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Effects of Different Nitrogen Levels on Growth and Nitrogen Utilization of Sugarcane

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Abstract [**Objectives**] To systematically study the effects of different nitrogen levels on the growth and nitrogen utilization of sugarcane in Guangxi. [**Methods**] Through field experiment and indoor analysis, different nitrogen application levels were set up to determine soil nitrogen content and sugarcane nitrogen content. The effects of different nitrogen levels on sugarcane yield, agronomic characters and nitrogen utilization were studied. [**Results**] The effect of nitrogen application rate on sugarcane yield showed a quadratic curve, and nitrogen application could significantly increase sugarcane yield, and the sugarcane yield reached the maximum when the nitrogen application rate reached 714 kg/ha. [**Conclusions**] With the increase of nitrogen application rate, sugarcane yield increased, but when it exceeded a certain range, the sugarcane yield decreased significantly.

Key words Nitrogen application rate, Nutrient utilization efficiency, Yield, Sugarcane

1 Introduction

Since the 1950s, a large quantity of chemical fertilizers have been applied in developed countries in Europe and the United States, which has caused eco-environmental problems such as surface water eutrophication. With the strengthening of national regulation and control, the amount of chemical fertilizer in European countries continued to decline after the 1980s, while the grain output remained stable, thus realizing the scientific reduction of chemical fertilizer[1 – 2]. Guangxi is an important sugar-producing area in China. In 2015, the planting area of sugarcane was 973.74 ha and the output reached 75.049 2 million t, accounting for more than 60% of the country's planting area and yield. Fertilization is an important part of sugarcane planting management and the material basis for stable yield. For a long time, the annual application amount of nitrogen, phosphorus and potassium only from chemical fertilizer in sugarcane planting area of Guangxi is 400 – 550, 270 – 320, 270 – 360 kg/ha, and the average amount of fertilizer applied is 3 times the world average and 5 – 10 times that of developed countries.

There is a large surplus of nitrogen and phosphorus nutrients in sugarcane fields, and Guangxi's sugarcane producing region has a nitrogen surplus of 65.1 kg/ha, with a surplus rate of 67.2%, which is 1.1 times of the national average nitrogen surplus[3 – 4]. Some scholars have proposed that the suitable threshold of nitrogen fertilizer in maize planting area of lateritic red soil in Guangxi should be 200 – 300 kg/ha, in order to take into account the factors such as crop yield, environmental effect and fertilizer effect in maize planting system. Excessive input of nitrogen fertilizer leads to high nitrogen surplus in farmland, which affects the residual amount of soil nutrients, and finally increases the risk of pollution caused by nitrogen entering the environment through various ways[7]. In this study, the quantitative relationship between sugarcane nitrogen nutrient demand, soil nutrient supply and fertilizer agronomic efficiency in main sugarcane producing areas was analyzed in order to determine the environmentally friendly nitrogen fertilizer application rate for high and stable yield of sugarcane and reduce agricultural non-point source pollution, and to provide a reference basis for the sustainable development of sugarcane industry in lateritic red soil region.

2 Materials and methods

2.1 Overview of the experimental site The experimental site is located in Luowei Town, Wuming County, Nanning City, Guangxi (23.242 75° N, 108.054 5° E). The experimental site, 120 m above sea level, has a humid monsoon climate, and sufficient light and heat resources. The average annual temperature is 21.7 ℃, the average number of annual sunshine hours is 1 660, and the average annual rainfall is 1 300 mm, which is mostly concentrated from July to September.

2.2 Test materials The sugarcane variety tested was "Guiliu05/136". The soil is typical lateritic red soil in Guangxi.

At the beginning of the experiment, the physical and chemical properties of the basic soil: pH 6.2, organic matter content 13.48 g/kg, available nitrogen content 53.4 mg/kg, nitrate

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nitrogen content 15.6 mg/kg, ammonium nitrogen content 3.24 mg/kg.

2.3 Experimental design There were 6 treatments: (a) no fertilizer treatment (CK), (b) no nitrogen fertilizer (OPT-N), (c) 281 kg/ha nitrogen fertilizer (OPT-75% N), (d) 375 kg/ha nitrogen fertilizer (OPT), (e) 469 kg/ha nitrogen fertilizer (OPT-125% N), and (f) 563 kg/ha nitrogen (OPT-150% N). The nitrogen fertilizer of all fertilization treatments was urea. Except for CK treatment, the amount of phosphorus and potassium fertilizer was the same in the other treatments, phosphorus fertilizer was calcium superphosphate, application rate was 937.5 kg/ha, potassium fertilizer was potassium chloride, application rate was 625 kg/ha (Table 1). Base fertilizer (33.3% phosphate fertilizer +5% potash fertilizer + 25% urea), tillering fertilizer (33.3% phosphate fertilizer + 65% potash fertilizer + 40% urea) and growth fertilizer (33.4% phosphate fertilizer + 30% potash fertilizer + 35% urea) were applied respectively.

The experiment began in 2019, with a plot area of 55 square meters, randomly arranged and repeated 3 times. There were 60 double-bud seedlings in each row and 300 double-bud seedlings per plot, that is, there are 600 buds per plot, and the planting density was 54 555 double-bud seedlings/ha. The ridge of the field was wrapped with plastic film around the plot to reduce the water flow and lateral seepage between the plots. The newly planted sugarcane was sown on March 9, and the base fertilizer was applied to the bottom of the sugarcane planting trench, then covered with fine soil. Tillering fertilizer was applied on May 23 and growth fertilizer was applied on June 25. Tillering fertilizer and growth fertilizer were applied to the planting trench and then covered with soil. There was no irrigation during the whole growth period, it was a typical rain-fed sugarcane, and the management of diseases and pests was consistent with that of local sugarcane planting.

Table 1 Application rate of nutrients and fertilizers in different fertilization treatments kg/ha

Treatment	N	P_2O_5	K_2O	Urea	Calcium superphosphate	Potassium chloride	Compound fertilize (15 – 15 – 15)
CK	0	0	0	0	0	0	0
OPT-N	0	112.5	375	0	937.5	625	0
75% N	281	112.5	375	611	937.5	625	0
100% N	375	112.5	375	815	937.5	625	0
125% N	469	112.5	375	1 019	937.5	625	0
150% N	563	112.5	375	1 223	937.5	625	0

2.4 Determination items and methods In the harvest period, all the sugarcane in each plot was harvested on the flat ground, and the leaves and the tips were removed. The plant height, stem diameter and juice brix were investigated, and the N nutrient content of sugarcane was measured in two parts: sugarcane stems and sugarcane leaves (tips, including some fallen leaves). After harvest, 5 soil samples from plough layer were collected in each plot to determine the content of soil pH, organic matter, alkali-hydrolyzable nitrogen, nitrate nitrogen and ammonium nitrogen. The total nitrogen content of soil and sugarcane was determined by Kjeldahl method, and the soil organic matter was determined by potassium dichromate volumetric method. Soil total nitrogen was determined by H_2SO_4 digestion-semi-micro Kjeldahl method, and soil pH was determined by point method using CO_2-free distilled water (solution-soil ratio at 2.5:1) for extraction. Ammonium nitrogen in sampled soil was determined by indophenol blue colorimetry using potassium chloride (liquid-soil ratio at 5:1) for extraction. Soil alkali hydrolyzable nitrogen was determined by alkali hydrolysis diffusion method, and soil nitrate nitrogen was determined by ultraviolet spectrophotometry using potassium chloride (liquid-soil ratio at 5:1) for extraction.

2.5 Data analysis The test data were sorted out by Excel 2010, statistically analyzed by SPSS 19 and plotted by Origin 8.0. Duncan's new multiple range method was used for multiple comparison among different treatments ($a = 0.05$).

3 Results and analysis

3.1 Effects of different nitrogen application levels on sugarcane yield and composition It can be seen from Table 2 that fertilization treatment significantly increased the total sugarcane biomass, sugarcane stem yield and straw yield compared with CK treatment, the highest increase reached 77.08%, 84.03% and 82.54%, respectively (higher than 75%). This shows that fertilization is an important way for sugarcane to obtain high yield. Even in the non-nitrogen treatment, through the application of phosphorus and potassium fertilizer, the total sugarcane biomass, sugarcane stem yield and straw yield were significantly increased by 26.71%, 28.63% and 28.21% compared with CK treatment. This shows that the soil nitrogen supply capacity of the experimental area will not become the limiting factor of sugarcane yield and fertilizer efficiency because of partial application of phosphorus and potassium fertilizer leading to insufficient nitrogen fertilizer under the fertilization level of 112.5 kg/ha phosphorus (P_2O_5) and 375 kg/ha potassium (K_2O).

It can also be seen from Table 2 that 75% N, 100% N, 125% N and 150% N treatments significantly increased sugarcane yield compared with OPT-N treatment, and sugarcane yield increased with the increase of nitrogen application rate among different nitrogen application treatments. Compared with the non-nitrogen treatment, the nitrogen application treatment significantly increased the sugarcane stem yield, showing a rapid increase at first and then tending to slow down. There was a certain binomial regression correlation between nitrogen application rate and sugarcane yield: $y = -0.000\ 08x^2 + 0.109x + 83.40$ ($R^2 = 0.943$). According to this equation, when the N application rate reached 714 kg/ha, the sugarcane yield reached the maximum, which was 122.48 t/ha. There was no significant difference among 75% N, 100% N and 125% N treatments, indicating that the application of nitrogen fertilizer significantly increased sugarcane yield, but the continuous excessive application of nitrogen fertilizer could not significantly increase sugarcane yield.

Table 2 Effects of different fertilization treatments on sugarcane yield composition t/ha

Nitrogen application level	Straw yield	Sugarcane stem yield	Overground part yield
CK	17.41 ±0.89 d	65.24 ±2.47 d	82.66 ±3.26 d
OPT-N	22.06 ±0.88 c	83.92 ±3.01 c	105.98 ±3.89 c
75% N	26.00 ±0.61 b	103.69 ±1.49 b	130.68 ±2.07 b
100% N	30.82 ±1.25 a	119.33 ±4.67 a	150.15 ±5.92 a
125% N	30.54 ±0.77 a	116.91 ±3.09 a	147.44 ±3.87 a
150% N	30.83 ±1.23 a	120.06 ±2.97 a	150.89 ±4.06 a

Note: Values followed by different letters in a column are significant among treatments at the 5% level.

3.2 Effects of different nitrogen treatments on agronomic characters of sugarcane It can be seen from the single factor analysis of variance (Table 3) that the single stem weight, stem diameter, plant height and effective stem of sugarcane increased with the increase of nitrogen application rate, while the sugarcane juice brix of each fertilization treatment was higher than that of non-fertilizer treatment. but the increase was not obvious. The single stem weight and stem diameter of sugarcane in 75% N, 100% N, 125% N and 150% N treatments were significantly higher than those in OPT-N treatment, and the highest increases reached 33.98% and 16.06%, respectively. However, 125% N and 150% N treatments had no significant effect on sugarcane stem weight and stem diameter compared with 100% N treatment, and incremental nitrogen application could not continuously increase sugarcane stem weight and stem diameter.

It can also be seen from Table 3 that compared with the blank control and non-nitrogen treatment, the sugarcane plant height increased significantly after applying nitrogen fertilizer, and there was the greatest increase in the 150% N treatment. Compared with CK treatment and OPT-N treatment, the increase reached 19.57% and 12.64%, respectively, but there was no significant difference among 100% N, 125% N and 150% N treatments. Altogether, the application of nitrogen fertilizer can increase the stem diameter, plant height and single stem weight of sugarcane, and the increase of single stem weight is particularly important for the sugarcane yield.

Table 3 Effects of different fertilization treatments on agronomic characters of sugarcane

Nitrogen application level	Single stem weight//kg	Sugarcane stem diameter//cm	Sugarcane plant height//cm	Sugarcane juice brix//BX°
CK	0.93 ±0.02 d	2.49 ±0.12 c	281.3 ±9.0 c	23.6 ±0.9 a
OPT-N	1.03 ±0.04 c	2.74 ±0.18 b	298.3 ±2.9 c	24.6 ±0.5 a
75% N	1.24 ±0.04 b	3.11 ±0.11 a	318.0 ±6.5 b	24.7 ±0.8 a
100% N	1.37 ±0.04 a	3.15 ±0.07 a	334.3 ±8.9 ab	24.7 ±0.7 a
125% N	1.37 ±0.03 a	3.14 ±0.05 a	334.7 ±8.2 ab	24.6 ±0.6 a
150% N	1.38 ±0.04 a	3.18 ±0.04 a	336.7 ±7.0 a	23.9 ±0.3 a

Note: Values followed by different letters in a column are significant among treatments at the 5% level.

3.3 Effects of different nitrogen treatments on the growth of sugarcane It can be seen from Table 4 that different fertilization treatments had different effects on emergence rate and effective stem of sugarcane. The emergence rate of sugarcane under different fertilization treatments was between 33.22% and 39.38%. The emergence rate of sugarcane treated with 150% N was the highest, and the emergence rate in CK treatment was the lowest. The emergence rate of sugarcane treated with 100% N, 125% N and 150% N was significantly higher than that under CK treatment. The treatments with the highest effective stem number were 150% N and 100% N, and the number of effective stems reached 8.7×10^4 ha. The number of effective stems of sugarcane under different nitrogen application treatments was significantly larger than that under CK treatment, and the number of effective stems of sugarcane treated with 100% N, 125% N and 150% N was significantly larger than that under nitrogen reduction and non-nitrogen treatment. However, there was no significant difference in the emergence rate and effective stem number of sugarcane among 100% N, 125% N and 150% N treatments, indicating that nitrogen deficiency would significantly affect the emergence rate and effective stem number of sugarcane, thus affecting the sugarcane yield. Too much nitrogen did not significantly increase the emergence rate and the number of effective stems of sugarcane.

Table 4 Effects of different fertilization treatments on emergence rate and effective stem of sugarcane

Nitrogen application level	Emergence rate//%	Effective stems// $\times10^4$ ha
CK	33.22 ±2.12 b	7.0 ±0.2 d
OPT-N	35.45 ±2.65 ab	8.1 ±0.1 c
75% N	37.00 ±3.14 ab	8.3 ±0.2 bc
100% N	38.05 ±1.13 a	8.7 ±0.2 a
125% N	37.95 ±1.45 a	8.5 ±0.1 ab
150% N	39.38 ±1.95 a	8.7 ±0.2 a

Note: Values followed by different letters in a column are significant among treatments at the 5% level.

It can be seen from Table 4 that the effective stem number of sugarcane in each fertilization treatment increased by 16.31% – 24.22% compared with that in non-fertilizer treatment, and the effective stem number of sugarcane in CK treatment was equivalent to 96.9% of that in 100% N treatment. The effective stem number of sugarcane increased by 2.99% – 7.01% when nitrogen fertilizer was applied, and there was a linear correlation between nitrogen application rate and effective stem number of sugarcane. With the increase of nitrogen application rate, the effective stem number of sugarcane also increased. With the application of nitrogen fertilizer, the number of effective stems of sugarcane in each stage was larger than that in non-fertilizer treatment. Before and after the growth stage, fertilization had the highest effect on the number of effective stems of sugarcane, and the difference in other periods was not obvious. After the application of nitrogen fertilizer, the increase of sugarcane yield was mainly due to the increase of the number of effective stems per unit area and the increase of single stem weight, but excessive application of nitrogen fertilizer could not increase the effective stems continuously.

3.4 Effects of different nitrogen treatments on nitrogen accumulation and distribution in sugarcane The results of correlation analysis showed that nitrogen application could promote the absorption of nitrogen by sugarcane (Table 5), appropriate amount of nitrogen application could promote the absorption of nitrogen by sugarcane plants, and the nitrogen in sugarcane was mainly concentrated in sugarcane stem and straw. The nitrogen nutrient content of sugarcane stem in different fertilization treatments increased by 0.30 - 1.44 g/kg, an increase of 4.87% - 24.86%, the difference reached a significant level. The nitrogen content of straw increased by 0.40 - 2.76 g/kg, an increase of 4.64% - 29.81%. Except for non-nitrogen treatment, the increase in other treatments reached a significant level. Compared with the non-nitrogen treatment, the N nutrient content of raw sugarcane under different nitrogen application treatments increased by 1.07 - 1.14 g/kg, an increase of 17.38% - 18.57%, the difference reached a very significant level, but the difference among different N application treatments was not significant. Compared with the non-nitrogen treatment, the N nutrient content of straw increased by 1.56 - 2.36 g/kg, an increase of 16.05% - 24.19%, the difference reached a significant or very significant level, but the difference among N treatments was not significant. Compared with the non-nitrogen treatment, sugarcane N nutrient accumulation increased by 66.3 - 105.15 kg/ha, an increase of 44.55% - 70.68%, and the difference reached a significant level. With the application of nitrogen fertilizer on the basis of nitrogen deficiency, the nitrogen absorbed by sugarcane from soil increased by 44.55% - 70.68%; the nitrogen provided by different fertilization treatments accounted for 26.33% - 56.81% of the N absorbed by sugarcane, and the tested soil provided 43.19% - 73.76% nitrogen guarantee.

Table 5 Effects of different fertilization treatments on nitrogen accumulation and distribution in sugarcane kg/ha

Nitrogen application level	Sugarcane stem nitrogen accumulation	Sugarcane straw nitrogen accumulation	Overground part nitrogen accumulation	Overground part nitrogen uptake for 1 t of raw sugarcane
OPT-N	95.10 ± 4.65 c	53.55 ± 1.64 c	148.80 ± 5.46 c	26.55 ± 0.91 b
75% N	139.95 ± 8.30 b	75.00 ± 1.46 b	214.95 ± 8.66 b	31.05 ± 1.66 a
100% N	160.20 ± 4.86 a	90.15 ± 5.44 a	250.35 ± 10.13 a	31.50 ± 0.09 a
125% N	158.25 ± 10.12 a	89.55 ± 4.99 a	247.80 ± 9.03 a	31.80 ± 0.85 a
150% N	161.40 ± 7.23 a	92.40 ± 1.09 a	253.95 ± 7.83 a	31.80 ± 0.83 a

Note: Values followed by different letters in a column are significant among treatments at the 5% level.

4 Conclusion and discussion

4.1 Effects of different nitrogen treatments on nitrogen use efficiency of sugarcane In this study, the nitrogen fertilizer nutrient utilization rate of sugarcane was 18.67% - 27.09%, and the average yield of sugarcane was 298 - 348 kg per kg of N absorbed. For every 1 t of raw sugarcane produced, each nitrogen application treatment needs to absorb 0.302 - 0.480 kg of N from the soil. The apparent surplus rate of soil nitrogen can reflect the nitrogen absorption and utilization of sugarcane and the surplus of nitrogen in soil to some extent. The apparent surplus rate of soil nitrogen in sugarcane field increased with the increase of nitrogen application rate. In this study, the soil nitrogen surplus rate was as high as 58.79% - 82.28%, indicating that there was a high amount of nitrogen residue in the soil, and there was a significant positive correlation between nitrogen application rate and soil inorganic nitrogen content in sugarcane field[8].

4.2 Effects of different nitrogen treatments on nitrogen use efficiency of sugarcane The apparent utilization rate of soil nitrogen refers to the ratio of plant nitrogen accumulation to nitrogen application amount, which reflects the soil nitrogen surplus and crop nitrogen absorption and utilization to a certain extent. Previous studies have found that there is a positive correlation between wheat grain yield and aboveground nitrogen accumulation during harvest, and reasonable application of nitrogen fertilizer can increase crop nitrogen uptake[9]. The apparent utilization rate of soil nitrogen was positively correlated with the amount of nitrogen fertilizer applied. When the amount of nitrogen application reached 563 kg/ha, the apparent utilization rate of soil nitrogen was 80.19% - 84.37%. The increase of apparent utilization rate of soil nitrogen meant the increase of soil nitrogen residue. Under different nitrogen treatments, the nitrogen nutrient use efficiency and agronomic use efficiency of sugarcane increased at first and then decreased with the increase of nitrogen application. However, the partial productivity of sugarcane decreased significantly with the increase of nitrogen application. Under the condition of increasing nitrogen application rate of sugarcane, the nitrogen accumulation of sugarcane stem and straw increased continuously, but the yield did not increase synchronously, and the nitrogen use efficiency decreased with the increase of nitrogen application. On the whole, the overground part nitrogen of sugarcane in the nitrogen application area was beneficial to the transfer of nitrogen to sugarcane stem, which is consistent with the results of previous studies[10]. The use of nitrogen fertilizer could increase the yield of sugarcane, but it did not increase with the increase of nitrogen application rate. The results showed that in a certain range, the sugarcane yield increased

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with the increase of nitrogen application rate, but when it exceeded a certain range, the sugarcane yield would be greatly decreased.

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