil conditions. In order to grow potatoes in low soil fertility fields, it should improve the soil fertility and soil structure by using organic fertilizers and soil amendments.

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CHAPTER VII

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

In this study, four experiments were carried out in two different fertility soils to evaluate the economics of nutrient management for potato production in Guizhou. The results can be concluded as following:

Applying N should be appropriate, too low or too high will decline the yield; with the increase in the amount of N applied, potato protein, sugar showed an increasing trend, while the starch content was decreasing. In this area, in high fertility soil, when applied N reached 197 kg/ha, yield reached maximum at 32,784 kg/ha while in low fertility soil, when applied N reached 319 kg/ha, yield reached maximum at 9,117 kg/ha, However, the N rate that produced the maximum yield did not give the maximum net profit from fertilization. In high soil fertility field, applied optimum N 193 kg/ha, resulted to the optimum yield price of 78,659 Yuan/ha while in low soil fertility field, applied optimum N 302 kg/ha, produced the optimum yield price of 21,825 Yuan/ha. The maximum net profit was 54,347 Yuan/ha in high soil fertility field and 1,543Yuan in low soil fertility field. The results also indicated that the benefit cost ratio in potato production was 2.24 Yuan in high soil fertility field while in low soil fertility field it was 0.076 Yuan.

Proper P management was one of the most important factors required to obtain high yield of excellent quality potatoes. The P rates that give the maximum and optimum yield were evaluated. Results showed that increasing P fertilizer resulted in increments of potato yield, plant height, LAI, starch, soluble protein, and dry matter, then as P rate still increased potato yield, plant height, LAI, starch, soluble protein, and dry matter did decreasing trend. Increased P rates resulted in reduction of the reducing sugar content of potato tubers. In high fertility soil, when applied P reached 156 kg/ha, yield reached the maximum at 27,117 kg/ha; in low soil fertility field, when applied P reached 208 kg/ha, yield reached the maximum at 5,879 kg/ha. However, P rate for the maximum yield did not produce the maximum profit. In high soil fertility field, applied optimum P rate of 151 kg/ha resulted in the optimum yield price of 65,058 Yuan/ha while in low soil fertility field, applied optimum P rate of 192 kg/ha, resulted in the optimum yield price of 14,101 Yuan/ha. The maximum net profit was 40,542Yuan/ha in high soil fertility field and -6,153 Yuan/ha in low soil fertility field. Benefit cost ratio in potato production was 1.71 in high soil fertility field while in low soil fertility field it was -0.30.

Proper K fertilizer application was able to improve the plant growth, results showed that increasing K fertilizer resulted in increments of potato yield, plant height, LAI, starch, soluble protein, and dry matter, then as K rate still increased, potato yield, plant height, LAI, starch, soluble protein, and dry matter did decreasing trend. Increased K rates resulted in reduction of the reducing sugar content of potato tubers. In high soil fertility field, when applied K reached 218 kg/ha, yield reached the maximum at 27,689 kg/ha; in low soil fertility field, when applied K reached 443 kg/ha, yield reached the maximum at 5,814 kg/ha. However, K rate for the maximum yield did not produce the maximum profit. In two different soil fertility fields, the result showed that: in high soil fertility field, K rate of 210 kg/ha, resulted in the optimum yield price of 66,423 Yuan/ha. In low soil fertility field, K rate of 341 kg/ha, resulted in the optimum yield price of 13,489 Yuan/ha. The maximum net profit was 42,100 Yuan/ha in high soil fertility field and -6740 Yuan/ha in low soil fertility field. Benefit cost ratio in potato production was 1.73 in high soil fertility field while in low soil fertility field it was -0.33.

From the regression analysis of the quadratic model in the combined N P K experiment, the result showed that in high soil fertility field maximum potato yield (31,863 kg/ha) was obtained at the rate of N 233 kg/ha, P180 kg/ha, and K171 kg/ha. While in low fertility soil maximum yield (10,292 kg/ha) was obtained at N 270 kg/ha, P170 kg/ha, and K 259 kg/ha. The optimum N P K fertilizer application in high soil fertility field was N 228 kg/ha, P 180 kg/ha, K 152 kg/ha and net profit from fertilization was 48,199 Yuan/ha. While in low soil fertility field was N 253 kg/ha, P156 kg/ha, K 232 kg/ha and net profit from fertilization was -248 Yuan/ha.

Comparing the results of all four experiments, the recommended amount of N P K fertilizer rates were 193-228 kg/ha, 151-180 kg/ha, 152-210 kg/ha in high soil fertility field. For low soil fertility field, from the overall results, the low soil fertility field was not suitable for planting potatoes under current soil conditions. In order to grow potatoes in low soil fertility fields, it should improve the soil fertility and soil structure by using organic fertilizers and soil amendments.

7.2 Recommendations

Recommendations for further studies include:

1. The results of this study confirm that the yield of potato and economic benefits are directly related to the soil fertility. Fertilizer recommendation by the DOA

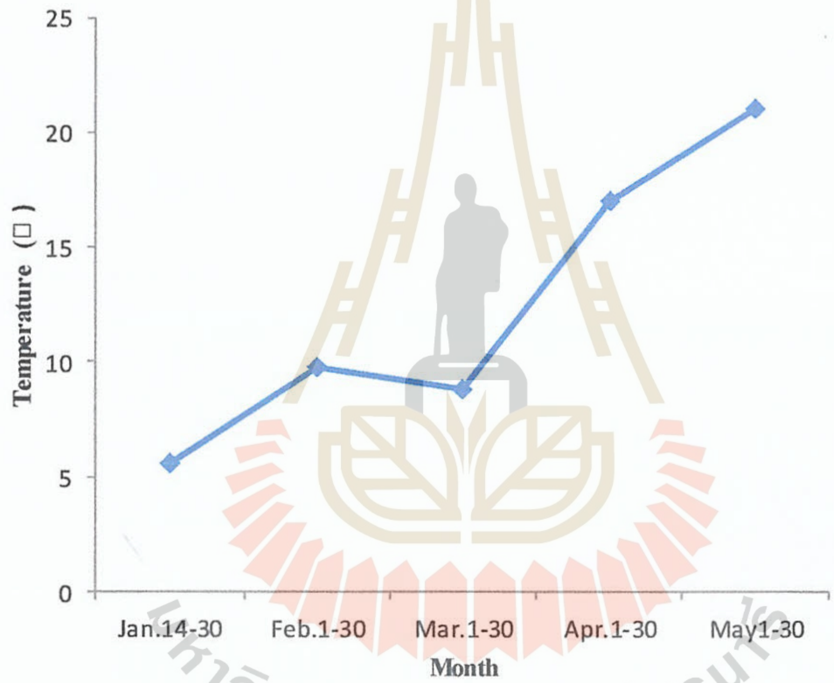
always considerate the region and potato varieties, and rarely considers soil fertility. Therefore, in future research, soil fertility should be recommended as a basis for fertilization.

2. Most researchers did not calculate all the costs of production when evaluating economic effects. They often ignore labor and land rent fees. In future research, the production cost should be considered.

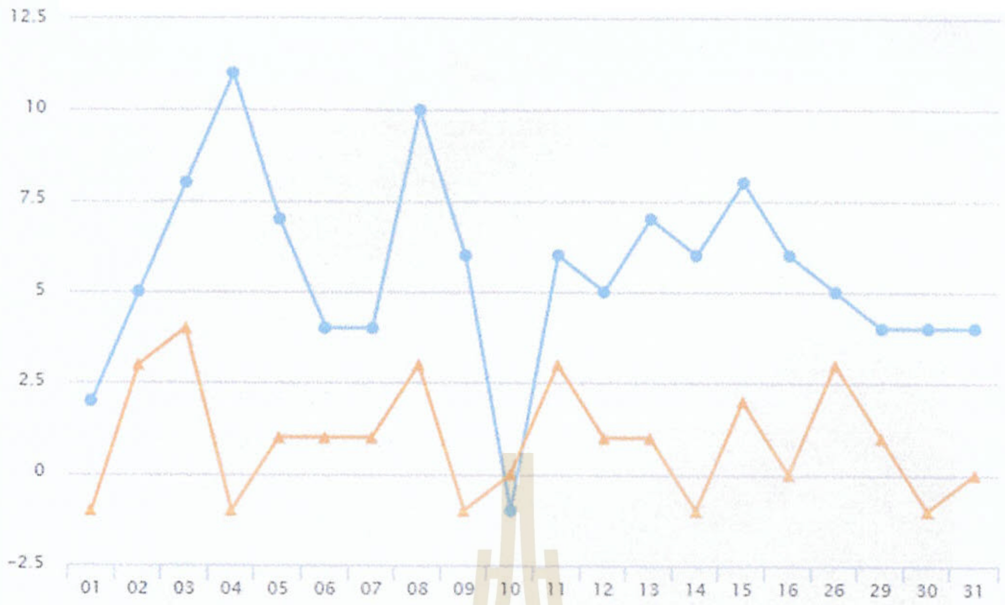
APPENDIX

Table 1 The grading standards of soil nutrients of potato field in Guizhou

Fertility	OM	Total N	Available N	Available P	Available K
	(g/kg)	(g/kg)	(mg/kg)	(mg/kg)	(mg/kg)
I	>26	>1.5	>100	>20	>100
II	18-26	1.1-1.5	50-100	15-20	50-100
III	<18	<1.1	<50	<15	<50



Attached figure 1 Average temperature at Huishui during potato growing season.



Attached figure 2 Weather temperature details in January 2011 at Huishui.

Attached figure 3 Potato growth in the high soil fertility field.

Attached figure 4 Potato growth in the low soil fertility field.

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