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RESEARCH ARTICLE

Combined application of NPK on yield quality of sugarcane applied through SSDI

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Abstract Field experiments were conducted to study the effects of combined application of nitrogen (N), phosphorus (P) and potassium (K) on growth, yield quality and nutrient balance of sugarcane with subsurface drip irrigation by using the sugarcane variety ROC89/1626 and adopting "3414" project design. It was observed that the appropriate rate of N, P_2O_5 and K_2O increased the plant height, cane yield and cane quality of sugarcane under the experimental conditions. The fertigation model recommended for highest cane yield was 367.2 kg N, 162.6 kg P_2O_5 and 423.3 kg K_2O per ha. The highest cane yield recorded with this dose was 101.8 t/ha. The best fertigation model recommended was 340.1 kg N, 141.9 kg P_2O_5 and 401.1 kg K_2O per ha for the cane yield of 101.6 t/ha.

Keywords Sugarcane, combined application, nitrogen, phosphorus, potassium, nutrient balance, yield

Introduction

Sugarcane (*Saccharum species* hybrid L.) is the most important sugar crop in China. Guangxi is the most productive sugarcane and sugar producing provinces, contributing over 70% of the total cane sugar output in China. Most of the sugarcane growing areas are on the slope uplands, which have low fertility and water holding capacity responsible for the low cane productivity (Li 2004). Water and nutrients play an important role in sugarcane production. Considerable variations are noted in the absorption and uptake of nutrients and water by sugarcane from the soil (Li 1993; Yang and Li 2005). Subsurface drip irrigation (SDI) is a combination of drip irrigation and fertilization technology (Bar 1999), which could not only save the water and fertilizer, but also improve crop yield and quality with lower costs and increase the efficiency of crop production (Zhou *et al*. 2001; Cheng *et al*. 1999). The advantages of SDI include easy operation, easy realization of automatic control of both irrigation and fertilization, saving water and fertilizer, effectively controlling insect pests and diseases, and improving labor and production efficiencies (Camp 1998). At present, SDI was mainly studied in cotton (Kan *et al*. 2007), corn (Caldwell *et al*. 1994; Lamm *et al*. 2002), vegetables (Clark *et al*. 1993; Neibling *et al*. 1995) and fruit (Cui 2007), etc. The aim of the present study was to investigate the effect of nitrogen, phosphorus, potassium combined application on sugarcane with subsurface drip irrigation, and provide a reference to improve fertilizer and water use efficiency, to increase the cane yield and sugar quality, and finally to improve the economic income in commercial sugarcane plantation in Guangxi, China.

Materials and Methods

Plant materials and soil characteristics

The experiments were conducted on Jinguang Farm, Guangxi, China during 2008 - 2009. The sugarcane variety ROC89/1626 supplied by Jinguang Farm was employed as the experimental material. The soil of the experiments was clay

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loam with pH4.89, organic matter 3.16%, total N 0.12%, alkalized N 97.4 mg/kg, available P 21.7 mg/kg and available K 130 mg/kg. For 0-20 cm soil layer, it was characterized by bulk density 1.32 g/cm^3, water content 31.5% and field capacity 39.9%. The fertilizer used included urea (N 46%), fused calcium magnesium phosphate (P_2O_5 18%) and KCl (K_2O 60%).

Experimental design and treatments

The experiment was conducted by "3414" project design that was recommended by China Ministry of Agriculture for *Fertilization Technical Specifications*. Three factors of N, P, K were designed with four levels and 14 treatments in 42 plots. The plot size was 90 m^2 each with the planting density of 82,410 buds/ha . The experiments were laid in randomized block design with three replications. Border rows were designed surrounding the experimental areas. The treatments were designed for this experiment, which are described in Table 1.

Table 1. "3414"design of the experiments (kg/ha)

Treatment Number	Treatments	N level	N (kg/ha)	P level	P_2O_5 (kg/ha)	K level	K_2O (kg/ha)
1	$N_0P_0K_0$	0	0	0	0	0	0
2	$N_0P_2K_2$	0	0	2	195.00	2	420.00
3	$N_1P_2K_2$	1	187.50	2	195.00	2	420.00
4	$N_2P_0K_2$	2	375.00	0	0	2	420.00
5	$N_2P_1K_2$	2	375.00	1	97.50	2	420.00
6	$N_2P_2K_2$	2	375.00	2	195.00	2	420.00
7	$N_2P_3K_2$	2	375.00	3	292.50	2	420.00
8	$N_2P_2K_0$	2	375.00	2	195.00	0	0
9	$N_2P_2K_1$	2	375.00	2	195.00	1	210.00
10	$N_2P_2K_3$	2	375.00	2	195.00	3	630.00
11	$N_3P_2K_2$	3	562.50	2	195.00	2	420.00
12	$N_1P_1K_2$	1	187.50	1	97.50	2	420.00
13	$N_1P_2K_1$	1	187.50	2	195.00	1	210.00
14	$N_2P_1K_1$	2	375.00	1	97.50	1	210.00

Results and Discussion

Effect on plant height of sugarcane

The plant height is very important for cultivation and breeding of sugarcane. The plant height data are given in Table 2, which showed that the treatment T5 ($N_2P_1K_2$) had maximum and the treatment T 8 ($N_2P_2K_0$) had minimum effect plant height. The plant height was increased by increasing application of N from level 0 ($N_0P_2K_2$) to level 2 ($N_2P_2K_2$), but decreased with the fertilizer application level 3 ($N_3P_2K_2$). For the effect of P, the level 0 ($N_2P_0K_2$) and level 2 ($N_2P_2K_2$) showed significantly higher plant height ($p<0.05$) than the level 3 ($N_2P_3K_2$). The plant height was higher at level 3 for K application, which was significantly higher ($p<0.05$) than that at other levels of K. Therefore, rational combined application of N, P_2O_5 and K_2O increased the plant height of sugarcane with subsurface drip irrigation.

Table 2. Effect of combined application of N, P and K on plant height of sugarcane at processing maturing stage (cm)

Treatment Number	Treatments	Average	Significance at 5% level
1	$N_0P_0K_0$	335.3	bc
2	$N_0P_2K_2$	325.0	cd
3	$N_1P_2K_2$	326.3	cd
4	$N_2P_0K_2$	339.7	abc
5	$N_2P_1K_2$	356.0	a
6	$N_2P_2K_2$	329.5	c
7	$N_2P_3K_2$	333.3	bc
8	$N_2P_2K_0$	307.8	d
9	$N_2P_2K_1$	335.3	bc
10	$N_2P_2K_3$	352.5	ab
11	$N_3P_2K_2$	322.0	cd
12	$N_1P_1K_2$	338.4	abc
13	$N_1P_2K_1$	340.4	abc
14	$N_2P_1K_1$	338.2	abc

Note: All the data were tested by means of LSR. Numbers in columns with different letters are significantly different ($P<0.05$), the same as this below.

Effect on cane quality

The data in Table 3 showed that there were differences in maturity and quality of sugarcane in different fertilization treatments under subsurface drip irrigation. The sucrose in cane in all the treatment was higher than 15% and the treatment T7 ($N_2P_3K_2$) was best. The fiber in cane in the treatment T1 $N_0P_0K_0$ was higher than others. The purity of juice was higher than 88% for all the treatments, and the highest was obtained in the treatment T6 and reached 93.06%. The lowest value was in T14 which was 88.11%. The reducing sugar in juice were all lower than 0.25%, the lowest were found in T3 and T14.The low reducing sugars level suggested that the sugarcane was at maturity stage and cane quality was good. The best cane quality was found in T7 and T3, which showed that rational combined application of N, P_2O_5 and K_2O was conducive to the accumulation of sugar and resulted in higher cane quality of sugarcane.

Table 3. Effect of combined application of N, P and K on cane quality of sugarcane

Treatment Number	Treatment	Sucrose in cane (%)	Fiber in cane (%)	Brix of juice (Bx°)	Purity of juice (%)	Reducing sugar in juice (%)
1	$N_0P_0K_0$	16.46	13.95	21.22	92.74	0.16
2	$N_0P_2K_2$	15.19	12.98	19.98	91.04	0.16
3	$N_1P_2K_2$	16.01	13.42	20.62	92.68	0.10
4	$N_2P_0K_2$	15.04	12.51	19.72	89.66	0.20
5	$N_2P_1K_2$	15.83	13.44	20.86	90.89	0.12
6	$N_2P_2K_2$	15.23	13.11	19.61	93.06	0.12
7	$N_2P_3K_2$	16.48	12.76	21.02	92.20	0.13
8	$N_2P_2K_0$	16.02	13.15	20.81	91.25	0.13
9	$N_2P_2K_1$	15.74	13.44	20.52	91.28	0.17
10	$N_2P_2K_3$	15.70	12.09	20.22	91.15	0.17
11	$N_3P_2K_2$	15.16	12.88	19.88	91.15	0.17
12	$N_1P_1K_2$	15.53	13.57	20.32	90.90	0.23
13	$N_1P_2K_1$	15.93	12.69	20.72	90.93	0.18
14	$N_2P_1K_1$	15.07	11.70	20.02	88.11	0.09

Effect on cane yield

Under the present subsurface drip irrigation condition, the data in Table 4 showed that the yield in the treatment T2 $N_0P_2K_2$ was lowest with 87.6 t/ha, then T1 $N_0P_0K_0$. Different ratio of N, P_2O_5 and K_2O had varied effects on the cane yield. The highest yield was observed in the treatment T4 $N_2P_0K_2$ with 114.0 t/ha, which was significantly higher than that in the other treatments and improved the cane yield by 28% as compared to the treatment T1 $N_0P_0K_0$. The treatment T6 $N_2P_2K_2$ also recorded significantly higher cane yield (108.2 t/ha) than the treatments T5, T8, T10, T13 and T14, which was 22% higher than that in the treatment T1 $N_0P_0K_0$. As the data shown in the Table 4, the highest output value was obtained in the treatment T4 $N_2P_0K_2$, then in T6 $N_2P_2K_2$, and the lowest in T1 $N_0P_0K_0$. The highest fertilizer cost was in in the treatment T10 $N_2P_2K_3$ because the K fertilizer was more expensive than N and P fertilizers, and the lower was in the treatment T8 $N_2P_2K_0$ except for the non fertilized control T1 $N_0P_0K_0$. The highest net income was obtained in the treatment T4 $N_2P_0K_2$, followed by T9 $N_2P_2K_1$, and they were 2476.0 Yuan/ha and 614.3 Yuan/ha higher as compared to T1 $N_0P_0K_0$.

Table 4. Effect of combined application of N, P and K on cane yield and economic benefit of sugarcane production

Treatment Number	Treatment	Cane yield (t/ha)	Fertilizer cost (Yuan/ha)	Output value (Yuan/ha)	Net income (Yuan/ha)
1	$N_0P_0K_0$	88.8cd	0	24430.6	24430.6
2	$N_0P_2K_2$	87.6d	3657.0	24097.5	20440.5
3	$N_1P_2K_2$	105.5ab	4575.8	29009.5	24433.7
4	$N_2P_0K_2$	114.0a	4441.5	31348.1	26906.6
5	$N_2P_1K_2$	98.9bcd	4968.0	27204.9	22236.9
6	$N_2P_2K_2$	108.2ab	5494.5	29752.6	24258.1
7	$N_2P_3K_2$	103.8ab	6021.0	28534.7	22513.7
8	$N_2P_2K_0$	96.8bcd	2890.5	26633.0	23742.5
9	$N_2P_2K_1$	106.3ab	4192.5	29237.4	25044.9
10	$N_2P_2K_3$	98.2bcd	6796.5	27017.4	20220.9
11	$N_3P_2K_2$	104.0ab	6413.3	28591.4	22178.1
12	$N_1P_1K_2$	101.1abc	4049.3	27790.2	23741.0
13	$N_1P_2K_1$	95.2bcd	3273.8	26171.8	22898.0
14	$N_2P_1K_1$	95.4bcd	3666.0	26232.5	22566.5

Note: 1. In 2008-2009 milling year, the price was 0.275 Yuan/kg for millable cane, 4.9 Yuan/kg for pure N, Yuan/kg for P_2O_5 and, 6.2 Yuan/kg for K_2O. 2. Pure income was calculated as total income substrate fertilizer cost only because other managements were the same.

Fertilizer effect function

The combined N, P_2O_5 and K_2O fertilizer effect functions were investigated under this experiment. The highest and economic yield was obtained by "3414" design.

The data in Table 5 showed that different functions recorded different results of highest yield. The ternary function of N gave lower fertilizer rate than the others, the binary functions of P and K showed the lower P rate, and the binary functions of N and K showed lower K rate. The ratio of N, P_2O_5 and K_2O were recommended by different functions (Table 5). The lowest rates of 306.50 t/ha N and 186.3 t/ha P were recommended by the Unitary function of N and binary function of PK, respectively, and the unitary function of K showed the lowest K rate. As a result, combined application of N 367.21 kg, P_2O_5 162.59 kg and K_2O 423.26 kg per ha could produce highest cane yield, and combined application of N 346.10 kg, P_2O_5 141.93kg and K_2O 401.11 kg per ha could produce economic cane yield under subsurface drip irrigation in the present experimental condition.

Table 5. Fertilizer rate recommended by different functions (kg/ha)

Function	Highest cane yield (t/ha)				Economic cane yield (t/ha)			
	N	P_2O_5	K_2O	Y	N	P_2O_5	K20	Y
Ternary function	333.45	30.30	620.67	112.2	320.63	39.54	569.8	110.0
Binary function of NP	402.71	263.37	420.00	105.1	387.89	235.98	420.00	103.4
Binary function of NK	370.50	195.00	325.50	102.3	369.36	195.00	305.04	102.3
Binary function of PK	375.00	194.4	418.52	102.1	375.00	186.3	503.37	101.2
Unitary function of N	362.19	195.00	420.00	101.8	306.50	195.00	420.00	100.2
Unitary function of K	375.00	195.00	328.34	102.4	375.00	195.00	225.86	101.9
Average	367.21	162.59	423.26	101.8	346.10	141.93	401.11	101.6

Nutrient balance method

Under subsurface drip irrigation, the data in Table 6 revealed that fertilizer application rates recommended by nutrient balance method. It was based on the expected cane yield the nutrient provided by soil, the effective components of fertilizer and the fertilizer availability. The fertilizer application rates recommended were N 373.82 kg, P_2O_5 304.76 kg and K_2O 404.83 kg per ha.

Table 6. Parameters and fertilizer application rates recommended by nutrient balance method

Nutrient	Nutrient per hundred kg	Nutrient for yield expected (kg)	Fertilizer availability (%)	Nutrient provided by soil (kg/ha)	Effective component of fertilizer (%)	Fertilizer amount recommended (kg/ha)
N	0.20	242.35	37.76	177.68	46.00	373.82
P_2O_5	0.02	23.98	7.50	17.58	18.00	304.76
K_2O	0.34	411.14	31.26	301.43	60.00	404.83

Conclusion

The experiment was conducted to study the effect of combined application of nitrogen, phosphorus and potassium on plant height, yield, and quality of rational combined application of N, P_2O_5 and K_2O increased plant height and enhance the growth of sugarcane. The highest cane yield, output value and net income were gained with combined application was of 375 kg N, 0 kg P_2O_5 and 420 kg K_2O per ha, which were 114 t/ha, 31348.13 Yuan/ha and 26906.63 Yuan/ha. The second best combined application of 375 kg N, 195 kg P_2O_5 and 420 kg K_2O per ha, in which cane yield, output value and net income were 108.2 t/ha, 27952.61 Yuan/ha and 24258.11 Yuan/ha, respectively. Different ratios of N, P_2O_5 and K_2O had varied effects on the cane quality. The appropriate rate of P_2O_5 seemed to improve the cane quality, but it was not significant under the present experiment condition. The cane quality was not affected by the application rates of N and K_2O. The two combinations viz., 375 kg N, 292.5 kg P_2O_5, 420 kg K_2O per ha and 375 kg N, 195.00 kg P_2O_5 and 420 kg K_2O per ha, produced the best cane quality. The fertilizer rates were recommended by fertilizer effect function and nutrient balance method. The highest and economic cane yield could be obtained by applying 346.1 kg N, 141.9 kg P_2O_5 and 401.1 kg K_2O per ha, which could produce 102t/ha of cane under subsurface drip irrigation.

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