



Effects of Soil and Foliar Applied Fertilizers on Growth, Yield and Sugar Quality of Two Sugarcane Cultivars under Rainfed Conditions

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ABSTRACT

Background: In north-eastern Thailand, sugarcane is planted normally in late rainy season wherein the plants may experience drought stress during its early growth stage in dry season and waterlogging stress during late growth stage at peak of rainy season. Hence, the objective of the present study was to investigate the effects of soil application alone and soil combined with foliar application of nutrients on growth, yield and sugar quality of sugarcane grown under rainfed conditions.

Methods: The field experiment was conducted during November 2016 to December 2017. A split-plot design with three replications was laid out. The two sugarcane cultivars (KK3, K93-219) were assigned as main plots. The fertilizer application methods were assigned as sub-plots that comprised of four treatments: (1) soil applied NPK, (2) soil NPK + foliar N and K applied at 90 days after planting (DAP), (3) soil NPK + foliar N and K applied at 210 DAP and (4) soil NPK + foliar N and K applied at 90 and 210 DAP.

Result: The soil NPK + foliar N and K applied at 90 and 210 DAP improved yield components and cane yield. The cultivar K93-219 produced significantly higher cane yield than KK3. The fertilizer application methods and cultivars had no significant effect on sugar quality such as brix (%), purity (%), polarity (%), fiber (%) and commercial cane sugar (CCS-%).

Key words: Drought, Flood, Foliar N and K, Soil NPK, Sugarcane.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is grown in over 1.91 million hectares in Thailand with an average productivity of 44.31 t ha⁻¹. Out of total area, 43.7% is cultivated in the northeast Thailand (Office of the Cane and Sugar Board, 2020) of which approximately 90% is under rainfed conditions. Most agricultural land in the region are toposequence; a sequence of sloped land separated into a series of upland fields and lowland fields. At different position lowland fields along the toposequence and the upper fields are commonly planted to early maturing rice (*Oryza sativa* L.) varieties while the lower fields are grown with late maturing rice varieties. In general, the upper paddy fields produced low yield since most underground water level occur below the soil surface during growing season (Hayashi *et al.*, 2007; Boling *et al.*, 2008). Recently, farmers began managing these paddies by growing sugarcane instead of rice crop. However, sugarcane planted in late rainy season may expose to drought during the period of dry season (January-March) and subsequently to temporary flooding (August-September) during the peak of rainy season in the region. As mentioned earlier, sugarcane faces drought in the formative phase and flood in the grand growth phase which may reduce yield. Nutrient uptake by plants generally decreases under drought conditions owing to a substantial decrease in transpiration rates and impaired active transport and membrane permeability. A decline in soil moisture content is associated with a decrease in the diffusion rate of nutrients from the soil matrix to the absorbing root surface (Steffens *et al.*, 2005). The application of potassium (K) has

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been found to increase sugarcane growth during drought consequently increasing cane yield (Manickam *et al.*, 2009). Under limited water supply, more K is required for the balance of photosynthetic CO₂ assimilation rates, defense of chloroplasts from oxidative damage, important of related disruption in carbohydrate metabolism, regulation of stomatal and relations of water status (Cakmak, 2005). Foliar application is the method to support plant nutrient uptake through leaves. Foliar application of potassium salt of active phosphorus increased the photosynthetic activities by protecting the photosynthetic machinery during unfavorable conditions (Verma *et al.*, 2021). In flooded soil, nutrient

uptake decreased due to reduce root activity cause by oxygen deficiency (Drew, 1992). Sugarcane flooded (three months) reduced by 10 to 78% of N, P and K concentration in leaf which indicated that the decrease in sugarcane growth during flooding might be due to reduced uptake of both macro and micro-nutrients (Gillbert *et al.*, 2007). The application of urea (0.3%), potassium nitrate (KNO_3 , 0.5%) and calcium nitrate (CaNO_3 , 0.4%) increased leaf area and shoot weight of sugarcane grown under flooding conditions (Jain *et al.*, 2016). In previous work, its focus normally on fertilizer application through the soil. There is little information on soil combined foliar fertilizer application and dual effect of drought and flood stress in different sugarcane cultivars. Hence, the present study was conducted to determine the effects of soil NPK and soil NPK combined foliar N and K fertilizer applied during drought and flood period on growth, yield and sugar quality of two sugarcane cultivars grown under rainfed conditions.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted on farmer's field at Na-Fai-Nue village, Nampong district with latitude of $16^\circ 43' \text{N}$ and longitude of $102^\circ 59' \text{E}$, Khon Kaen province of Thailand from November 2016 to December 2017. The field was converted from a paddy field where rice was cultivated for one year. The soil is loamy sand in texture; sand 73.6%, silt 15.6% and clay 10.7%. The soil is slightly acidic with a pH of 5.23, electric conductivity (EC) 0.025 dS/m and low organic matter content (0.5%). The total N, available P and exchangeable K measured from the soil were 138.51, 7.42 kg and 254.4 mg/kg, respectively. The total amount of rainfall during the growth period was 890 mm with rainfall peak in July. However, rainfall exhibited distribution for the entire growth period with an additional summer rain in March and April at tillering stage and late rain in October at ripening phase.

Experimental design and treatments

The experiment was laid out in a split-plot design with three replications. The two sugarcane cultivars (KK3 and K93-219) were assigned as main-plot. The four methods of fertilizer application were assigned as sub-plots (Table 1). Soil was tilled two times and the furrows were built from topsoil by tractor with 1.5 m spacing between rows. Sugarcane stalks at 11 months of age were used for planting material with the middle section of the stalks mostly used as material. Single node stalk segments of each cultivar were planted on December 19, 2016, in 5 rows \times 4 meters long plots with 0.50-meter plant spacing. The crop used residual soil moisture at early growth stage with initial soil moisture at 17% (by weight). Soil-applied fertilizers using fertilizer grade 16-16-8 (N, P_2O_5 , K_2O) at rate of (100-100-50) kg ha^{-1} in all treatments were applied in split, first at planting (50%) and then 120 DAP (50%) in all treatments. For foliar application, urea 5% (12.4 kg ha^{-1}) (Sangplung, 1978) and K_2O 0.5% (1.24 kg ha^{-1}) (Jain *et al.*, 2016) were diluted in one liter water and sprayed to the crop about 30-40 cm from the leaf canopy using backpack sprayer. The foliar fertilizer application was done at 90 DAP during rainless period (30 March) and at 210 DAP during flooding period (28 July). The plots were kept weed-free by manual weeding twice at 60 and 90 DAP. No insects and disease were detected thus no control was implemented in the present experiment.

Water level below and above ground surface

Observation wells of perforated polyvinyl chloride (PVC) tubes were installed at 150 cm depth in the middle of experimental field. Ground water level below soil surface and standing water above soil surface were recorded at two-weeks interval for entire the growth period according to Polthanee (1989). In the present experiment mean ground water level initiated about 100 cm below soil surface at time of planting (December) (Fig 1). Then, ground water level came up above soil surface at the peak (June to mid-August) of rainy season for 85 d (Fig 1).

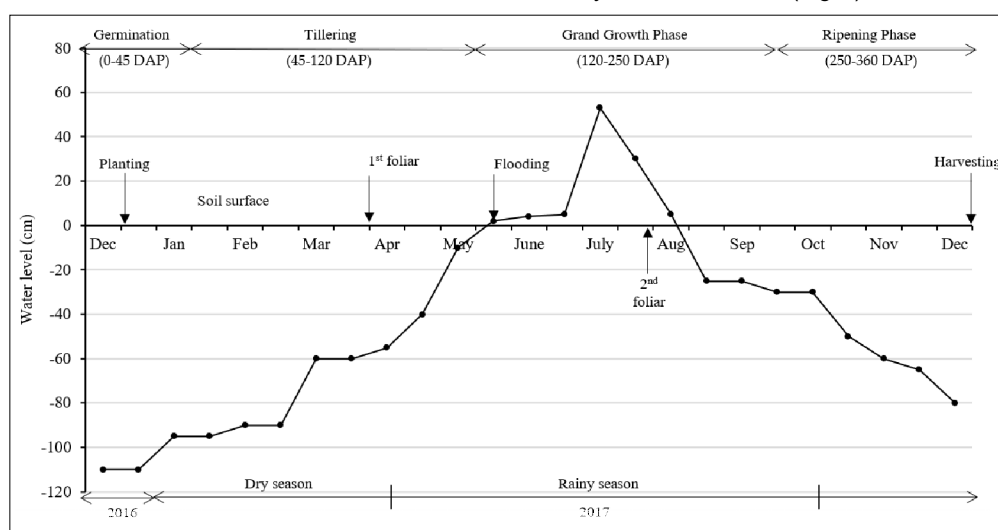


Fig 1: Water level below soil surface (-values) and above soil surface (+values) at experimental site during the growth period; DAP = Days after planting.

Plant growth

The plant height was measured at harvest by measured from base (soil surface) to the leaf tip of main stalk using a meter rod. For leaf area, the leaves were selected randomly from 10 main stems at 90 and 210 DAP of each plots. Thereafter, the leaf samples were measured with a leaf area meter (ACC-400, Hayashi Denken, Japan).

Yield components and cane yield

The number of millable cane was counted from four plants randomly selected from each plot at harvest. Thereafter, the samples were determined as fresh weight plant. The single millable cane fresh weight was calculated with fresh weight plant⁻¹ divided by the number plant. For cane yield, the millable cane fresh weight was recorded from the areas of 3.50 m × 6.50 m located in the middle rows of the plots and expressed as cane yield (t ha⁻¹).

Nutrient concentration and sugar qualitative parameters

The top visible dewlap (TVD) of three plants were randomly selected from each plot at 300 DAP. The plant samples were dried at 80°C for 48 h until constant dry weight and analyzed for total N (%) and total K (%). The qualitative parameters such as brix (%), purity (%), polarity (%), fiber (%) and commercial cane sugar (CCS-%) were evaluated at harvest from the stalk samples.

Statistical analysis

The data was analyzed using the computer software Statistix 10 (Statistix 10, Analytical Software, USA). Analysis of variance (ANOVA) with the main factor fertilization treatment and cultivar (factor fertilization treatment nested in factor cultivar) was performed for the parameters yield and other variables. For parameters with significant fertilizer treatment effect ($p \leq 0.05$), comparison of treatment means was performed using the least significant difference test (LSD) at $p \leq 0.05$ level of confidence.

RESULTS AND DISCUSSION

Nutrient concentration in top visible dewlap leaf (TVD)

Fertilizer application methods and cultivars had no significant effect on N and K concentration in TVD leaf but there was significantly effect on K (Table 2). Foliar N and K application gave higher N and K concentration than that of no-foliar application in all treatments (Table 2). As mentioned above, the plants experienced prolong flooding stress. For this reason, sugarcane plants formed adventitious roots on their submerged stems during the flooding events. The adventitious roots formation is considered an important adaptation of sugarcane to flooding stress (Gomathi *et al.*, 2010a; Jaiphong *et al.*, 2016). Under flooding condition, soil rapidly become anoxic, causing nutrient availability in the

Table 1: Treatments in sub-plots of application fertilizer methods.

Treatments	Soil applied (kg ha ⁻¹)			Foliar applied (kg ha ⁻¹)	
	N	P ₂ O ₅	K ₂ O	N	K ₂ O
Soil NPK	56	28	56	none	none
Soil NPK+Foliar at 90 DAP	56	28	56	12.4	1.24
Soil NPK+Foliar at 210 DAP	56	28	56	12.4	1.24
Soil NPK+Foliar at 90 and 210 DAP	56	28	56	24.8	2.48

Note: Foliar applied N (urea 5 %) diluted in one liter water, K (K₂O 0.5%) diluted in one liter water, soil applied by split at planting (50%) and 120 DAP (50%), DAP = Days after planting.

Table 2: Yield components, cane yield and growth parameters of sugarcane as affected by methods of fertilizer application and cultivars under rainfed conditions.

Treatment	Millable cane	Single millable	Cane yield	Leaf area (cm ² /tiller)		Plant height
	number (no./plant)	cane weight (kg)	(t ha ⁻¹)	90 DAP	210 DAP	(cm)
Method of application (M)						
Soil NPK	3.6c	1.4b	66.2c	884.4	1372.6	245.8
Soil NPK+Foliar at 90 DAP	4.1ab	1.3b	87.5b	897.1	1305.6	245.9
Soil NPK+Foliar at 210 DAP	4.6b	1.6ab	76.8bc	757.7	1238.7	252.1
Soil NPK+Foliar at 90 and 210 DAP	4.7a	1.8a	111.8a	877.7	1471.2	245.3
F-test	*	*	**	ns	ns	ns
Cultivar (C)						
KK3	4.4	1.3b	78.1b	698.4b	1104.2b	251.1a
K93-219	5.2	1.7a	117.5a	855.3a	1347.1a	243.5b
F-test	ns	*	**	**	**	*
Interaction M×C	ns	ns	ns	ns	ns	ns

Notes: ns, *, ** = non-significant and significant at $p \leq 0.01$ probability levels, respectively. Mean with the difference small letters in each column is significantly different by least significant difference ($p \leq 0.05$); DAP = Days after planting.

soil to decrease (Kozłowski and Pallardy, 1984). Flooding induced severe deficiencies of N, P and K in sugarcane; the N and K concentration were below critical deficiency level (Singh *et al.*, 2019). Furthermore, the lack of oxygen may cause decay of the primary root systems (Visser *et al.*, 2015). By lower nutrient availability together with impeded functioning of the primary roots may lead to nutrient deficiency in the plant (Trought and Drew, 1980). Previous studies reported that the adventitious roots can take up nutrients and water from flood water (Trought and Drew, 1980; Khan *et al.*, 1982; Zhang *et al.*, 2017). However, flooding in sugarcane (three months) resulted in reduction by 10 to 78% in N, P and K concentration in leaf (Gilbert *et al.*, 2007). The application of farm yard manure and foliar spray of KCl and urea proved effective in increasing K ions concentration which regulates the opening and closing of stomata hence transpiration rate (Chand *et al.*, 2010). Under drought conditions, the application of nitrogen (N) in solid and foliar forms on two broad leave and narrow leave cane varieties proved to be advantageous (Ali *et al.*, 1997). Foliar N and K under waterlogged conditions can improved nutrients uptake through leaves. Foliar absorption occurs through a process that initially requires penetration into the cuticle (passive percolation or surface adsorption) and then passes (active absorption) through the cells (Fernandez and Brown, 2013). For cultivars, KK3 was significantly ($p \leq 0.05$) higher K⁺ concentration in TVD leaf than K93-219 (Table 2). Waterlogging induced 28% and 30% reduction in leaf and stem N content, respectively and the reduction was comparatively lesser in resistant clones (Gomathi *et al.*, 2010a; Gomathi and Chandran, 2012).

Growth character performances

Plant height at harvest and leaf area at 90 and 210 DAP had no significant affected by fertilizer application methods but there is significantly different between two cultivars in plant height and leaf area (Table 3). The highest plant height was observed in KK3. While, K93-219 gave the highest leaf area at 90 and 210 DAP. Foliar N application under waterlogged condition increased leaf area and shoot weight was reported by Jain *et al.* (2016).

Yield components and cane yield

Fertilizer application methods was significantly different ($p \leq 0.05$) in millable cane number (Table 3). The maximum millable cane numbers were attained in the soil NPK + foliar N and K application at 90 and 210 DAP. Similar result was observed in single millable cane weight (Table 3). This was associated with higher K concentration in TVD of such treatment than those of the other treatments in the present study (Table 2). This means that high K content in plants play an important role in contribution the single millable cane weight. A sustained supply of K⁺ throughout the growing season will facilitate greater shifting of dry matter from leaf to stem, enhancing the translocation of more assimilates from source to sink (Mengel and Haeder, 1977). It is an

enzyme activator in photosynthesis, protein synthesis, starch formation and translocation of proteins and sugars (Filho, 1985; Kwong, 2002; Wood and Schroeder, 2004). Furthermore, additional foliar N and K at 90 and 210 DAP providing N and K for sugarcane at tillering and grand growth phase supports better plant growth and development reach to ripening phase (millable cane) than the other treatments. Foliar K application at tillering phase (90 DAP) resulted in increased millable cane count was reported by Mathew *et al.* (2004). The increase in blackgram and cowpea grain weight due to the application of foliar spray were also reported by Geetha and Velayutham (2016); Anitha *et al.* (2005).

For cultivars, millable cane number and single millable cane weight were significant different in single millable cane weight (Table 3). The cultivars K93-219 produced higher single millable cane weight than KK3 cultivar. This was associated with K93-219 cultivar gave higher leaf area than KK3 cultivar (Table 3). The cultivar K93-219 identified as waterlogging tolerance cultivar (Office of the Cane and Sugar Board Thailand, 2016; Palachai *et al.*, 2019). Therefore, the K93-219 could provide more of food from photosynthesis and translocate to stalk than that of KK3 cultivar.

Regarding cane yield, fertilizer application methods and cultivars were significantly different in cane yield (Table 3). The maximum cane yield was obtained in soil NPK combined foliar N and K application at 90 and 210 DAP. This was probably due to higher single millable cane weight and millable cane number than those of other treatments. The cultivar K93-219 produced significantly higher cane yield than KK3. This was due to the K93-219 gave higher single millable cane weight and millable cane number than KK3 cultivar.

Table 3: Total nitrogen and total potassium concentration of top visible dewlap (TVD) leaf of sugarcane as affected by methods of fertilizer application and cultivars under rainfed conditions.

Treatment	Total N (%)	Total K (%)
Method of application (M)		
Soil NPK	1.52	1.45b
Soil NPK+Foliar at 90 DAP	1.72	2.05a
Soil NPK+Foliar at 210 DAP	1.68	1.76ab
Soil NPK+Foliar at 90 and 210 DAP	1.78	2.10a
F-test	ns	*
Cultivar (C)		
KK3	1.68	2.00a
K93-219	1.53	1.68b
F-test	ns	*
Interaction M×C	ns	ns

Notes: ns, * = non-significant and significant at ($p \leq 0.05$) probability levels, respectively. Mean with the difference small letters in each column is significantly different by least significant difference ($p \leq 0.05$); DAP = Days after planting.

Table 4: Sugar quality parameters of sugarcane as affected by methods of fertilizer application and cultivars under rainfed conditions.

Treatment	Brix (%)	Polarity (%)	Purity (%)	Fiber (%)	CCS (%)
Method of application (M)					
Soil NPK	19.9	16.2	75.1	11.5	12.4
Soil NPK+Foliar at 90 DAP	19.3	15.8	73.1	11.2	11.9
Soil NPK+Foliar at 210 DAP	18.9	15.4	71.8	11.0	11.8
Soil NPK+Foliar at 90 and 210 DAP	21.4	17.2	80.6	12.2	13.4
F-test	ns	ns	ns	ns	ns
Cultivar (C)					
KK3	22.5	18.3	81.1	12.8	14.8
K93-219	20.6	16.8	81.6	12.1	12.5
F-test	ns	ns	ns	ns	ns
Interaction M×C	ns	ns	ns	ns	ns

Notes: ns = non-significant. Mean with the difference small letters in each column is significantly different by least significant difference ($p \leq 0.05$); DAP = Days after planting.

Sugar quality

Fertilizer application methods and cultivars had no significant effect on sugar quality components including brix (%), polarity (%), purity (%), fiber (%) and CCS (%) (Table 4). In general, sugarcane responded to K fertilizer by an increase in cane yield without any change in sucrose concentration in the cane (Kwong, 2002; Shukla *et al.*, 2009). In contrast, nitrogen applied split into solid and foliar forms on two broad leaves and narrow leaves cane varieties increased polarity (%) juice and CCS (%) of sugarcane (Ali *et al.*, 1997).

CONCLUSION

The soil NPK + foliar N and K application in dry season at 90 DAP and rainy season at 210 DAP during flooding stress had compounding positive effect on yield components and subsequently improving cane yield, but it had no significant effect on sugar quality components. The sugarcane cultivar K93-219 produced significantly higher cane yield than KK3.

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Conflict of interest: None.

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