Research Findings

Experiment site in Gia Lai province, 2014. Photo by Nguyen Duy Phuong.

Potassium Effects on the Productivity and Quality of Sugarcane in Vietnam

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Abstract

Sugarcane (*Saccharum* spp.) is an important industrial agricultural crop in Vietnam. Average sugarcane productivity in Vietnam is 64 Mg ha^{-1}, and the average commercial cane sugar (CCS) content is 10%, significantly lower than in leading sugarcane producing countries that achieve 75 Mg ha^{-1} and 14-15% CCS content. Under rain-fed conditions in Vietnam, low sugarcane performance may be the result of poor nutrition management. In farmers' practices (FP), nitrogen (N) is generously applied, while phosphorus (P) and potassium (K) are generally ignored. The objectives of this 3-year study were to examine and demonstrate the contribution of increased K application to sugarcane yield, quality, and economic benefit under commercial conditions. Field experiments took place from 2012 to 2015 in a parallel design in Gia Lai (Central Highlands) and in Khanh Hoa (Central Coast) provinces. Treatments included six K (KCl) rates (0, 200, 300,

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Photos 1. Sugarcane with a bowl of refined sugar (left) and cut sugarcane (right). *Source:* http://www.scienceimage.csiro.au/.

350, 400, 450 kg K_2O ha^{-1}) together with 250 kg N and 150 kg P_2O_5 ha^{-1}. A local FP was also included as a control. Potassium application significantly improved sugarcane yields by 18.5-31.5% in Khanh Hoa, and 9.2-26.8% in Gia Lai, compared to FP. CCS content increased from 8% at 0 kg K_2O ha^{-1} to 11-12% at 200 kg K_2O ha^{-1}, reaching about 12.5% at the highest doses. In spite of the impressive response to K, the K agronomic efficiency (KAE) was very low, at 67 and 40 kg of cane per kg K_2O, in Gia Lai and Khanh Hoa, respectively. The low KAE may be attributed to water deficit problems and rapid nutrient leaching from the root zone. Thus, although the apparent economic optimal K dose is 350-400 kg K_2O ha^{-1}, use of additional approaches – such as soil enrichment with organic matter, more frequent K applications, and irrigation - are expected to improve K uptake efficiency, further increase sugarcane yield and quality, and reduce the required annual K dose.

Introduction

Sugarcane is an important industrial crop in Vietnam's agriculture sector and has greatly contributed to the economic development of rural communities in midland and mountainous regions. Vietnam Sugarcane Association (VSA) estimated that total cane production area in 2014 was about 305,000 ha, distributed across different ecological zones (Fig. 1), with production of 19.8 million tonnes of sugar for domestic consumption and export (VSA, 2014).

The average sugarcane yield in 2014 reached 64.2 Mg ha^{-1}, with an average national commercial cane sugar (CCS) content of 10%. In spite of a significant improvement in sugarcane productivity from 50 Mg ha^{-1} in 2000 to 64 Mg ha^{-1} in 2012 (FAO, 2012), sugarcane production in Vietnam still faces many challenges such as climate change, large-scale droughts in midland and mountainous regions, outdated varieties, and slow adoption of new cultivation technologies. Thus, Vietnamese sugarcane productivity and economic efficiency is lower than in Thailand (74.2 Mg ha^{-1}), Brazil (74.3 Mg ha^{-1}), and the United States (75.4 Mg ha^{-1}). Moreover, Vietnamese CCS content remains low (10%), compared to Thailand and Indonesia (12-13%), and Australia and some regions of China (14-15%) (Trang, 2015). The relatively low sugarcane productivity and quality is currently considered to be the major disadvantage of the sector. Therefore, improving these parameters is a priority to ensure sustainable sugarcane production in Vietnam.

Potassium (K) is an essential nutrient in sugarcane production, with a number of roles being attributed to it within the plant (Anderson and Bowen, 1990). These roles include: translocation of sugar in plants; starch formation; chlorophyll development and the promotion of photosynthesis; prevention of premature cell

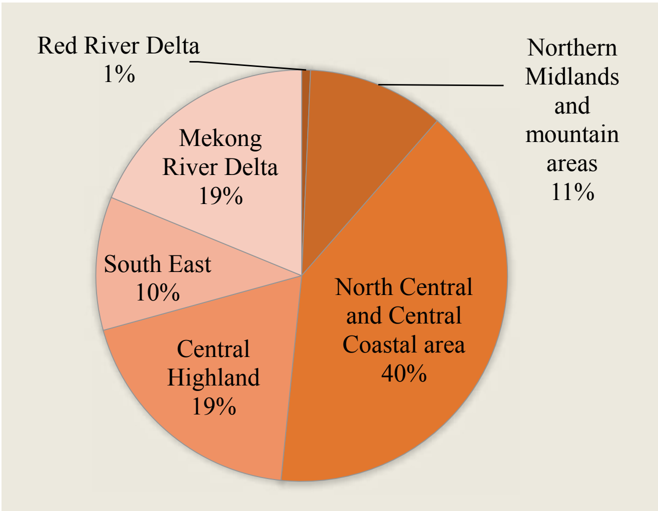
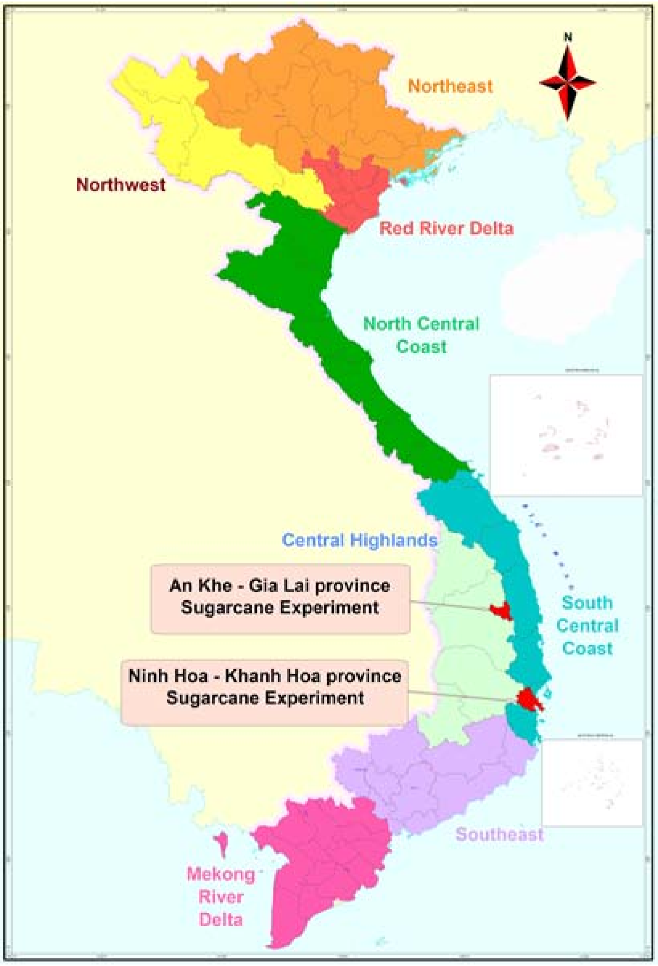


Fig. 1. Distribution of sugarcane area in Vietnam.

death; stomatal opening and closure; and uptake of water (and nutrients) by osmosis. However, the importance of these roles is not fully understood by growers when considering K application to their crops (Wood and Schroeder, 2004). Although K deficiency symptoms are apparent in sugarcane, sub-optimal concentrations do not generally give rise to a marked yield depression. This is probably the result of processes that occur in soils in replenishing the plant available K (exchangeable and soil solution K) from non-exchangeable K sources (Chapman, 1980). Nevertheless, rapid soil erosion processes, particularly typical to afforestation in humid tropical regions, significantly reduce the ability of soils to replenish nutrients (D'haeze *et al.*, 2005; Tran Minh Tien *et al.*, 2015).

A field survey on sugarcane fertilization, carried out in Khanh Hoa and Gia Lai provinces in 2012, indicated that farmers commonly applied inadequate quantities of fertilizers and suffered from an imbalanced ratio of nutrients. On average, fertilizer rates for N, P_2O_5, and K_2O in Gia Lai were 190, 110, and 90 kg ha^{-1} respectively, and 160, 120, and 120 kg ha^{-1} in Khanh Hoa. The recommended application rates are 120-350 kg ha^{-1} N, 50-170 kg ha^{-1} P_2O_5, 100-350 kg ha^{-1} K_2O, and 15-20 Mg ha^{-1} of farm yard manure (FYM), depending on the soil fertility of each agro-ecological zone (SFRI, 2005). These data reveal a significant deficit in fertilizer application of about 45-54% of N, 65-71% of P_2O_5, and 26-34% of K_2O. Moreover, the survey revealed that about 90% of farmers ignored the recommendation to apply FYM to sugarcane. Inadequate fertilization, especially of K, in the farmers' fields, appears to be the main reason for low productivity and poor quality.

The objectives of this study were to: i) reassess K fertilization efficiency on sugarcane yield and quality in Central Highlands and Central Coast provinces; ii) define an optimum K application rate for economic yield and quality; and, iii) broaden the research results to national scale for future sugarcane production.



Map 1. Experiment sites in Gia Lai and Khanh Hoa provinces.

Table 1. Soil characteristics in the experimental sites.

Soil properties	Khanh Hoa	Gia Lai
pH_{KCl}	4.7	4.6
Organic carbon (OC) (%)	0.92	0.85
N (%)	0.07	0.074
P_2O_5 (%)	0.029	0.051
K_2O (%)	0.33	0.12
P_2O_5 available (mg 100 g^{-1})	1.36	3.85
K_2O available (mg 100 g^{-1})	8.20	7.73
Cation exchange capacity (CEC) (meq 100 g^{-1})	4.13	5.42
Clay (%)	14	14.8
Limon (%)	12	16.6
Sand (%)	74	68.6

Materials and methods

Experiment site: Field experiments were conducted in three consecutive years (2012-2015) at two sites. The first, Gia Lai province, which represents Central Highlands provinces, and the second, Khanh Hoa province, representing South-Central Coast provinces of Vietnam. These two regions contain 60% of Vietnam's total sugarcane area.

Soil properties in experiment sites

Soil samples from the two experimental sites were collected at a depth of 0-20 cm and their soil properties and soil fertiity status analyzed (Table 1). In both sites, analyzed data indicated that soil fertility was low in both total and available forms. The available K contents at both sites were especially poor, ranging from 7.73-8.20 mg 100 g^{-1} of soil. Soil texture was light (more than 80% loess and sand). Therefore the light texture and low soil fertility are the main constraints for sugarcane production in these regions.

Climate

The climate of Vietnam's central regions is tropical. Average temperatures range from 26-32°C and annual precipitation varies from 1,200-2,400 mm, with distinct dry and wet seasons. In Gia Lai, the average annual rainfall is about 1,940 mm, 50% higher than in Khanh Hoa. Also, the wet season occurs from June to September in the Central Highlands (Gia Lai), providing about 67% of annual rainfall. In South Central Coast, the wet season is milder and more prolonged, taking place from May to November. The dry season in both regions occurs from December to March, providing less than 5% of annual rainfall (Fig. 2).

Field experiments

The sugarcane cultivar tested in the study was K88-92, a new variety from Thailand. Experiments in each site included seven treatments with three replications using a random complete block (RCB) design. The area of each plot was 200 m^2, with total area of 4,200 m^2. Seven different levels of K were examined (Table 2). Fertilizers were applied directly to the furrow and both field experiments were conducted under rainfed conditions.

Fertilizer application during the year was divided into three steps (Table 3): i) basal fertilization, applied at planting; ii) fertilization carried out 3 months after planting; and, iii) fertilization conducted 6 months after planting.

Harvest productivity: Sugarcane harvesting takes place between March and April in Khanh Hoa, and between December and January in Gia Lai. Total yield was determined for each plot. Sugarcane quality was determined through laboratory analysis that included °Bx, and % juice and CCS content.

Economic analysis: The economic efficiency of K fertilization in sugarcane was calculated as a cost and benefit analysis, based on yield, quality, and prices.

Results

Large differences in sugarcane productivity occurred between the two experimental sites. Average 3-year yields in Gia Lai were 15-40% higher than in Khanh Hoa. The farmers' practice control in Gia Lai obtained an average of 84 Mg ha^{-1}, 40% higher than the same treatment in Khanh Hoa. Furthermore, while the yields in Khanh Hoa fluctuated significantly year-to-year, yield levels in Gia Lai remained considerably stable during the 3-year experiment (Fig. 3). Potassium application gave rise to significant yield increases in both sites, however, the intensity and pattern of this response were remarkably different (Fig. 4). As a rule, wherever K was applied at doses equal to or higher than 200 kg K_2O ha^{-1}, yields were higher than those of the FP (Fig. 3). In Gia Lai, yield response to K application was quite linear and sharp, as expressed by the constant contribution margin of about 67 kg^{-1} K_2O, and produced 38% more yield at the highest K application dose. In Khanh Hoa, the average contribution margin was much smaller at about 40 kg^{-1} K_2O, remaining constant up to a K dose of 350 kg K_2O ha^{-1}, after which it diminished to a negligible level of about

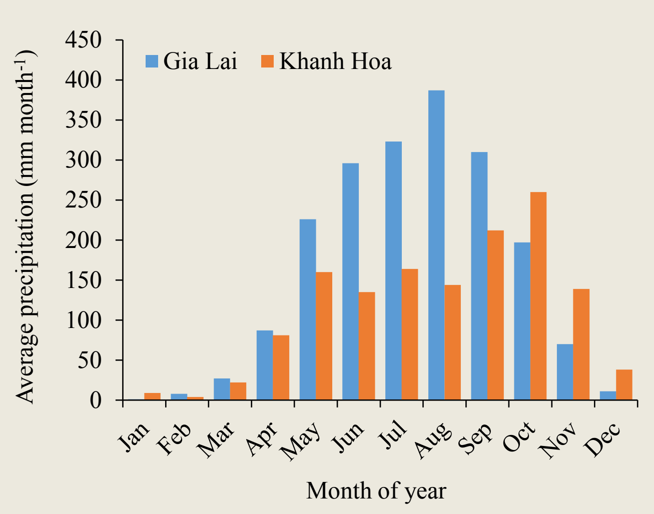


Fig. 2. Monthly distribution of average annual precipitation in Gia Kai and Khanh Hoa. *Sources:* http://mekongarcc.net/sites/default/files/province_profile-gia_lai_press.pdf; and http://en.climate-data.org/location/717532/.

Table 2. Treatments of K application dose (kg ha^{-1}) in Gai Lai and Khanh Hoa.

Treatment	N	P_2O_5	K_2O
T_1 Control(1)			
T_2	250	150	200
T_3	250	150	300
T_4	250	150	350
T_5	250	150	400
T_6	250	150	450
T_7(2)	250	150	0

(1)In FP Control (T_1) - rates of N, P_2O_5, and K_2O applied were 190, 110, and 90 kg ha^{-1} respectively at Gai Lai and 160, 120, and 120 kg ha^{-1} at Khanh Hoa.

(2)In Khanh Hoa, treatment T_7 was added only after the first cropping season.

Table 3. Proportion of fertilizers distributed to sugarcane during the year.

Fertilizer	Basal application, at planting	Second application, 3 months after planting	Third application, 6 months after planting
	-------------------	%	-------------------
N	30	40	30
P	100	0	0
K	30	40	30

11 kg^{-1} K_2O. Thus, the highest yield was obtained at 350 kg K_2O ha^{-1}, only 17% higher than the 0 kg K_2O ha^{-1} treatment (Fig. 4). Noteworthy are the differences in the farmers' practices between the sites; while in Gia Lai FP yield matched the general response to K dose, it was significantly below the expected value in Khanh Hoa (Fig. 4).

Sugarcane quality is often determined by CCS content of the raw material. This parameter is used by manufacturers to define the raw material's price. In contrast to the clear differences in yield (Figs. 3 and 4), CCS content reached quite similar values in both sites (Fig. 5). Again, significant differences occurred between years at Khanh Hoa. CCS content response to K application dose became clear when 3-year averages were used. At 0 kg K_2O (T_7), CCS content was very low at about 8%. CCS increased to values above 11% in response to the lowest K dose, but the response weakened with the increasing K doses. A maximum CCS content of 12.8% was obtained at the highest K dose, 450 kg K_2O ha^{-1} (Fig. 5). Noteworthy, however, is that the response was significant only in 2013 in Gia Lai and in 2014 in Khanh Hoa, whereas it was almost absent in the two other years. Also interesting were the intermediate CCS content values of 9.5-10% obtained from FP (T_1) which obeyed the general response to K doses (Fig. 5).

Juice content of the raw material is another important sugarcane quality parameter. Excluding the first year, 2013, where juice contents were significantly higher in both sites (especially in Khanh Hoa, where it was >75%), this parameter was quite stable, ranging from 58-68% throughout the study (Fig. 6). Potassium doses had no significant effect on sugarcane juice content.

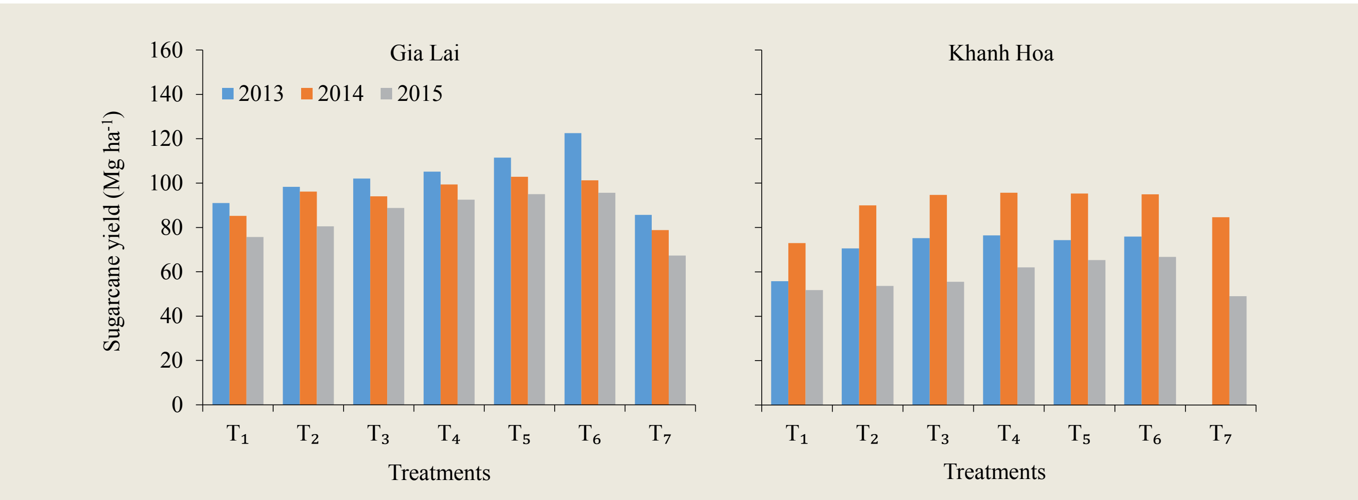


Fig. 3. Effect of annual K dose on sugarcane yield at Gia Lai and Khanh Hoa experiment sites.

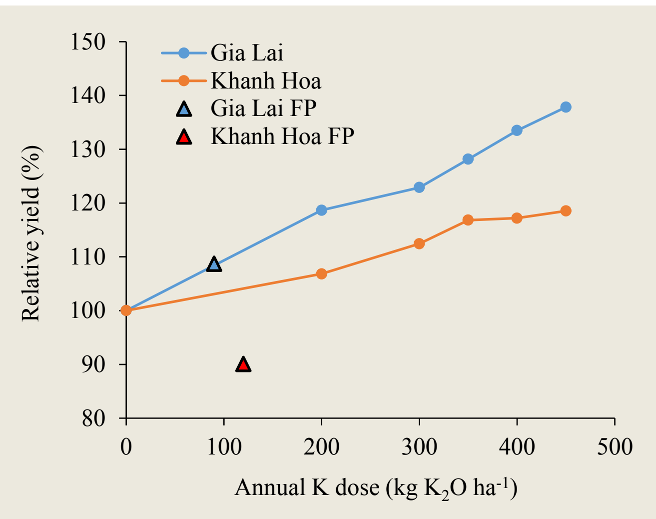
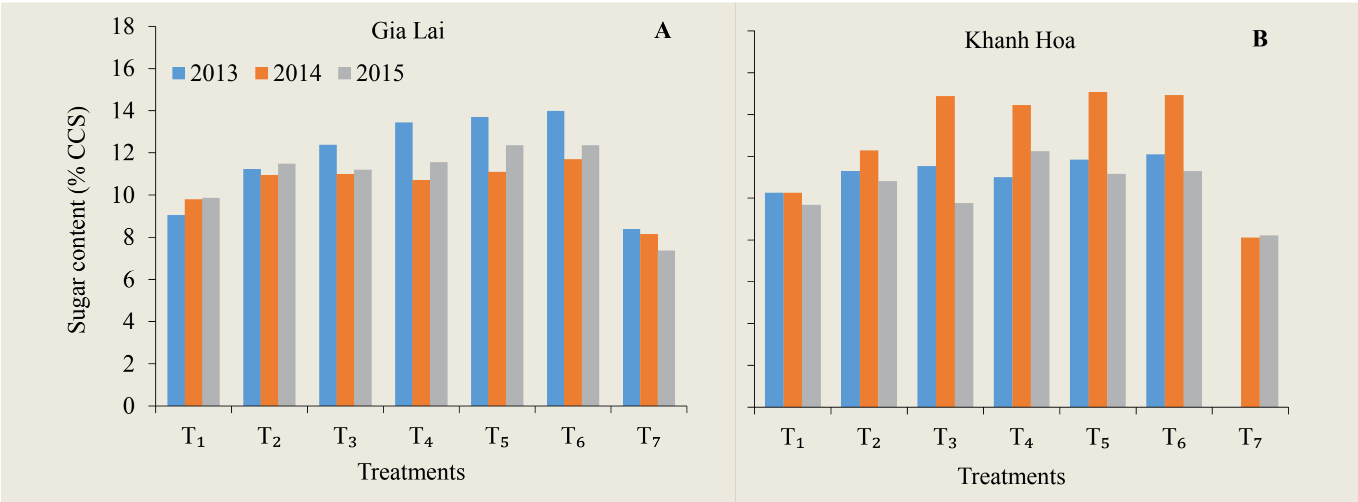


Fig. 4. Effect of increased annual K dose on the relative average sugarcane yield in Gia Lai and Khanh Hoa. Yield increments relate to the 0 kg K_2O control yield (T_7) as 100%. FP = farmers' practices.

Discussion

The substantial dissimilarity in sugarcane productivity between the Central Highlands (Gia Lai) and the South Central Coast experimental sites (Khanh Hoa), as well as the significant year-to-year variations in yields within each site, indicate that major factors, other than K availability, are involved. In spite of the humid tropic climate of Vietnam and the considerable annual precipitation, sugarcane crops often experience water stress that limit growth and productivity (Inman-Bamber and Smith, 2005; Zhao *et al.*, 2010; Cabral *et al.*, 2012; Zingaretti *et al.*, 2012; da Silva *et al.*, 2013). In central Vietnam, there are at least 5 months, from December to April, with less than 100 mm of rain per month (Fig. 2), which is below sugarcane water requirements. Therefore to improve sugarcane productivity in Vietnam, supplementing irrigation during the dry season must be considered alongside logistic and economic costs. Water shortages may also occur during the wet season, because water availability largely depends on soil water capacity and retention. Actually, in the humid tropics, water stress predominantly occurs in sugarcane due to



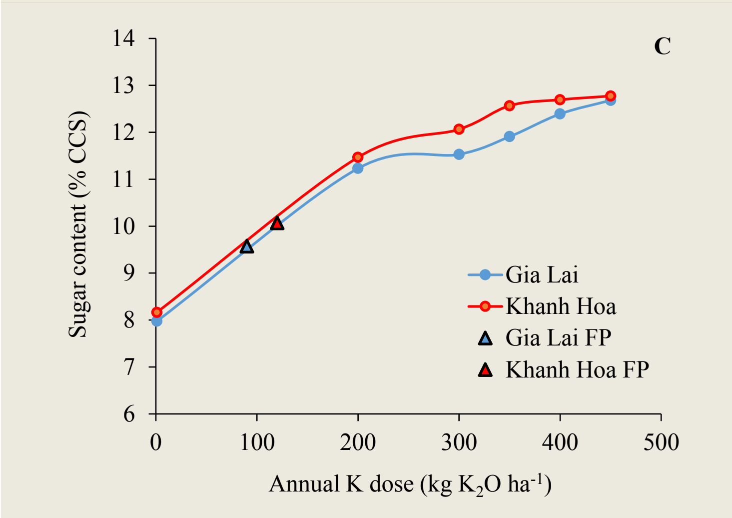


Fig. 5. Effect of annual K dose on CCS content in sugarcane raw material at Gia Lai and Khanh Hoa, 2013-2015. Fig. 5C: 3-year CCS content averages in response to elevated K doses. FP = farmers' practices.

inadequate soil water retention between consecutive rain events (Zhao *et al.*, 2010; Monteiro and Sentelhas, 2014). Light, sandy soils that typify the two experimental sites (Table 1) are characterized by low water retention and are therefore especially prone to frequent drought events. The considerably lower precipitation in the South Central Coast (Khanh Hoa) (Fig. 2), together with the larger sandy soil fraction (Table 1), may provide a sufficient explanation for the significantly lower productivity of this region.

On top of the current water availability problems, global climate change has already affected, and is predicted to further affect Vietnam (USAID, 2012; Nguyen *et al.*, 2014). A significant tendency of increasing annual precipitation has been identified in the central regions of Vietnam, however, rain quantities are anticipated to significantly increase during the wet season, and to decline

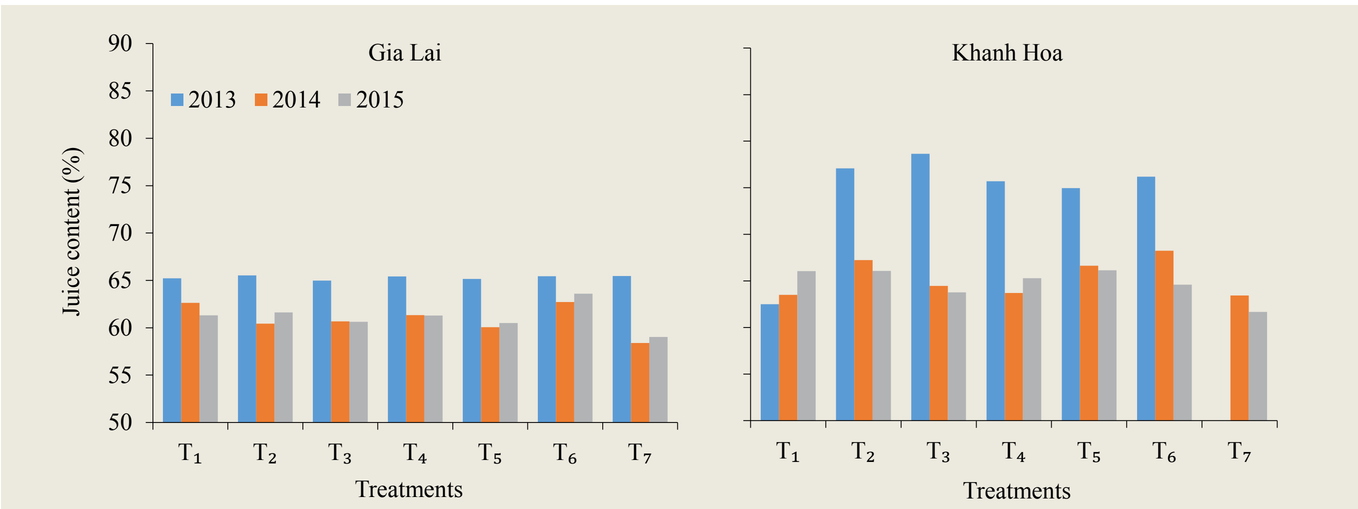


Fig. 6. Effect of annual K dose on sugarcane juice content (%) at Gia Lai and Khanh Hoa, 2013-2015.

Photos 2. Experiment sites in Gia Lai and Khanh Hoa provinces (2012-2015). Photos by Nguyen Duy Phuong.

during the dry season. In addition, year-to-year diversity and the number of extreme rain events are expected to grow (Nguyễn Thị Quỳnh Trang, 2014). As is already happening in other sugarcane growing countries that are facing climate change (de Carvalho *et al.*, 2015), the Vietnamese sugarcane industry may also face increasing water deficit problems that will require systematic as well as local solutions.

In agreement with many previous studies (Anderson and Bowen, 1990; Wood and Schroeder, 2004; Rice *et al.*, 2006; Singh *et al.*, 2008; Hunsigi, 2011; de Almeida *et al.*, 2015; de Oliveira *et al.*, 2016), K application resulted in unequivocal enhancements of sugarcane yields in both sites. The almost linear yield increase in Gia Lai (Fig. 4) suggests that K is the predominant limiting factor of sugarcane productivity in this region. However, the consistent increase, even at the highest K dose, may indicate a low K uptake efficiency. Singh *et al.* (2008) reported a K agronomic efficiency (KAE) ranging from 700-900 kg cane per kg K_2O; Hunsigi (2011) estimated that under rain-fed conditions, KAE would be about 270 kg kg^{-1}. In Gia Lai, KAE was lower by one order at only 67 kg kg^{-1} (Fig. 4), indicating a rapid depletion of available K in the root zone, curtailing the plants' opportunity for sufficient K uptake. This phenomenon is quite common in humid tropical regions, where loose soils are drained of nutrients by heavy rainfall events (Rhodes *et al.*, 2013; Rossato *et al.*, 2014; Tran *et al.*, 2015). Possible solutions may include soil enrichment with organic matter (de Almeida *et al.*, 2015), and much more frequent K broadcast (Wood and Schroeder, 2004).

The situation in the South Central Coast (Khanh Hoa) seems different. Here, water deficit is probably the major limiting factor to plant growth. Potassium uptake, when it occurs, cannot be fully manifested by the drought-affected plants. Thus, KAE is even lower at about 40 kg kg^{-1}, remaining constant up to K dose of 350 kg ha^{-1}, thereafter no further response could be observed (Fig. 4). It may well be, however, that in South Central Coast K is also being rapidly leached from the root zone by intensive rain events, as leaching and water deficit problems may take place simultaneously.

Potassium is required for sugar production, translocation, and storage (Marschner, 1995). In sugarcane, fulfilling K requirements would contribute significantly to quality traits, namely CCS content (Singh *et al.*, 2008; Hunsigi, 2011; de Oliveira *et al.*, 2016). In this study, CCS content responded dramatically, increasing from 8% to 11-12% as a result of the lowest dose, 200 kg K_2O ha^{-1} (Fig. 5). Yet, a further increase in K gave rise to a much weaker response. In light of the very low KAE mentioned above, it is questionable whether high CCS contents could have been obtained at a much lower K dose under normal K uptake rates. CCS content, however, was enhanced by K application which improved the economic value of sugarcane at both sites.

An economic analysis of sugarcane productivity as a function of K application doses (as expressed by the net return in million VND ha^{-1}) (Fig. 7), demonstrated linear relationships in both sites. It appears that CCS content enhancement, with its significant influence on the price of raw sugarcane, compensated for the irresponsive yields in Khanh Hoa. Still, the differences in yields between the two sites are strongly expressed by the economic performances. According to this analysis, K application would be beneficial even at a dosage higher than tested here. Nevertheless, 450 kg K_2O ha^{-1} is considered too high. In Florida, recommended K dose has been as high as 450 kg K_2O ha^{-1} for the first growth cycle (ratoon), but reduced to 270 kg K_2O ha^{-1} for the second and third ratoons (Rice *et al.*, 2006). Hunsigi (2011) suggested focusing on the responsive phase of sugarcane's K-optimum curve, applying up to 350 kg K_2O ha^{-1} and 117 kg K_2O ha^{-1} for the

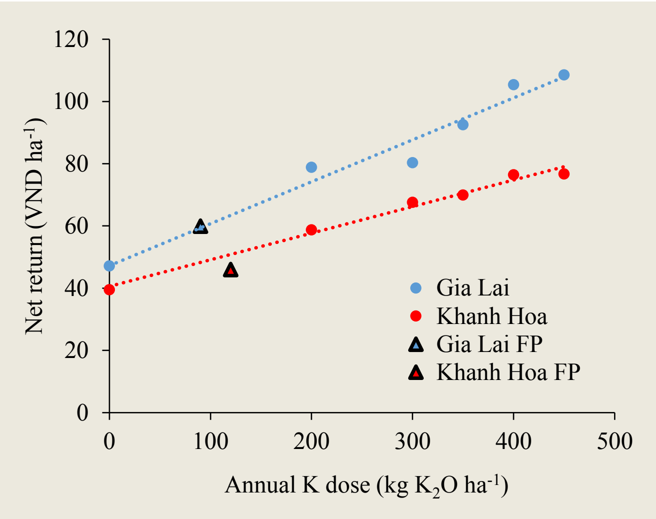


Fig. 7. Economic analysis: Net return (in Million Vietnamese Dollars, VND) of sugarcane production as a function of K application in Gia Lai and Khanh Hoa, Vietnam. FP = farmers' practices.

Photo 3. Harvesting sugarcane. Photo by Nguyen Duy Phuong.

first and second ratoons, respectively. Singh *et al.* (2008) settled on a standard dose of 150 kg K_2O ha^{-1} in their experimental studies in India, while de Oliveira *et al.* (2016) concluded that a dose of 98 kg K_2O ha^{-1} would be sufficient to obtain a stable sugarcane yield of 80 Mg ha^{-1}. The presence of such high K doses at the responsive phase also indicates a very low K uptake efficiency in the present study.

Apparently, the results shown here suggest that to improve sugarcane yield, quality and economic benefits, farmers should apply about 400 kg K_2O ha^{-1}, together with 250 kg N and 150 kg P_2O_5 ha^{-1}, in both regions. Potassium clearly plays a pivotal role in sugarcane production, however most K fertilizer, and probably N fertilizers, seem to be lost and wasted due to rapid draining and leaching processes. All facets relating to K in the soil-plant system need to be optimized to ensure efficient K supply, uptake and utilization by the crop (Wood and Schroeder, 2004). This will ensure that the crop is able to take up a more balanced suite of nutrients and can better withstand periodic drought conditions that occur in the sugarcane growing regions. Thus, enriching the soil with organic material would be a reasonable step toward improving soil CEC, and consequently increase K uptake rates. The fact that the farmers' practices tested here, which included considerable FYM application, resulted in the highest benefit to cost ratios of 8.5 (Gia Lai) and 6.7 (Khanh Hoa) compared to 7.8 (Gia Lai) and 5.9 (Khanh Hoa) in the chemically fertilized treatments, clearly supports this approach. Additionally, dividing the annual dose to frequent applications along the year, where practical, may significantly improve K uptake rates. Applying these two approaches may increase the agronomic efficiency of nutrients, which might even lead to reduced fertilizer doses and lessen the negative impacts on the environment.

References

Anderson, D.L., and J.E. Bowen. 1990. Sugarcane Nutrition. Potash and Phosphate Institute, Narcross, Georgia, USA.

Cabral, O.M., H.R. Rocha, J.H. Gash, M.A. Ligo, J.D. Tatsch, H.C. Freitas, and E. Brasilio. 2012. Water Use in a Sugarcane Plantation. GCB Bioenergy 4:555-565.

Chapman, L.S. 1980. Long-Term Responses in Cane Yield and Soil Analyses from Potassium Fertilizer. Proc. Aust. Soc. Sugar Cane Technol. 18:175-181.

Da Silva, V.D.P., B.B. da Silva, W.G. Albuquerque, C.J. Borges, I.F. de Sousa, and J.D. Neto. 2013. Crop Coefficient, Water Requirements, Yield and Water Use Efficiency of Sugarcane Growth in Brazil. Agricultural Water Management 128:102-109.

De Almeida, H.J., F.J. Cruz, M.A. Pancelli, R.A. Flores, R. de Lima Vasconcelos, and R. de Mello Prado. 2015. Decreased Potassium Fertilization in Sugarcane Ratoons Grown Under Straw in Different Soils. Australian J. Crop Sci. 9:596-604.

De Carvalho, A.L., R.S.C. Menezes, R.S. Nóbrega, A. de Siqueira Pinto, J.P.H.B. Ometto, C. von Randow, and A. Giarolla. 2015. Impact of Climate Changes on Potential Sugarcane Yield in Pernambuco, Northeastern Region of Brazil. Renewable Energy 78:26-34.

De Oliveira, R.I., M.R.F.A. de Medeiros, C.S. Freire, F.J. Freire, D.E.S. Neto, and E.C.A. de Oliveira. 2016. Nutrient Partitioning and Nutritional Requirement in Sugarcane. Australian J. Crop Sci. 10:69-75.

D'haeze, D., J. Deckers, D. Raes, T.A. Phong, and H.V. Loi. 2005. Environmental and Socio-Economic Impacts of Institutional Reforms on the Agricultural Sector of Vietnam: Land Suitability Assessment for Robusta Coffee in the Dak Gan Region. Agriculture, Ecosystems and Environment 105:59-76.

FAO. 2013. http://faostat3.fao.org/

Hunsigi, G. 2011. Potassium Management Strategies to Realize High Yield and Quality of Sugarcane. Karnataka J. Agri Sci. 24:45-47.

Inman-Bamber, N.G., and D.M. Smith. 2005. Water Relations in Sugarcane and Response to Water Deficits. Field Crops Res. 92:185-202.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press, New York, USA. 889 p.

Ministry of Agriculture and Rural Development (MARD). 2014. Statistical Data of Sugarcane Production. Database in website of Ministry of Agriculture and Rural development.

Monteiro, L.A., and P.C. Sentelhas. 2014. Potential and Actual Sugarcane Yields in Southern Brazil as a Function of Climate Conditions and Crop Management. Sugar Tech. 16:264-276.

Nguyen, D-Q., J. Renwick, and J. McGregor. 2014. Variations of Surface Temperature and Rainfall in Vietnam from 1971 to 2010. International J. Climatolology 34:249-264.

Nguyễn Thị Quỳnh Trang. 2014. Research Medium-Resolution Satellite Images for Drought Warning in Central Highland, Vietnam. http://www.a-a-r-s.org/acrs/index.php/acrs/acrs-overview/proceedings-1?view=publication&task=show&id=1522.

Rice, R.W., R.A. Gilbert, and R.S. Lentini. 2006. Nutritional Requirements for Florida Sugarcane. Sugarcane Handbook 2:1-8.

Rhodes, R., N. Miles, and M.G. Keeping. 2013. Crop Nutrition and Soil Textural Effects on Eldana Damage in Sugarcane. Proceedings of the 86th Annual Congress of the South African Sugar Technologists' Association. p. 212-136.

Rossato, O.B., C.A.C. Crusciol, S.S.P. Guerra, and C.R.L. Zimback. 2014. Implication of Soil Sampling Processes on Recommendations of Phosphate and Potassium Fertilizers on Sugarcane. Energia Na Agricultura 30:109-118.

Singh, V.K., A.K. Shukla, M.S. Gill, S.K. Sharma, and K.N. Tiwari. 2008. Improving Sugarcane Productivity through Balance Nutrient with Potassium, Sulphur, and Magnesium. Better Crops India 24:12-24.

Tran Minh Tien, Ho Cong Truc, and Nguyen Van Bo. 2015. Potassium Application and Uptake in Coffee (*Coffea robusta*) Plantations in Vietnam. International Potash Institute *e-ifc* 42:3-9.

Trang, P.T. 2015. Annual Report on Sugarcane Production, 2015. Bao Viet Securities.

USAID. 2012. Mekong ARCC Climate Change Impact and Adaptation Study: Hotspot Identification. http://www.slideshare.net/MekongARCC/mekong-arcc-cc-impact-and-adaptation-study-hotspot-identification.

Vietnam Sugarcane Association (VSA). 2014. Annual Report of Sugarcane Production in Vietnam. 2014 and Perspectives for 2015 (in Vietnamese).

Wood, A.W., and B.L. Schroeder. 2004. Potassium: A Critical Role in Sugarcane Production, Particularly in Drought Conditions. Proceedings of the Australian Society of Sugar Cane Technologists 26:27-37.

Zhao, D., B. Glaz, and J.C. Comstock. 2010. Sugarcane Response to Water-Deficit Stress During Early Growth on Organic and Sandy Soils. American Journal of Agricultural and Biological Sciences 5:403-414.

Zingaretti, S.M., F.A. Rodrigues, J.P. da Graça, L. de Matos Pereira, and M.V. Lourenço. 2012. Sugarcane Responses at Water Deficit Conditions. http://cdn.intechopen.com/pdfs-wm/26982.pdf.

The paper "Potassium Effects on the Productivity and Quality of Sugarcane in Vietnam" also appears on the IPI website at:

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