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Evaluation of Alternate-row Furrow Irrigation Technique on the Growth and Performance of Sugarcane (Saccharum hybrid spp.) Grown in Reddish Brown Earth Soil in Sri Lanka

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ABSTRACT

A field experiment was conducted at the research farm of the Sugarcane Research Institute, Uda Walawe,Sri Lanka to find out the feasibility of reducing gross irrigation water requirement of irrigated sugarcane by practising alternate-row furrow irrigation method in Reddish Brown Earth soil (RBE). The effects of the three treatments, i.e., every furrow irrigation, alternate-row furrow irrigation and rain-fed on growth and performances of plant and ratoon yield were evaluated in randomised completely block design (RCBD) with 4 replicates. The results revealed that mean productivity of irrigation water use in alternate-row furrow irrigation method was 16 kg/m^3 and was 45% higher than that for every furrow irrigation. The alternate-row furrow irrigation method reduced the consumption of water by maha-and yala-planted sugarcane by 39% and 43% respectively without reducing sugarcane yield. In addition, sugarcane juice quality was improved significantly by alternate-row furrow irrigation method.

Keywords: Reddish Brown Earth soil, Sri Lanka, Sugarcane, Water productivity

INTRODUCTION

Furrow irrigation is the widely-adopted surface irrigation method for irrigating sugarcane in Sri Lanka. The maximum achievable field application efficiency of water by a furrow irrigated crop is around 60% (Ramos *et al*., 2011). In sugarcane cultivation in Sri Lanka, it has been estimated at 25-45% (Shanmuganathan, 1990).Low irrigation efficiency increases water wastage in farmers' fields, and causes water shortage to other irrigable land. On the other hand, available water for agricultural purpose has been constrained with the increasing demand for water from non-agricultural purposes like domestic consumption and industrial use. Also, the severity of this problem has aggravated further under the present scenario of changing climate. Moreover, shortage of irrigation water reduces productivity of sugarcane land. Efficient methods, such as, use of sprinklers, drip irrigation, etc., are available for irrigating sugarcane, but their high costs of installation, operation and maintenance are prohibitive for their adoption. Therefore, there is a need to introduce low-cost techniques to increase efficiency of irrigation without affecting productivity of sugarcane lands

Alternate-row furrow irrigation (skipped furrow irrigation), which has a higher water use efficiency is one of the effective methods to minimise wastage of irrigation water (Halim, 2013). Unlike sprinkler and drip irrigation methods, alternate-row furrow irrigation does not require additional cost or sophisticated technology. Bakker et al. (1997) reported that the alternate-row furrow irrigation with well-scheduled irrigation program was the best practice to irrigate sugarcane in Colombia. It has reduced the irrigation water requirement by 50% per irrigation cycle in addition to reduction of labour requirement for irrigation. In India, alternate-row furrow irrigation is practised for sugarcane (Shrivastava *et al*., 2011), and it saves irrigation water by 36% while increasing water use efficiency by 64% compared to every furrow irrigated sugarcane (Visha *et al*., 2014). Pandian, et.al. (1992) reported, 43-46% reduction in water use was achieved by alternate-row furrow irrigation in irrigated sugarcane in India. Naouri and Nasab (2011) have reported 27% saving of irrigation water by alternate-row furrow irrigation method without significant yield loss in sugarcane in Iran. However, Bakker *et al.* (1997) have noticed a reduction of sugarcane yield by 38 t/ha with alternate-row furrow irrigation compared to every-row furrow irrigated sugarcane in Australia. This gives evidence that the alternate-row furrow irrigation method does not perform equally well everywhere. Performance of alternate-row furrow irrigation method has a close relationship with the properties of soil in which the crop is grown. For an example, alternate-row furrow irrigated maize crop grown in soils with different textural classes gave different water use efficiencies (Sepaskhah & Khajehabdollahi, 2005). The predominant soil type found in commercial sugarcane-growing areas in Sri Lanka is Reddish Brown Earths (RBE), which has specific chemical and physical properties (Irrigation Department of Sri Lanka, 1988). The impermeable gravel layer found at sub surface soil horizon limits drainage characteristics of RBE (Punyawardhana, 2008). In sugarcane-growing soils at Uda Walawe, this gravel layer was found at 25-60 cm depth (Saputhantree, 2015). This impeded drainage condition may have a favourable impact on the alternate-row furrow irrigation as impermeable layer enhances lateral movement of soil water in subsurface soil towards non-irrigated rows.

Therefore, this study was conducted to examine growth, yield and irrigation water productivity of alternate-row furrow irrigation methods and compare with every furrow irrigation and rain-fed cultivation, in order to assess the feasibility to increase irrigation water productivity in sugarcane-growing areas in RBE soils in Sri Lanka.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted from 2010 to 2014 in the research farm of the Sugarcane Research Institute (SRI), Uda Walawe, Sri Lanka (latitudes 60 24' N and 6025' N and longitudes 800 49' E and 800 50' E). The area belongs to the low-country dry zone (DL1a) (Punyawardana, 2008) and receives an annual rainfall of 1452 mm (Wijayawardhana, *et al*., 2014). Average annual ambient air temperature ranges from 28^0 C to 32^0 C (Witharama, *et al*., 2015). The rainfall is characterised by a bi-modal pattern of distribution where two-thirds of rainfall is received from September to January in maha season. The predominant soil group is Reddish Brown Earths (Panabokke, 1996; Punyawadhana, 2008).The top soil layer (10 20 cm depth) of the experimental location is characterised by sandy clay-loam in texture, bulk density, porosity and gravel content range from 1.4 g/cm^3 to 1.7g/cm3, 40% to 50% and 20% to 30% respectively. In sub-surface soil layer (40 cm 50 cm depth), the soil is sandy clay and sandy clay-loam in texture, bulk density, porosity and gravel content range from 1.4 g/cm^3 to 1.7 g/cm^3, 30%to 40% and10% to 30% respectively (Saputhanthree, 2015).

Experimental Procedures

An even land with uniform gradient was selected for the study. The land was ploughed to a depth of 20-30 cm and furrowed following the recommended procedure (SRI, 1991). The sugarcane seed setts were planted in the furrows. The spacing between two adjoining furrows was 1.37 cm. The furrows prepared were "V" in shape and the original depths were 18- 22 cm and they became 13-17 cm deep with 40-45 cm wide flat base after planting sugarcane. The field was laid out to make four blocks, each having three treatment plots. A treatment plot consisted of 25 m long 9 cane rows (308 m^2). The following three treatments were tested in RCBD experimental design with 4 replicates. The treatments were;

T1- Every furrow irrigation (EF)
T2- Alternate-row furrow irrigation (ARF)
T3 Rain-fed (RF): control

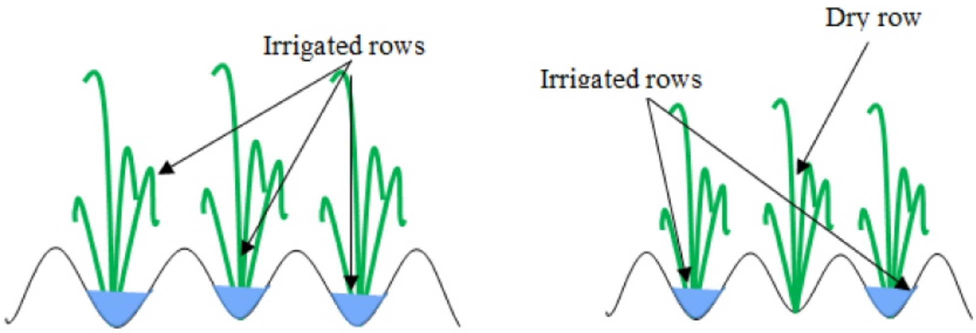

Figure 1: Every furrow irrigation **Alternate-row furrow irrigation**

In alternate-row furrow irrigation method, one furrow was skipped (left-out) and irrigation was given to every other furrows (Figure 1). Two types of alternate-row furrow irrigation methods are available, namely, fixed and variable alternate-row furrow irrigations. In the fixed furrow method, the furrows to be irrigated are decided at the beginning and the same alternate-row furrows are irrigated during the whole cropping cycle. In the variable alternate-row furrow method, every alternate furrows are irrigated, and the furrows kept un-irrigated are irrigated in the subsequent irrigation.

Variable alternate-row furrow irrigation method is difficult to be practised in sugarcane lands because non-irrigated furrows are used for keeping sugarcane residues and thrash. Therefore, the fixed alternate-row furrow irrigation method was practised in this study.

In order to avoid sub-surface soil moisture movement between different treatment plots and between adjoining other areas, a thick poly-ethylene sheet was placed vertically across soil profile to a depth of 100 cm around each treatment plot.

Planting and Crop Management

The experiments were conducted in both *maha* and *yala* cropping seasons. Field planting was coincided with the onset of rain in each season to assure maximum germination and field establishment of RF crop. The *maha* trial was planted in October 2010 and the *yala* trial was in April 2011, and both the experiments were continued until harvesting 2nd ratoon crop in 2014.The recommended practices were followed in establishing and maintaining both plant and ratoon crops (SRI, 1991).

Application of Irrigation Treatments

In plant crop, water was allowed to flow along the planted furrows as shown in Figure (1). But, in the case of ratoon crop, soil in-between the cane rows was heaped up either side of the cane rows to make original furrows into ridges and original ridges into furrows. Accordingly, water was allowed along the newly-formed furrows in-between the cane rows of ratoon crop.

Application of 60 mm at 9 day irrigation interval and optimum water discharge rate of 2.0 l/sec recommended to get maximum yield from irrigated sugarcane in Uda Walawe area (Katupitiya, 1986) was practised in this study. The discharge rate was estimated using bucket calibration method.

Estimation of Irrigation Performance Indices

The performance of alternate-row furrow irrigation method was evaluated by estimating following parameters:

a. Irrigation Depth

The depth of water applied into each plot by each irrigation event was calculated using the following equation (Halim, 2013).

$d = Qt \times 1000/A$ --------------------------- 01

Where: d = depth of irrigation applied,
Q = water flow rate at the inlet (L/min),
t = time of water allocated or cut-off time (min),
A = plot size (m^2)

b. Water Productivity

Water productivity was determined using the following formula:

$WP = Y/Ir$ ---------------------------------- 02

Where: WP=Water productivity (kg/m^3), Y =Yield (kg/ha), and Ir =Irrigation (m^3/ha).

Estimation of Sugarcane Yield and Quality Indices

The weight of cane harvested in each treatment plot excluding the border rows was measured to estimate cane yield. In addition, the number of cane stalks harvested from each treatment plots were recorded. The cane samples obtained from each treatment plots were analysed for brix, polarisation and fibre percentages to estimate POCS (pure obtainable cane sugar) as a quality parameter. These estimated sugarcane yield parameters were used to compare growth and performance of sugarcane under each treatment.

Statistical Analysis

The analysis of variance (ANOVA) procedure was used with DMRT mean separation method at 5% probability level for comparing the effects of the treatment on the crop parameters and the moisture parameters.

RESULTS AND DISCUSSION

Irrigation Application

In the maha-planted experiment, the average amounts of water consumption for one irrigation of plant crop and ratoon I crop by EF irrigation were 817 and 856 m^3/ha respectively. In irrigation by ARF, the water consumption of plant and ratoon I crops have reduced to 532 and 494 m^3/ha irrigation respectively (Table1). Similarly, in the yala-planted experiment, for each EF irrigation in plant crop, ratoon 1 and 11, water requirements were 775, 725 and 745 m^3/ ha respectively, and the respective levels of irrigation water requirement for ARF irrigation were 438, 398 and 448 m^3/ha. When the average water consumption of each of the irrigation event made for plant, ratoon I and II crops over both *maha* and *yala* seasons, the water consumption by ARF irrigation treatment was 462.0 m^3/ha; it was 41% less than the amount of water consumed by EF treatment (783.6 m^3/ha). Even though, the water was allowed only to half of the total number of furrows due to 50% of furrows are skipped in ARF irrigation treatment, the water consumption has not reduced by equal proportion (by half) compared with EF irrigation. This may be due to lateral movement of water at subsurface soil horizons. This phenomenon has been reported to be quite high in the fields irrigated with ARF method because two adjoining rows in both sides are dry. But, in EF method, since all furrows are used for irrigation, downward movement of water is greater than the lateral movement. Capillary action is another phenomenon which could be attributed to this difference (Mahomedand Imara, 2010).

Table 1: Irrigation application (m^3/ha) for each irrigation event of EF and ARF irrigation methods adopted to plant and ratoon crops of *maha* and *yala* - planted sugarcane

	maha-Planting				*yala*-Planting					
Irrigation event	Plant crop		Ratoon I		Plant crop		Ratoon I		Ratoon II	
	EF	ARF	EF	ARF	EF	ARF	EF	ARF	EF	ARF
1	754 ±14	521 ±07	911 ±11	541 ±11	752 ±09	399 ±09	997 ±03	565 ±06	838 ±17	474 ±12
2	821 ±14	342 ±06	927 ±10	501 ±10	794 ±20	307 ±19	644 ±17	447 ±08	844 ±17	413 ±17
3	927 ±12	656 ±06	831 ±12	564 ±1	695 ±11	437 ±9	668 ±18	372 ±09	811 ±14	480 ±13
4	918 ±04	481 ±12	871 ±10	486 ±10	775 ±15	252 ±19	679 ±11	427 ±05	788 ±08	571 ±18
5	851 ±08	591 ±15	769 ±8	504 ±8	647 ±09	232 ±14	654 ±07	376 ±03	732 ±17	569 ±7
6	951 ±12	598 ±13	859 ±11	532 ±11	731 ±14	298 ±18	746 ±17	387 ±8	662 ±12	476 ±17
7	800 ±11	511 ±18	839 ±7	446 ±7	826 ±18	572 ±9	635 ±19	351 ±10	810 ±13	482 ±19
8	740 ±11	554 ±12	926 ±21	553 ±21	818 ±9	470 ±8	644 ±4	307 ±2	674 ±10	527 ±17
9	600 ±9	532 ±8	856 ±13	544 ±13	842 ±12	472 ±9	784 ±6	349 ±3	772 ±13	466 ±11
10			744 ±1	541 ±12	833 ±8	627 ±12	664 ±13	378 ±6	662 ±14	352 ±14
11			816 ±13	405 ±14	788 ±8	547 ±9	714 ±18	360 ±9	601 ±11	312 ±16
12			892 ±17	393 ±17	799 ±11	649 ±12	707 ±14	428 ±7		
13			880 ±19	418 ±18			748 ±13	357 ±6		
14							689 ±16	418 ±8		
15							908 ±3	444 ±12		
Avg	817	532	856	494	775	438	725	398	745	448

Note: The *maha*-trial was panted in October 2010; the *yala*-trial was planted in April 2011. The duration of each crop cycle is 12 months.

Water Productivity (WP)

WP has increased substantially by adopting ARF method compared to EF method. The average WP of plant, ratoon I and Ratoon II crops over both *maha* and *yala* seasons were 11 kg/m^3 in EF irrigated plots and 16 kg/m^3in ARF irrigated plots. This is an increase of WP by 46% due to adoption of ARF irrigation method compared to EF irrigation. According to Srivasthava *et al*, (2011), WP of ARF irrigated sugarcane was 17 kg/m^3in India, and there was a 31% saving of irrigation water by ARF irrigation than every furrow irrigation.

Water saving by ARF irrigation was more in *yala*-planted crop (40% 45%) than that in *maha*-planted crop (35% 42%). In yala-planted experiment, the average water consumption over plant, ratoon I and ratoon II crops was 43% less in alternate-row furrow irrigation than that in every furrow irrigation. In maha-planted experiment, the irrigation water consumption averaged over plant and ratoon I crops by alternate-row furrow irrigationwas 39% less than that by the every furrow irrigation (Table 2).

Table 2: Annual total irrigation application (mm),water productivity (WP) and irrigation water saving (%) in EF and ARF irrigated plant and ratoon crops of maha- and yala-planted sugarcane

	***Maha*-planting**				***Yala*-Planting**					
	Plant crop		Ratoon 1		Plant crop		Ratoon I		Ratoon II	
	EF	ARF	EF	ARF	EF	ARF	EF	ARF	EF	ARF
Irrigation (mm/year)	736^{a} ±2.6	479^{b} ±3.5	1112^{a} ±7.9	643^{b} ±7.9	930^{a} ±3.4	526^{b} ±3.4	1088^{a} ±4.8	596^{b} ±5.5	819^{a} ±2.8	512^{b} ±2.9
WP (kg/m^3)	12^{b} ±0.6	18^{a} ±0.9	09^{b} ±0.3	16^{a} ±0.8	13^{a} ±1.5	16^{a} ±1.3	10^{b} ±0.5	15^{a} ±0.6	10^{a} ±0.5	13^{a} ±0.8
Water saving %		35.0		42.2		43.4		45.0		39.8

Notes: WP = Water productivity. Means were separated using DMRT at 5% probability level.

Sugarcane Yield and Juice Quality

In the *maha*-planted experiment, there was no significant reduction of cane yield between ARF irrigated plots and EF irrigated plots in plant crop and ratoon I. However, in RF plots, cane yield was significantly lower than that in the other two treatments, of ARF and EF irrigations (Table3). In plant crop, RF plots have shown a significant reduction of yield by 17 and 19% compared to ARF and EF irrigated plots respectively. In ratoon I, the cane yields of the RF plots have reduced by 23% and 15% compared to ARF and EF irrigated plots respectively (Table 3).

There were no significant differences of stalk densities between EF and ARF treatments in both plant and ratoon I crops. However, stalk densities have reduced significantly by about 19% in both plant and ratoon 1 crops RF fields compared to that in EF and ARF irrigated fields. In contrast, there was no significant difference in sugarcane juice quality, either brix or POCS values between two irrigation methods in the *maha*-planted experiments (Table 3).

Table 3: The estimated parameters of sugarcane yield and quality of plant and ratoon I crops of Maha (2010) planted experiment

	Plant crop			Ratoon I		
	EF	ARF	RF	EF	ARF	RF
Yield t/ha	90.9[a] ±4.4	85.8[a] ±4.3	71.9[b] ±1.5	103.2[a] ±3.7	101.5[a] ±4.8	74.8[b] ±0.6
Stalks/ha	78637[a] ±1356	76414[a] ±1709	62950[b] ±1945	96269[a] ±4897	86782[a] ±2570	73978[b] ±612
Brix %	20.8[a] ±0.49	21.1[a] ±0.07	21.9[a] ±0.24	18.3[b] ±0.23	18.1[b] ±0.36	19.7[a] ±0.42
POCS %	13.5[a] ±0.22	13.7[a] ±0.52	14.4[a] ±0.31	11.6[a] ±0.23	11.4[a] ±0.27	12.5[a] ±0.42

Note; Means were separated using DMRT at 5% probability level.

In the *yala*-planted experiment, there was no significant yield difference in both plant and ratoon 1 crops between ARF irrigated and EF irrigated plots. Also, the cane yield of RF crop also was not shown significant difference with ARF irrigation treatment. However, there were significant differences of cane yields between EF irrigated and RF treatments both in plant and ratoon I crops. But, this trend has changed in ratoon II. ARF irrigated plots showed significantly lower cane yield by 18% than EF irrigated plots, and RF plots showed significantly low yield by about 37% than the ARF irrigated plots. The yield decline in RF plot was 49 % compared to that in EF irrigated plots (Table 4).

The stalk densities between EF and ARF irrigated plots in plant and ratoon I and ratoon II crops was not significantly different in *yala*-planted experiments (Table 4). However, the stalk densities of plant crop of RF plots was 38% less and that in ratoon II crop. It was 34% less compared to EF irrigation treatment. The stalk densities between EF and ARF in plant crop, ratoon II and between any treatments in ratoon I were statistically not significant (Table 4).

In the *yala*-planted experiment, POCS (%) values showed significant differences between different irrigation treatments. In plant crop, POCS was significantly higher in ARF irrigated crop than that in EF irrigated and RF crops. The patterns were different in the other two crop classes. In ratoon I, POCS values were significantly higher in EF and ARF irrigation treatments than that in RF treatment whereas in ratoon II crop, POCS values were significantly higher in ARF irrigation treatment and RF treatment than that in EF irrigation treatment. Thus, the ARF treatment has contributed to significant improvement of sugar content (POCS %) in harvested cane in all three crop classes under EF irrigation and RF treatments. On average, the ARF irrigation treatment has increased POCS levels by 4% and 10% than EF and RF plots respectively. Thus, the ARF irrigation treatment is favourable for improving juice quality in harvestable cane. Generally, RF crops take longer time for maturity than the irrigated, often more than 12 months. Furthermore, the EF irrigated plots usually contain high moisture levels that could significantly reduce the sugar content.

Table 4: The estimated parameters of sugarcane yield and quality of both plant, ratoon I and II crops of yala 2011-planted experiment

	Plant crop			**Ratoon I**			**Ratoon II**		
	EF	ARF	RF	EF	ARF	RF	EF	ARF	RF
Yield (t/ha)	118.5[a] ±15.1	83.4[ab] ±6.9	58.6[b] ±2.5	104.1[a] ±5.7	89.1[ab] ±4.1	75.8[b] ±2.5	79.2[a] ±4.0	64.8[b] ±3.6	40.7[c] ±1.5
Stalks/ha	115246[a] ±1932	85051[ab] ±5479	70362[b] ±2745	94626[a] ±1829	91212[a] ±3027	90905[a] ±2113	80214[a] ±3301	72224[a] ±5749	52981[b] ±2531
Brix %	17.6[b] ±0.22	18.4[a] ±0.31	17.2[b] ±0.25	20.2[a] ±0.17	19.9[a] ±0.33	17.2[b] ±0.21	20.4[a] ±0.20	20.9[a] ±0.49	21.4[a] ±0.17
POCS %	11.2[b] ±0.21	11.9[a] ±0.29	10.8[b] ±0.22	13.5[a] ±0.27	13.4[a] ±0.25	10.8[b] ±0.31	14.3[b] ±0.13	15.3[a] ±0.35	15.4[a] ±0.20

Note; Means were separated using DMRT at 5% probability level.

CONCLUSIONS

The results of this study confirmed that the ARF irrigation method can be practised effectively to irrigate sugarcane fields in RBE soil in Sri Lanka. Adoption of this method helps saving irrigation water by 35-45% and increasing water productivity of the crop by 46% compared to that in EF irrigation. Quality of sugarcane grown by practising this method is higher than that under EF (4%) or RF conditions (10%).

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Response of Sugarcane (*Saccharum* hybrid spp.) Varieties SL 96 128 and SL 96 328 to Nitrogen, Phosphorous and Potassium under Irrigation at Uda Walawe, Sri Lanka: A Preliminary Analysis

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ABSTRACT

This study investigates the effects of N, P and K on cane yield and quality of the plant crop of two new sugarcane varieties, SL 96 128 and SL 96 328 and determines the optimum level of N. A field trial was carried out in a confounded-factorial design with 18 treatment combinations with 5 levels of N and 4 levels of each P and K, with 3 replicates at the research farm of the Sugarcane Research Institute, Uda Walawe, Sri Lanka from September 2010 to November 2011. Cane yield and quality parameters such as brix, pol, and fibre percent of cane were measured and pure obtainable cane sugar (POCS) was calculated at harvest of 12-month old crop. Sugar yields were estimated using cane yield and POCS.

The analysis of variance was performed on cane yield, POCS and sugar yield to examine the effects of N, P and K on these three variables. The optimum level of nutrients was determined by estimating the income and value:cost ratios for each fertiliser level.

The results showed that both varieties were responsive to N, and not so to P and K. The optimum level of N for the variety SL 96 128 was between 150 and 200 and that for the variety SL 96 328 was between 100 and 150. Analyses of soil and leaf in ratoon crops are required for devising a comprehensive recommendation.

Keywords: Fertiliser response, Nitrogen, Phosphorous, Potassium, SL 96 128, SL 96 328, Sri Lanka, Sugarcane

INTRODUCTION

The crop improvement programme of the Sugarcane Research Institute (SRI) develops high-cane- and sugar-yielding sugarcane varieties adaptable to various sugarcane-growing conditions in the island aiming at sustainable increase of the productivity and profitability of the Sri Lankan sugarcane industry (SRI, 2011). Selection of varieties for high cane and sugar yields is done under recommended management conditions at the initial and intermediate selection stages in the varietal development programme. The most promising varieties are subjected to nutrient response studies to determine the optimum nutrient levels for making fertiliser recommendations for those varieties at the final stage of varietal selection.

A substantial application of fertiliser, mainly Nitrogen (N), is required to achieve a successful harvest of high cane and sugar yields in sugarcane cultivation (Roy et al., 2006). Nitrogen application for sugarcane is as high as 300 kg/ha in India and China while in other countries like Guatemala, Mexico, Australia, South Africa and parts of the USA, the recommended N ranges from 150 kg/ha to 200 kg/ha (Thorburn et al., 2011). Tabayoyoung and Robeniol (1962) reported that N deficiency could decrease cane yields whereas excess N would also adversely affect the quality of cane juice. In Pakistan, the use of imbalanced fertiliser has caused constantly low cane yield which is the lowest among sugarcane-growing countries in the world (Khan et al., 2005). Nitrogenous fertiliser in the absence of Potassium (K) steadily decreases the sucrose percentage in cane, and addition of K counteracted this trend, producing a favourable response. The best N:K ratio lie between 1:1 and 1:1.5 (Stewart, 1969). Besides achieving maximum cane and sugar yields, application of correct levels of fertiliser is important for minimising cost of cultivation and environmental pollution (Cheeseman, 2004; Thorburn et al., 2011). The profitability levels can also be considerably improved with the use of N, P and K fertilisers in balanced quantities (Khan et al., 2005), and it requires the determination of the optimum amounts of these nutrients (Kadian et al., 1981).

Thus, to realise the genetic potential of high-yielding new sugarcane varieties, the amount of nutrients removed should be replaced balancing the inputs and output, i.e., sugarcane as suggested by Janssen and De Willinen (2006) and Thorburn et al. (2011). In the sugarcane variety development programme of SRI, new sugarcane varieties are tested for their response to N, P and K to provide the growers with balanced fertiliser recommendations for those varieties to maximise cane and sugar yields at minimum cost to the grower and to the environment.

This study was conducted to determine the effects of N, P and K on cane yield and quality of two new sugarcane varieties SL 96 128 and SL 96 328 and to determine the optimum levels of these three nutrients for application based on plant crop data of these new sugarcane varieties. The experiment is being continued with the ratoon 1 crop.

Materials and Methods

Experimental design

The field experiment was conducted using a confounded-factorial structure with 18 treatment combinations of five levels (0, 50, 100, 150 and 200 kg/ha) of N, four levels (0, 20, 40 and 60 kg/ha) of P and four levels (0, 50, 100 and 150 kg/ha) of K with 3 replicates. Each plot was 7 m long with 5 rows prepared 1.37 m apart. The middle 3 rows were used for taking observations, and the 2 outer rows were maintained as guard rows. The land represented the general topography of the area of the Research Farm (6° 21' N, 80° 48' E) of the Sugarcane Research Institute. The field experiment was established in September 2010, and the crop was harvested in September 2011.

Soil and climate

The soil of the selected experimental site is classified as Reddish Brown Earths (Order - Alfisols, Sub order - Ustalfs, Great group - Rhodustalfs), and its texture ranges from sandy loam to sandy clay loam. The area receives an annual rainfall of about 1450 mm and 900 mm at 75 % expectancy with a distinct bimodal distribution. The average annual minimum and maximum temperatures are 22 ± 1.4 °C and 33 ± 1.4 °C, respectively (Panabokke, 1996). Evaporation from a free-water surface is approximately 5 mm per day (Shanmuganathan, 1992).

Field operations

The land was prepared in accordance with the recommendations for commercial sugarcane planting (SRI, 1991). Three-budded stem cuttings (setts) obtained from ten-month-old sugarcane plants of the varieties SL 96 128 and SL 96 328 were used as seed material. Planting was done using 3 seedcane setts per metre. The experiment was carried out under irrigated conditions. The plots were fertilised according to the treatment levels of N, P and K, and their sources were Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP), respectively. At planting, 1/6 of N, total P and ½ K were applied. One third of N was applied 45 days after planting and ½ of N and ½ of K were applied 90 days after planting.

Measurements and analyses

The plant crop of the two varieties was harvested at 12 months, in September 2011 to determine the cane yield. Six cane stalks were sampled from each plot to determine cane juice quality, i.e., brix, pol and fibre percent. Pure Obtainable Cane Sugar was calculated using brix, pol and fibre contents. Sugar yield was estimated by multiplying POCS with cane yield.

The analysis of variance (ANOVA) was carried out to determine the effect of N, P and K on cane and sugar yields and POCS using GLM procedure of the SAS software system (Version 9.1.3).

Since the coefficients of N fertiliser of the production functions of various forms estimated using the method of Ordinary Least Squares were not significant, the economic analysis was done by estimating costs and returns of the above-mentioned fertiliser levels at the prices of fertiliser without the subsidy obtained from the fertiliser secretariat of Sri Lanka and at the farm-gate price of sugarcane. The income[1] was compared with the value:cost ratio for both varieties to determine the optimum level of N to be fertilised. The value:cost ratios of the two varieties were estimated at the fertiliser price with the subsidy (market price) as well for comparison of the effect without the subsidy.

Results and Discussion

The effects of N, P and K on yield and quality of sugarcane

The results indicated that only the level of N affects significantly the cane yield and quality of the sugarcane varieties, SL 96 128 and SL 96 328. Therefore, mean separation of cane yield, POCS and sugar yield of SL 96 128 and SL 96 328 were performed for N levels only (Table 1).

Table 1: Variation of cane yield, POCS and sugar yield of SL 96 128 and SL 96 328 with the level of N (kg/ha)

Level	SL 96 128			SL 96 328		
N (kg/ha)	CY (t/ha)	POCS %	SY (t/ha)	CY (t/ha)	POCS %	SY (t/ha)
0	73.45 d	13.21 a	9.78 c	64.65 c	14.19 a	9.23 b
50	77.51 cd	13.03 ab	10.08 bc	79.01 b	13.84 a	10.95 b
100	93.69 bc	13.04 ab	12.13 ab	90.48 ab	13.85 a	12.57 ab
150	103.65 ab	11.99 c	12.38 a	95.85 a	13.47 ab	13.01 a
200	114.59 a	12.43 bc	14.28 a	100.15 a	12.61 b	13.28 a

CY = Cane yield, SY = Sugar yield
Note: Means with the same letters are not significantly different at 5% probability.

The effect of N on cane yield

Of the N levels tested, 200 kg/ha which was the highest level tested, produced the highest cane yield of about 115 t/ha in SL 96 128 and 100 t/ha in SL 96 328. Further, both sugarcane varieties showed similar increasing trend in cane yield with the increase of the level of N. The cane yields at 150 kg and 200 kg of N per hectare were significantly higher than that at 0 kg and 50 kg of N per hectare. However, the cane yields at N levels 100 kg/ha and 150 kg/ha were not significantly different (Table 1 and Figure 1).

[1] Since all management practices except the level of fertiliser application were the same for treatments, the income was calculated subtracting the fertiliser cost only

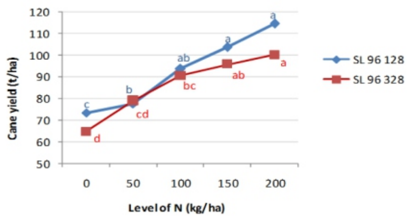

Figure 1. Variation of cane yield of SL 96 128 and SL 96 328 with the level of N
(Note: Means with the same letters are not significantly different at 5% probability)

The effect of N on sugar content

The results showed that the sugar content measured as POCS of the varieties SL 96 128 and SL 96 328 dropped with the increase of the level of N. The highest POCS level of nearly13.2% and 14.2% for the varieties SL 96 128 and SL 96 328, respectively were recorded at zero level of N (Table 1 and Figure 2).

The variety SL 96 128 showed a significantly low level of POCS at the N level of 150 kg/ha than at 0 kg/ha, 50 kg/ha and 100 kg/ha. The variety SL 96 328 exhibited a significant decrease in POCS at N level 200 kg/ha than at 0 kg/ha, 50 kg/ha and 100 kg/ha. There was no significant difference in POCS at 150 kg and 200 kg of N per hectare (Figure 2).

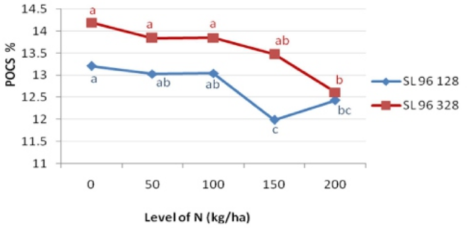

Figure 2. Variation of POCS of SL 96 128 and SL 96 328 with the level of N
Note: Means with the same letters are not significantly different at 5% probability

The effect of N on sugar yield

The highest sugar yields of 14.3 t/ha and 13.3 t/ha respectively for the varieties SL 96 128 and SL 96 328 were observed at the N level 200 kg/ha. Sugar yield increased gradually with the increase of the level of N for both varieties. The sugar yields at N level 150 kg/ha and 200 kg/ha were significantly higher than that at 0 kg and 50 kg of N per hectare (Figure 3).

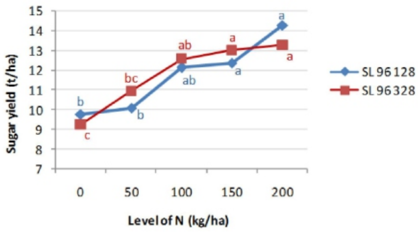

Figure 3. Variation of sugar yield of SL 96 128 and SL 96 328 with the level of N
Note: Means with the same letters are not significantly different at 5% probability

Though, POCS was inversely related to N level, sugar yields increased with the increase of the level of N through the greater contribution of cane yield to sugar yield than POCS.

The results of economic analysis

Since a significant response of cane yield and quality was observed only for the level of N, the economic analysis was confined only to the N application. The results of economic analysis performed based on cane and sugar yield of the varieties SL 96 128 and SL 96 328 are depicted in Figures 4 and 5.

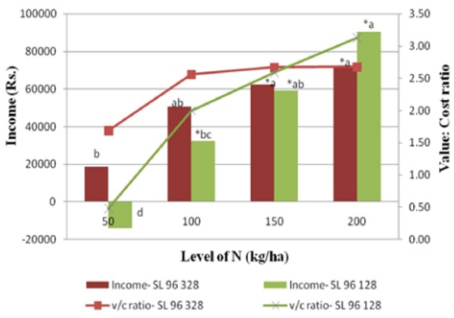

Figure 4. Variation of income and value-cost ratio based on cane yields at different N levels
Note: Means with the same letters are not significantly different at 5% probability

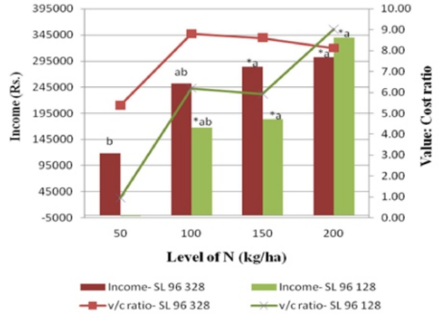

Figure 5. Variation of income and value:cost ratio based on sugar yield at different N levels
Note: Means with the same letters are not significantly different at 5% probability

SL 96 128

The income, based on the cane yield at 200 kg of N per hectare was significantly higher than that at N levels 50 kg/ha and 100 kg/ha. The value:cost ratios estimated based on the cane yields at 150 kg and 200 kg of N per hectare ranged between 2.5 and 3.25 (Figure 4). The incomes based on the sugar yield at N level 150 kg/ha and 200 kg/ha were significantly higher than that at 50 kg of N per hectare. The value:cost ratios estimated based on sugar yield ranged from 6 to 9 (Figure 5). Therefore, for the variety SL 96 128, the optimum level of N fertiliser application was between 150 and 200 kg/ha.

SL 96 328

The income, based on the cane yield at both 150 kg and 200 kg of N per hectare was significantly higher than that at N level 50 kg/ha. The cane yield at 100 kg of N per hectare did not show a significant difference with that at150 kg and 200 kg of N per hectare. The value:cost ratios estimated based on cane yields at 100 kg, 150 kg and 200 kg N per hectare were slightly above 2.5 (Figure 4) and that based on sugar yields were between 8 and 9 (Figure 5). The highest value:cost ratio was obtained at N level 100 kg/ha. Therefore, considering the results obtained for the variety SL 96 328, the most economic level of N application was between 100 kg/ha and 150 kg/ha.

The effect of fertiliser subsidy on value:cost ratios

The value:cost ratios of the two varieties, SL 96 128 and SL 96 328 cane and sugar yields have almost doubled due to the fertiliser subsidy (Table 2).

Table 2: Value: Cost ratios of SL 96 128 and SL 96 328 with and without fertiliser subsidy

Variety	Level N (kg/ha)	V/C ratio based on cane yield (kg/ha)		V/C ratio based on sugar yield (kg/ha)	
		Without subsidy	With subsidy	Without subsidy	With subsidy
SL 96 128	50	0.48	1.06	0.94	2.08
	100	2.00	4.37	6.19	13.49
	150	2.59	5.55	5.91	12.68
	200	3.13	6.64	9.01	19.11
SL96 328	50	1.69	3.75	5.37	11.94
	100	2.56	5.58	8.80	19.17
	150	2.67	5.73	8.60	18.44
	200	2.68	5.68	8.11	17.20

CONCLUSIONS

The results presented in the forgoing section proved that the varieties SL 96 128 and SL 96 328 are highly responsive to N level, but not so to P and K. The optimum level of N for the plant crop of the variety SL 96 128 was between 150 kg/ha and 200 kg/ha and that for the variety SL 96 328 was between 100 kg/ha and 150 kg/ha.

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Factors Effecting Quantity and Price of Sugarcane and Sugar Production in Sri Lanka

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ABSTRACT

The domestic sugar production in 2016 was sufficient only to meet 9% percent of the total consumption requirement in Sri Lanka. Quantitative analysis of factors related to the quantity of sugarcane and sugar production and their prices will be vital to design policies for the development of the sugarcane industry. This study examines important factors affecting the production and prices of sugarcane and sugar over the period of 26 years from 1990 to 2015 using the secondary data obtained from various sources.

An algebraic model was specified and the co-efficients of the model were estimated using the ordinary least squares method. The results showed that the quantity of cane crushed was positively influenced by the cane area harvested. One percent increase in quantity of cane crushed has showed 0.086% increase in quantity of sugar produced. Average cane and sugar yields are low in Sri Lanka. One-year lagged sugar price was positively related to cane price, and privatisation of sugar mills had a negative effect on cane price. The world price of sugar and import tax were the main determinants of local sugar price, which in turn affect the profit of local sugar mills. The government intervention through price policies on sugarcane and sugar and regulatory mechanisms on the management of sugar industry is needed to develop the sugarcane industry in Sri Lanka.

Keywords: Policies, Sri Lanka, Sugar production, Sugar price, Sugarcane production Sugarcane price

INTRODUCTION

Sugar is an important sub-sector in the economy of Sri Lanka, making a significant contribution to the national balance of payments. The domestic production in 2016 was nearly 62,000 tonnes which was sufficient to meet less than nine percent of the total consumption requirement. As such, imports make up the major component of supply with a contribution around 90% of the total supply. In the year 2016, 648,000 tonnes of sugar have been imported costing nearly Rs 48 billion which was nearly 2.2% of the outlay on the total imports (Central Bank of Sri Lanka (CBSL), 2016). Sugar is the food commodity on which Sri Lanka spends the highest foreign exchange on its importation next to wheat.

The current domestic requirement of sugar (at per capita consumption of 28.8 kg and population of 20.96 million and population growth rate of one per cent), is estimated at about 680,000 tonnes. It is projected to increase to about 730,000 tonnes by the year 2020 and to about 800,000 tonnes by the year 2030 with population growth, without considering income and price elasticities of demand.

Sri Lanka has a vast potential for sugar production, and thereby, to improve of livelihoods of the people in rural areas in dry and intermediate zones in the country and to produce renewable energy such as bagasse-based electricity and molasses-based ethanol and as an alternative to fossil fuel energy (Ministry of Plantation Industries, 2004). According to the Sugar Sector Development Policy approved by the cabinet, the Government of Sri Lanka (GoSL) has planned to increase sugar production up to 50 per cent self-sufficiency by the year 2020 and 100% by the year 2025 (Ministry of Finance, 2017). The government, in its 2013 budget proposals, has allocated 130,000 ha of lands for sugar development. To achieve the target of producing 50% of the requirement, the area under sugarcane cultivation and the crushing capacity of sugar mills need to be expanded to 61,300 ha and 19,350 tonnes cane per day (TCD) respectively at the full capacity utilisation of the sugar mills (Ministry of Finance, 2016). According to a study of the Sugarcane Research Institute (2010), about 200,000 hectares of unutilised lands suitable for sugarcane cultivation are available in the country, particularly in Moneragala, Ampara, Badulla, Trincomalee, Anuradhapura, Kilinochchi and Vauniya districts.

Realisation of the sugar production target set by the Ministry of Finance requires expansion of sugarcane cultivation and processing capacities. Government intervention through well-directed policies related to price, cost of production, infrastructure development, research and development and land use will be vital in this regard. According to Kodituwakku (2013), most of the leading cane sugar-producing countries have production-promoting policies for developing their sugar industries. Cafiero (2003) argues that market failures[1] such as failure of competition[2], public goods[3] and incomplete[4] markets are the reasons that prevent the economy to realise the optimal use of resources and to provide socially optimal level of goods and services. Market failures are common in agriculture sector of developing countries due to imperfections and inefficiencies of agricultural industries. Inefficiency leads to higher unit cost of production and makes the industry relatively uncompetitive in the international market (Ganewatta and Edward, 2000). Government policies are, therefore, needed to promote long-term development of the agriculture-based industries such as sugarcane by reducing market failures (Brook, 2010).

Quantitative analysis of the factors related to sugarcane and sugar production and their prices, viz., sugarcane area, crushing capacity, management efficiencies of mills, world market sugar price and sugar import tax are important from the point of view of designing policies for the development of the sugar industry. This paper examines the factors affecting production of sugarcane and sugar and their prices in Sri Lanka from 1990 to 2015.

MATERIALS AND METHODS

This study used secondary data. The details of the variables, sources of data and the reference periods of each type of data are discussed below:

Data Collection

The data were obtained from the reports brought out by the Central Bank of Sri Lanka and the Department of Census and Statistics of Sri Lanka. These included harvested sugarcane area, quantity of sugarcane production, price of sugarcane, quantity of cane crushed, sugar recovery rate, quantity of sugar production, cane-crushing capacity of sugar mills, retail price of sugar and privatisation of sugar mills for the period from 1990 to 2015.

1 The reasons that prevent the economy to settle on optimal use of resources and provide socially optimal level of goods and services have been termed as market failures (Cafiero, 2003).

2 Social benefits are optimum when the market for any good is operating in a perfect competitive situation. Imperfect competition might prevail in markets where there is either one buyer (monopsony) and or seller (monopoly) or few buyers (oligopsony) and sellers (oligopoly).

3 Public goods such as infrastructure facilities and research and technology development are freely accessible to all members of a given public (Ellis, 1992).

4 The market does not provide some goods and services adequately even though the costs of providing these are less than the individual's willingness to pay. Insurance and capital markets are the common examples of the incomplete markets that need government intervention to provide the socially desirable level of such commodities (Stiglitz, 1986).

Data Analysis

The data collected were analysed by using production and price models of sugarcane and sugar describe below.

The conceptual model to represent possible relationships between different factors affecting the quantities of sugarcane and sugar production and there prices in Sri Lanka are depicted in figure 1

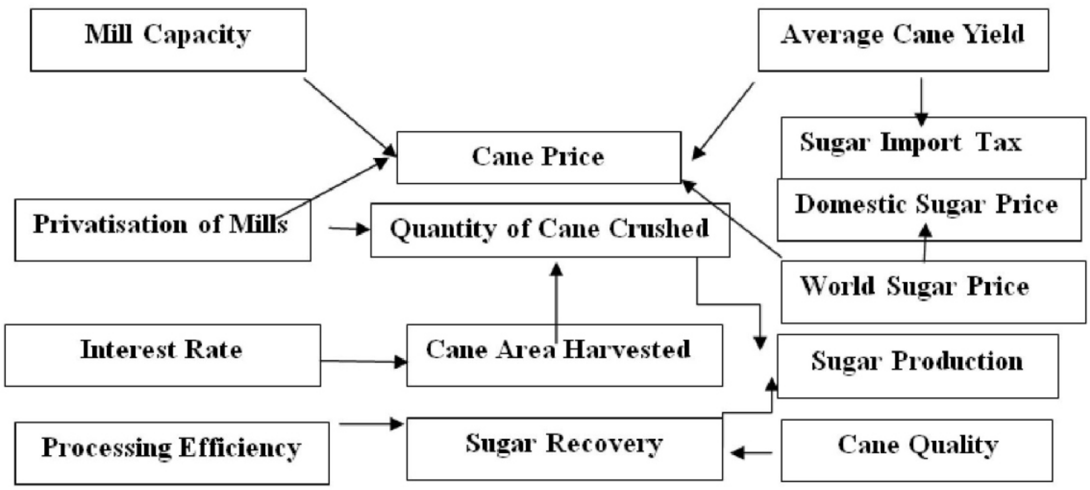

Figure 1: Conceptual Model of Sugarcane and Sugar Production in Sri Lanka

Based on the conceptual model, the algebraic models for sugarcane production, sugar production, sugarcane price and sugar price (Equations 1, 2, 3 and 4 respectively) were fitted including relevant variables and are described below:

$QC_t = f(AC_t, T)$ (01)
$QS_t = f(QC_t, PS_t\text{-}1, G_t, T)$ (02)
$PC_t = f(PS_t\text{-}1, G_t, T)$ (03)
$PS_t = f(SA_t, WP_t, IT_t, T)$ (04)

Where;
QC_t = Quantity of cane crushed in the year t (tonne)
PS_t-1 = Real retail price of sugar, lagged by one year (Rs/kg)
G_t = Privatisation of sugar mills (Dummy variable (0) for government control and (1) for private control)
AC_t = Cane area harvested in the year t (ha)
PC_t = Price of cane. Lagged by one year (Rs/tonne)
SA_t = Sugar availability (local sugar production + imports) in the year t (tonne)
WP_t = World sugar price in the year t (Rs/kg)
IT = Import tax of sugar in year t (Rs/kg)
T = Trend variable and t = 1, 2, ……..23 (1990 2015)

Subscript 't' denotes year.

The Equation-01 represents the sugarcane supply to the mill, which is mainly determined by the cane area harvested. Since the companies have monopsony power to dictate the price of cane and the mills have been run under capacity, the price of cane and capacity of mills were not included as variables in Equation 01. The quantity of sugar produced is related to quantity of cane crushed and privatisation of sugar mills (Equation 02). It was assumed that the price of sugarcane is related to one-year lagged price of sugar (Equation-03). The retail price of sugar was used as a proxy to the whole-sale sugar price.

In addition, the privatisation of sugar mills also had an effect on sugarcane price, and hence, it was also included. The quantity of cane crushed was not included in Equation 3 since mills have been run below their capacities. Equation 04 examines the effects of sugar availability in the country, world sugar price and sugar import tax on the local price of sugar. Sugar availability includes the quantity of sugar imports and local sugar production.

It is likely that the real prices of sugarcane and sugar may be different from the market prices due to inflation. Therefore, to eliminate the effect of inflation, the prices were deflated to the base year of 1990 by using gross domestic product deflators reported by the Central Bank of Sri Lanka. The coefficients of the four equations were estimated using the Ordinary Least Squares Method. For computation purposes, the statistical package SPSS 14 was used. The coefficient of multiple determinations (R^2) was used to choose the best fit of the functional forms of the equations. The significance of the coefficients of the equations was tested by using the Student's t-test values. Presence/absence of auto-correlation of the relevant variables in different years was tested by using the Durbin-Watson statistic. Similarly, the presence/absence of multicollinearity among the independent variables was tested by estimating the correlation co-efficients.

RESULTS AND DISCUSSION

Assuming a linear relationship between the variables affecting sugarcane and sugar production and price, the coefficients of the three models were estimated using the ordinary least squares technique. The best-fit form was chosen considering the value of R2, sign of the coefficients estimated as implied by economic theory and the significance of the estimated coefficients. According to the results of the tests of normality of the variables and R^2 value of the three models, real price of sugar, quantity of sugar produced and quantity of cane crushed were transformed to log values before entering into the model.

The Durbin-watson statistics estimated for the three equations was close to two indicating the minimal autocorrelation (Table 1). The correlation coefficients estimated for the independent variables have indicated that there was no considerable multi-collinearity between independent variables in each Equation.

The extent of sugarcane area harvested exhibited a positive effect on quantity of cane crushed as expected (Equation 1). The value of the co-efficient of area harvested indicate that the average cane yield was 49.00 tonnes/ha, while in India and Thailand its 61 tonnes/ha and 65 tonnes/ha respectively. According to Equation-2, 97 per cent of the variation in quantity of sugar production was explained by the quantity of cane crushed and managerial ownership of the sugar mills. As expected, quantity of cane crushed had positive and significant influence on sugar production. One percent increase in quantity of cane crushed results 0.086 percent increase of sugar production. It indicates that the average sugar recovery during the period was 8.6%. Privatisation has a negative influence on the quantity of sugar production. It may be due to failures of management of private companies.

The results of Equation -3 revealed that the

Table 1: Coefficients of the Sugarcane and Sugar Production Model

Variables	QC_t	QS_t	PC_t	PS_t
Constant	75967.37^{NS}	-3128.29^{NS}	1201.80***	36.36***
	(0.50)	(-0.72)	(5.72)	(4.52)
PS_{t-1}			11.36**	
			(3.88)	
G_t		-791.81^{NS}	-273.18**	
		(-0.66)	(-3.98)	
AC_t	49.00***			
	(5.03)			
QC_t		0.086***		
		(17.60)		
SA_t				-9.34^{NS}
				(-0.632)
WP_t				0.05***
				(6.51)
IT_t				1.08***
				(3.44)
T	365.80^{NS}	51.18^{NS}	-11.68^{NS}	-1.05***
	(0.113)	(0.49)	(-1.98)	(-5.94)
Adjusted R^2	0.63	0.97	0.86	0.90
Durbin-Watson statistic	1.81	1.24	1.72	1.14

Figures in the parentheses are t statistics.
NS Not significant ** Significant at 5% probability *** Significant at 1% probability.

one-year-lagged real sugar price has a positive and significant influence on real price of cane. It indicates that if the real price of sugar is increased by one rupee, the real price of cane would increase by Rs. 11.36. Privatisation of sugar mills had a negative and significant effect on real cane price. This equation was able to explain 86 per cent of the total variation of real price of cane ($R^2 = 0.86$). The world price of sugar and the sugar import tax had a positive and significant effect on the local market price of sugar (Equation 4). Sugar availability in the local market has no significant effect on the price of sugar, and it indicates that the price of sugar in the local market is mainly determined by the world price and the import tax.

CONCLUSIONS

Based on the results of this study, it is concluded that the following areas should be considered in formulating the policies for sugar industry development in Sri Lanka:

1. The average sugarcane yield and recovery of sugar in Sri Lanka are very low compared to those in other sugarcane-producing countries. Hence, farmers should be encouraged to grow high-cane and sugar-yielding sugarcane varieties and to adopt improved crop management practices. The Sugarcane Research Institute should expand their technology transfer activities in order to deliver their high-cane and sugar-yielding varieties and crop management practices to sugarcane farmers. The sugar mills should be upgraded to increase the sugar recovery. The government should help the sugar mills by providing low-cost credit facilities and tax exemptions. Sugar development fund as in other sugar-producing countries should be established for this purpose. The fund could be maintained through the tax imposed on imported sugar.

2. The price of a produce is an important factor that determines its relative profitability. The prevailing sugarcane pricing system in Sri Lanka represents the price of sugar, and retail sugar price is determined by the world

price and import tax. However, the sugarcane price does not represent the prices of by-products of sugar production, viz. ethanol and electricity and prices of competitive crops. In addition, the existence of fewer number of mills and large number of growers allows the millers to enjoy the monopsony power and dictate the cane price, and therefore, the privatisation of sugar mills had a negative effect on cane price. Hence, it is necessary to introduce a sugarcane price policy and it should provide remunerative prices to meet costs of production and give due value for the main and by-products. The price policy should also be considerate of the profitability of other competing crops and price of the inputs.

3. Retail sugar prices in Sri Lanka are directly related to world prices due to higher reliance on imports. The world market sugar price is highly volatile owing to the imperfections of the market, and therefore, most of the sugar-producing countries have sugar price policies to insulate their sugar industries from adverse world price changes. A sugar pricing policy as suggested by Keerthipala (2000) should be implemented to stabilise the local market price of sugar.

4. Privatisation of sugar mills has a negative effect on cane price and quantity of sugar produced. Hence, the government should consider the management capabilities of the private investors when privatising the mills introduce regulatory mechanism for better management of the industry.

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Optimal Plot and Sample Sizes for Sugarcane (Saccharum spp. Hybrids) Varietal Assessment

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ABSTRACT

A uniformity trial was conducted using the variety SL 95 4430 at the Sugarcane Research Institute, Uda Walawe Sri Lanka to determine the optimal plot sizes and sample sizes of sugarcane for their efficient assessment in different stages of the varietal selection program in Sri Lanka. The optimal plot sizes were determined for the characteristics; plot weight (WT), number of millable stalks (ST), hand refractometer brix (HB), laboratory brix (Brix), stalk length (SL), stalk diameter (SD), rind hardness (RD), pol in juice (Pol), purity (Pur), pure obtainable cane sugar (POCS) and fibre content (Fib) by determining the point of inflection of the coefficient of variation (CV) verses plot size graph through split line regression and maximum curvature methods. The optimal sample sizes were found for the prescribed margin of error of 10% of the plot mean for the above-mentioned variables except for the number of millable stalks. Three-metre long single-row plots and five-metre long two-row plots were found as the optimum for sugarcane variety evaluation in stages 2 and 3 of the selection program, respectively. For assessing the varieties for hand refractometer brix and rind hardness at stage 1, samples of three and four millable stalks, respectively from a clump was found as the optimum. The optimal sample sizes to appraise varieties in variety selection stage 2 for stalk length, field brix and rind hardness were six, three and four millable stalks; respectively Six millable stalks for stalk length and 3 millable stalks for laboratory brix, purity and fibre content were found to be the optimum sample sizes for assessing the varieties at stage 3. For the evaluation of varieties in Preliminary Yield Trials and Replicated Yield Trials, a sample of 12 stalks should be obtained and eight stalks should be used for extracting mixed juice for the analysis of brix, pol, and purity and the remaining four stalks for the analysis of fibre content.

Keywords: Crop improvement, Optimum plot size, Optimum sample size, Sugarcane, Variety selection

INTRODUCTION

New sugarcane varieties are produced primarily by hybridisation and subsequent clonal propagation of the progenies. Each year, a population consisting of many thousand seedlings of new varieties is produced. These varieties are passed through a series of stages of selection and the selected varieties in each stage are evaluated for their performance in larger plots in the subsequent stage. At the latter stages of selection, the varieties are replicated to reduce the effect of environmental variation, and evaluations are carried out in the sites representing sugarcane-growing areas with different environmental conditions. Subsequently, the varieties superior to the existing commercial varieties are propagated and released for commercial cultivation (Skinner et al., 1987).

In Sri Lanka, sugarcane variety selection starts from stage 1 where more than sixty thousand seedlings of different varieties produced by true seeds of crosses are assessed for sucrose and fibre contents approximated by hand refractometer brix and rind hardness, respectively. Each clump of an individual variety is evaluated visually for its morphology, infection of diseases and cane yield at this stage. Annually, a fairly large tissue culture sub-clone population produced by exploiting somaclonal variation is also assessed in similar manner, parallel to selection stage 1. The better varieties consisting of nearly ten percent of the population are selected in stage 1 and are advanced into stage 2 where stem cuttings of each selected variety are planted in a 5 m-long single-row plot for evaluation. The better varieties selected in stage 2 are advanced into stage 3 for evaluation in 10 m-long 2-row plots. Selection stage 3 usually consists of about 10 percent of the varieties at stage 2, and the better varieties selected in stage 3 are screened for resistance to major pests and diseases. The varieties found to be resistant to the major pests and diseases are advanced for testing in Preliminary Yield Trials (PYTs) in plots of 5 m x 4 rows. Replicated Yield Trails (RYTs) are conducted using the plots of size, 10 m x 5 rows to evaluate the promising varieties selected from PYTs. The varieties in both PYT and RYT stages are tested for cane yield and biochemical characteristics (sugar and fibre) in each sugar industry site. In RYTs, the varieties are tested up to second ratoon crop. The experimental designs for PYTs and RYTs are decided based on the number of varieties to be tested and the type of the lands where the trials are established.

The selection index "I1 = 0.3 (rank of stalk length) + 0.4 (rank of hand refractometer brix) + 0.3 (rank of absolute deviation of rind hardness from the standard)" is employed in selecting varieties at stage 2 and the index "I2 = 0.3 (rank of stalk length) + 0.2 (rank of purity) + 0.2 (rank of laboratory brix) + 0.3 (rank of absolute deviation of fibre percent from the standard)" is used for selection of varieties at stage 3 (Wijesuriya et al., 1997). The use of indices that manipulate several attributes simultaneously in these stages of varietal selection is of great importance for selecting the varieties base on the overall performance.

The plot sizes used for the stages 2 and 3 of the variety selection programme are determined solely based on the planting material requirement for establishing the next stage of selection. The plot sizes used in these stages require a large land area to accommodate a large number of test varieties in the initial stages of variety selection. The variation in soil conditions in a larger experimental area causes bias over selection of varieties grown under better soil conditions and vice-versa under poor soil conditions. The use of optimal plot sizes and sample sizes assures obtaining reliable, accurate and precise parameter estimates of the variables used for selection of varieties in different selection stages and eventually improves selection efficiency.

There are not many findings in literature regarding the optimal plot sizes in sugarcane variety selection. Leite et al., (2009) has evaluated the number of rows and individual plants per plot required for the assessment of sugarcane families based on cane and sugar yield components. Barbosa et al., (2001) have studied a population of 500 sugarcane plants and concluded that 50 individual plants are sufficient to estimate the production of stalks, and ten individuals per plot are enough to estimate the mean Brix of the families. Those findings on optimal plot sizes were based on the sugarcane seedling families where each seedling varies genetically to each other. In such cases, within-family variation and genotype x environment variation warranted bigger plot sizes as optimal for estimating the parameters. Such situations arise only at stage 1 if combined selection (individual selection followed by family selection) is practised, and it does not happen in other stages of sugarcane variety selection as all the plants in a plot are genetically identical.

There is hardly any literature on optimal plot sizes for use in selection of varieties in different stages of sugarcane crop improvement. Therefore, this research is the pioneering attempt in this discipline for determining the optimal sample sizes together with the optimal plot sizes for more accurate assessment of sugarcane at different stages of selection with efficient utilisation of resources; land, labour and funds.

MATERIALS AND METHODS

Layout of the uniformity trial

The field experiment for the determination of optimal plot and sample sizes for sugarcane variety selection was carried out at the Research Farm of the Sugarcane Research Institute (SRI), Uda Walawe, Sri Lanka. This area belongs to agro-ecological zone DL1a. The sugarcane field was established in February 2013 using ridge and furrow system with the recommended spacing of 1.37 m apart. A block of uniform sugarcane field of the variety SL 95 4430 at harvestable maturity was selected for sampling to derive optimal plot and sample sizes.

Harvesting and collection of data for determining optimal plot sizes

Harvesting and collection of data were carried out in February, 2014. The whole block of the land was pegged along the cane rows to create a grid where one-meter-long cane harvesting units (plots) were demarcated before commencing the harvesting. This will accomplish amalgamation of harvesting units in both row and column directions in the grid to generate different plot sizes and shapes required for the analysis. Each unit was harvested separately, from one end to the other in each cane row. The canes were cut at the bottom and the tops were removed at the highest fully-formed internode of the stem. Only the millable stalks were used for recording the data.

The number of millable stalks per plot (ST) and their weight (WT) were taken after removing water shoots and unproductive tillers. Having counted the number of millable stalks and weighing canes in each plot, a sample of randomly-selected 5 millable canes was obtained and tagged. These 5-stalked samples were used to measure hand refractometer brix (HB), stalk length (SL), stalk diameter (SD) and rind hardness (RD) in the field. After recording these data, the cane samples were analysed forbrix (Brix), pol in juice (Pol) and, fibre content (Fib) at the Laboratory of the Sugarcane Research Institute. The variables, purity (Pur) and pure obtainable cane sugar (POCS) content in juice were estimated based on the results of these analyses.

Harvesting of canes for determining optimal sample sizes

The individual stalks of a randomly-selected 5 m-long cane plot in the uniformity trial was harvested from one corner to the other, and the harvested canes were labelled in numerical order up to the last stalk in the plot. HB, WT, RD, SL, SD were recorded, Brix, Pol and Fib were measured and Pur and POCS were estimated for each millable stalk.

Analysis of Data

Determination of optimal plot sizes

Amalgamation of basic harvesting units in both row and column directions in the trial block can form plots of different sizes. Co-efficient of variation (CV) values for each characteristic for these plot sizes were calculated using the computer programme developed through R programming language by Jeewanthi et al., (2014). Subsequently, the estimated CV values were plotted against corresponding plot sizes. This relationship was estimated in exponential form (Figure. 1); $Y = aX^b$, where Y is the CV for the characteristic concerned and X is the plot size and a and b are the estimated coefficients. The optimum plot size for each variable was found by finding the point of inflection of this graph through split-line regression and maximum curvature methods, suggested by Ryan and Porth (2007) and Vallejo and Mendoza (1992), respectively. The methodology proposed in www.mathworld.wolfram.com/curvature.html was used for the maximum curvature method (Wolfram Math World. (Undated) Retrieved January 1, 2016 from http://www.mathworld.wolfram.com/curvature.html), and the software Genstat 17 was used in split-line regression method.

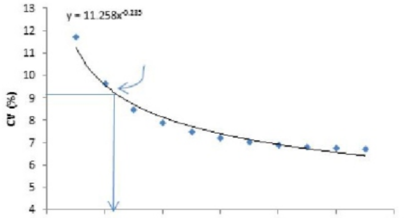

Figure 1: The typical relationship between plot size and Coefficient of Variation (CV) of the variable concerned, derived through the sugarcane uniformity trial

The variation of CV against plot size in single-row plots was used in determining the optimum plot size in variety selection stage 2 and that was used in the determination of the optimum plot size in variety selection stage 3.

Determination of optimal sample sizes

Using the estimate of the sampling variance, the required sample size can be determined based on a prescribed margin of error of the plot mean, or the treatment mean (Gomez and Gomez, 1984). The sample size for a random sampling design that can satisfy a prescribed margin of error of the plot mean is computed as:

$$n = \frac{(z_\alpha^2)(v_s)}{(d^2)(\bar{x}^2)}$$

Where, n = sample size, z_α= value of the standardized normal variate corresponding to the level of significance α (the value z_α can be obtained from Cumulative Normal Frequency Distribution Table), v_s = sampling variance, x = mean and d = margin of error expressed as a fraction of the plot mean. In this study, the margin of error was taken as 0.1.

RESULTS AND DISCUSSION

Optimal plot sizes for different characteristics used in sugarcane varietal assessment

The sugarcane variety selection programme conducted at the Sugarcane Research Institute, Sri Lanka, begins with the selection of individual sugarcane plants (clump) generated through true seeds in selection stage 1. Therefore, the plot size at this stage is invariably a single plant.

Optimal plot sizes for selection stage 2 of sugarcane

The selected plot sizes that determined through both split-line regression method and maximum curvature method (Table 1) indicated that the use of 3 m-long plots in the selection stage 2 is sufficient for accurate assessment of varieties for hand refractometer brix, stalk length, stalk diameter, rind hardness, laboratory brix, Pol, Purity and pure obtainable cane sugar. The results showed that 5 m-long plots are required to appraise varieties for number of stalks and plot weight at this stage and the results proved that these two characteristics, among the characteristics studied, possessed the highest variability. Two-metre-long plots are sufficient for evaluation of varieties for fibre at this stage.

Currently, at this stage, data on stalk length, hand refractometer brix and rind hardness are recorded from five randomly-selected millable stalks from 5 m x 1-row plots for calculating of index values of the varieties under evaluation. The results of optimal plot sizes for characteristics under study (Table 1) indicated that 3 m-long plots are sufficient to evaluate varieties for these three variables in the index.

Therefore, it is evident that the plot size used currently (5 m x 1 row) is larger than the optimum size, i.e., 3 m x 1 row in selection stage 2. Accordingly, 3 m-long plots in the establishment of varieties in selection stage 2 is recommended for adoption in the future. Adoption of this new recommendation provides space for 1606 plots per hectare as compared to 1095 plots per hectare in the current practice.

Optimal plot sizes for stage 3 of sugarcane variety selection programme

The selected plot sizes determined through split-line regression method and maximum curvature method (Table 2) indicated that 3 m-long, 2-row plots in the selection stage 3 are sufficient for accurate assessment of varieties for stalk length, hand refractometer brix, laboratory brix, pol, purity, pure obtainable cane sugar and fibre. The results indicated that 4 m-long 2-row plots are required to appraise varieties for number of stalks and 5 m-long 2-row plots are needed for evaluating varieties for stalk diameter and rind hardness. At this stage, 6 m-long 2-row plots are required to assess varieties for plot weight. The results proved that, among the

Table 1: Optimal plot sizes determined by split line regression method and maximum curvature method and selected plot sizes for different characteristics in sugarcane variety selection stage 2

Characteristic	Optimum plot size [single row (m)]		Selected plot size for stage 2 [m]
	Split line regression	Maximum curvature	
Hand refractometer brix	3	2	3
Stalk length	3	2	3
Stalk diameter	3	2	3
Rind hardness	3	3	3
Number of stalks	2	5	5
Plot weight	2	5	5
Laboratory brix	3	1	3
Pol % in juice	3	2	3
Purity	3	1	3
Pure obtainable cane sugar	3	2	3
Fibre content	2	2	2

Table 2: Optimum plot sizes determined by split line regression method and maximum curvature method and selected plot sizes for different characteristics in sugarcane variety selection stage 3

Characteristic	Optimum plot size [m x 2 rows]		Selected plot size for stage 2 [m x 2 rows]
	Split line regression	Maximum curvature	
Hand refractometer brix	3	2	3
Stalk length	3	2	3
Stalk diameter	5	2	5
Rind hardness	5	4	5
Number of stalks	3	4	4
Plot weight	3	6	6
Laboratory brix	3	2	3
Pol % in juice	3	2	3
Purity	3	2	3
Pure obtainable cane sugar	3	2	3
Fibre content	3	2	3

characteristics studied, plot weight possesses the highest variability. Two-metre-long 2-row plots are sufficient for evaluation of varieties for fibre at this stage.

The index used in this stage comprised four measurable variables, namely; stalk length, purity, laboratory brix, and fibre content. The results obtained for optimum plot sizes relevant to these four characteristics indicated that 3 m x 2-row plots (Table 2) are sufficient to evaluate varieties for these four characteristics in stage 3 of the variety selection programme. Therefore, the plot size used at present, i.e., 10 m x 2 rows is larger than the required plot size for variety evaluation at selection stage 3. However, sufficient quantities of planting materials from the selected varieties are required to establish trials in the variety multiplication stage that is followed by stage 3 of the variety selection programme and to provide planting materials of the selected varieties for establishing field experiments for screening those varieties for resistance to major sugarcane diseases. As such, considering the level of precision of the results of evaluation and the amount of planting materials of the selected varieties required to be provided, the plot size, 5 m x 2-row is proposed in the establishment of the trials in stage 3 of the sugarcane variety selection programme. Adoption of 5 m x 2-row plots in the establishment of variety selection stage 3 allows establishing 1095 plots per hectare of land as compared to 584 plots in the current practice of 10 m x 2-row plots.

Optimal sample sizes for different characteristics used in sugarcane variety assessment

The optimal sample sizes derived through calculations together with descriptive statistics for the characteristics studied are given in Table 3. Among the characteristics studied, plot weight showed the highest variability. It needs a sample of more than 22 millable stalks for more accurate assessment of cane weight. Measurements from 7 and 6 millable stalks are needed for the assessment of stalk diameter and stalk length, respectively. Hand refractometer brix needs 3 millable stalks as the sample and a 4-stalked sample is needed for rind hardness. All characteristics that are measured in the laboratory required less number of stalks for a sample compared to those measured in the field. Single-stalked sample is enough to measure laboratory brix, pol and purity while a two-stalked sample is needed to measure pure obtainable cane sugar. The required sample size for fibre was determined as four, which is separately used for fibre analysis. The variable, pure obtainable cane sugar is an estimation based on the sample analysis of laboratory brix, pol and fibre content. Therefore, to achieve the required accuracy for pure obtainable cane sugar, laboratory brix and pol should be measured from juice extracted at least from a 2-stalked sample.

Optimal sample sizes for different characteristics in Selection stage 1

Genotypes in this stage are evaluated on two measurable variables namely; hand refractometer brix and rind hardness. Visual estimations on clump weight (cane yield), plant architecture and morphology and free from diseases and pests are used for selection of genotypes in this stage.

At present, one juice sample extracted from one mature cane is taken for assessing of hand refractometer brix and one rind hardness value is taken for measurement of fibre. The results show that 3- and 4-stalked samples are required for accurate assessment of hand refractometer brix and rind hardness, respectively. Therefore, it is proposed to use 3 and 4 stalks in a clump respectively, for determining the average values of hand refractometer brix and rind hardness in evaluating genotypes at this stage of selection.

Optimal sample sizes for different characteristics in Selection stage 2

The index used for this selection stage comprised three variables; namely, stalk length, hand refractometer brix and rind hardness. At present, average values of 5 millable stalks for each variable is used for

Table 3: Descriptive statistics and optimal sample sizes under the margin of error = 0.1 for each characteristic of sugarcane

Characteristic	Unit	Average	CV	Calculated sample size	Sample size (No. of stalks)
Hand refractometer brix	Degrees	19.33	8.18	2.57	3
Stalk length	cm	260.84	12.39	5.89	6
Stalk diameter	mm	26.93	13.40	6.90	7
Rind hardness	mm	20.00	10.50	4.23	4
Plot weight	kg	1.28	23.65	21.49	22
Laboratory brix	degrees	20.10	4.50	0.78	1
Pol % in juice	%	17.18	5.94	1.36	1
Purity	%	85.42	2.84	0.31	1
Pure obtainable cane sugar	%	12.98	6.97	1.86	2
Fibre content	%	11.17	9.35	3.36	3

estimating the index values for each variety at this selection stage. The optimal sample sizes for more accurate assessment of stalk length, hand refractometer brix and rind hardness are 6, 3 and 4 millable stalks, respectively. Thus, the sample size currently being used is sufficient for assessing hand refractometer brix and rind hardness, but is not adequate for the assessment of stalk length. As such, this study proposes to use average values of stalk length, hand refractometer brix, and rind hardness from 6, 3 and 4 stalks respectively, from varieties under evaluation.

Optimal sample sizes for different characteristics in Selection stage 3

The index used for this stage possesses four measurable variables namely; stalk length, purity, laboratory brix and fibre content. At present, average length of 12 randomly-selected millable stalks from each variety is used to calculate the index. The same cane sample is used for laboratory analysis from which 10 millable canes are used to derive the values of laboratory brix and purity and 2 millable canes are used for analysis of fibre content. According to the study, 6-stalked sample for stalk length, 1-stalked sample for laboratory brix and purity and 3-stalked sample for measurement of fibre are found to be sufficient. Thus, the sample sizes used at present for stalk length, laboratory brix and purity are larger and that for fibre is smaller than the optimum. Therefore, the average values of 6-stalked samples are adequate for evaluation of varieties for stalk length at this stage. This 6-stalked sample can be divided into two samples of three stalks each at the laboratory and one can be used for analysis of laboratory, brix and purity and the other for analysis of fibre.

Optimal sample sizes for different characteristics in Preliminary Yield Trials (PYTs) and Replicated Yield Trials (RYTs)

The varieties selected from stage 3, which are resistant or moderately resistant to major diseases and pests are advanced to PYTs after variety multiplication for testing them in comparatively large plots. Plots of 5 m x 4 rows are used in this stage. Varieties at PYTs are basically selected on high cane and sugar yields and moderate fibre contents. Cane yields estimated based on the cane weight of the middle two rows of the plot are used for assessing the varieties for cane yield at this stage. The plot size used in Replicated Yield Trials is 10 m x 5 rows. Cane yield is estimated based on the weight of cane in the middle three rows of the plot. In RYTs also, the varieties are evaluated on high cane and sugar yields and moderate fibre content

A sample of 12 randomly-selected stalks obtained from the middle rows in both PYTs and RYTs are used for testing varieties for sugar and fibre contents at the laboratory. From this sample, 10-stalks are separated for juice extraction for measuring laboratory brix, pol and estimation of purity and the remaining 2 stalks for the analysis for fibre content to determine pure obtainable cane sugar.

According to the results of this study, plot weight has the maximum variability, and therefore, the plot sizes used at present for the assessment of cane yield at these two stages should not be changed. Moreover, at these stages, cane weight of each plot is extrapolated to one hectare. However, the sample size used for fibre analysis at present is proven inadequate. Thus, it is proposed to mix the juice from 8 stalks of the 12-stalked sample for measuring laboratory brix and pol and to use the remaining 4 stalks for fibre analysis. Sugar yield (tonnes/ha) of the varieties should be estimated after estimation of pure obtainable cane sugar using the relevant formula.

CONCLUSIONS

The findings of this study indicated that the measurements from 3 and 4 stalks in a clump are required for accurate assessment of genotypes respectively for determining the average values of hand refractometer brix and rind hardness at selection stage 1. The selected plot sizes that determined through split-line regression method and maximum curvature method indicated that the use of 3 m-long plots in the selection stage 2 is sufficient for assessment of varieties for hand refractometer brix, stalk length and rind hardness measured from 6, 3 and 4 stalks, respectively. The average values of these characteristics should be used in the selection index for varietal evaluation. The plot size, 3 m x 2 rows is sufficient for assessing varieties for stalk length, laboratory brix, purity and fibre content, which are the index characteristics used in variety selection stage 3. This study proposes that the average values of 6 stalks should be used for stalk length and for measuring laboratory brix and purity from mixed-juice extracted from 3 stalks obtained from 6-stalked sample and for measuring fibre using the other 3 stalks should be used. Based on the planting material requirement for establishing subsequent varietal selection stage, the plot size 5 m x 2 rows was proposed for the establishment of variety selection stage 3.

This study did not propose any changes to the plot sizes used in Preliminary Yield Trials and Replicated Yield Trials. However, changes to sample sizes for accurate assessment of characteristics were proposed. Having recorded stalk length and stalk diameter from the currently-used 12-stalked sample in the field, mixed juice extracted from 8 stalks out of this 12-stalked sample is proposed for measuring laboratory brix and pol. The remaining 4 stalks are proposed to be used in fibre analysis.

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Management of Physical Properties of Reddish Brown Earth Soils at Uda Walawe (Walawa Series) for Sustainable Sugarcane Production

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ABSTRACT

A study was conducted at the research farm of the Sugarcane Research Institute, Uda Walawe, Sri Lanka to investigate its soil physical properties which are important for planning in-situ soil and water management for sustainable sugarcane production. A total of 182 soil samples over 92.05 ha land were collected from two depths;10-20 cm and 40-50 cm below the earth surface, according to 100 m x100 m grid layout. The bulk density, porosity, texture and gravel content of the soil were assessed. The geographical information system was used for mapping and geo-statistical analysis of the soil properties.

The results revealed that the mean bulk density values varied from 1.48gcm^{-3} to 1.92gcm^{-3}at 10-20 cm depth with an average of 1.67gcm-3. The average bulk density value at 40-50 cm depth was 1.68 gcm^{-3} with a variation from1.48 gcm^{-3} to 1.96 gcm^{-3}. The predominant textural category of the soilwassandy clayloam as per the USDA (United States Department of Agriculture) system. Sandy clay, sandy loam and loamy sand soils also were found in few locations. The apparent gravel percentage detected in all soil samples averaged nearly20% and 19% for 10-20 cm and 40-50 cm depths respectively. The gravel content of soil samples was nearly 4% higher in 10-20 cm depth than that in 40-50 cm depth soil layer. The soil porosity values varied from 0.18 to 0.48 at 10-20 cm depth with an average of 0.34. According to the variation of soil properties and topography, guidelines on ploughing, irrigation, drainage, mulching, organic matter incorporation, soil conservation, etc.were prepared for management of the soil for sustainablesugarcane production.

Keywords: Reddish Brown Earth Soils, Soil Physical Properties, Sugarcane, Sustainable Production

INTRODUCTION

Soil is a highly heterogeneous natural substance found on the earth crust, and occurrence of spatial and temporal variation of its properties is an inherent feature. The spatial variations of soil properties exist horizontally across the landscape and vertically between different soil layers (Rogerio *et al*., 2006). The information on the spatial variability of soil properties is vital for land management and adopting irrigation, drainage and soil conservation practices (FAO, 1988). Sugarcane is a crop grown in Sri Lanka with the intense use of heavy machinery for land preparation. Most of the sugarcane-growing lands in Sri Lanka consist of five major soil groups, namely, Reddish Brown Earths (RBE), Non-Calcic Brown (NCB), Immature Brown Loam (IBL), Alluvial and Low Humic Gley (LHG) (Mettananda, 1990; Panabokke, 1967). Out of these, nearly 4,680 ha in Sevanagala and Uda Walawe area is RBE (Bodhinayake, 2000).

RBE is the most widespread great soil group in Sri Lanka, occupying the largest area with large variations compared to all other soil groups. According to Joshua (1988), the average bulk density of RBE soil is comparatively high, and it tends to get compacted, limiting root distribution and penetration and reducing infiltration. RBE soil is often problematic if agricultural land preparation practices are carried out during wet seasons. Soil erosion risk is significant in RBE soils as a result of surface run-off of a considerable fraction of rainfall due to low rate of infiltration. The adverse effects of natural phenomenon of rainfall can be minimised by judicious management of soil and water resources. Thus, proper understanding of the variation of soil parameters which are important for managing soil and water resource is an essential prerequisite. Bulk density, porosity, infiltration, water-holding capacity and texture of soils are the most important parameters required for designing soil and water conservation practices for sustainable sugarcane cultivation (Dharmawardena, 2004). Therefore, the present study was conducted to evaluate the physical properties of sugarcane-growing soils at Uda Walawe where the Walawa series of RBE is the predominant soil group, for making suggestions to improve its sustainable management.

MATERIALS AND METHODS

Study Area

The study was conducted at the research farm of the Sugarcane Research Institute (SRI), Uda Walawe, Sri Lanka (latitudes 6 25'E and 6 35' N and longitudes 80 45'N and 81 00' E), which is in the low-country dry zone (DL1a) agro-ecological region of Sri Lanka (Punyawardana, 2008). The area receives an annual rainfall of about 1450 mm (Wijyawardhana et al., 2014). The average annual temperature is 28-32^{0}C (Witharama *et al.*, 2015). The climate is characterised by a bi-modal pattern of rainfall distribution where two-thirds of rainfall is received during September to January in *maha* season (Panabokke, 1996).

Sampling Design

The sampling design of a soil study depends on the purpose for which the soil sampling is carried out (Mason, 1992). Often, it should sufficiently fulfil the requirements of geo-statistical analysis. Starks *et al*. (1989) have mentioned that properly-designed sampling network is a must for geospatial studies. In most cases, soil scientists use grid layout technique for collecting soil samples to evaluate the spatial variability of soil properties (Eduardo *et al*., 2014). On the other hand, data collected on grid layout can easily be used for geographical information analysis. In order to determine sampling locations, a grid map with 100 x 100 m checks covering the entire extent of 92.05 hectare of the research farm of SRI was prepared using Geographical Information System (GIS) software. The land pieces which were utilised for non-agricultural purposes, like, buildings, residences, playgrounds, roads and other abundant unproductive gravel lands were omitted from the sampling network. The most possible centre location of each grid (100m x 100m) cell was selected as the soil sampling point. The geographical coordinates of all sampling locations were recorded using Global Positioning System (GPS). Undisturbed soils samples were collected from two depths 10-20 cm and 40-50 cm, with two replicates using a soil core sampler. Sugarcane root density is usually high at about 40 cm depth from the surface (Bakker, 1999).

Data Analysis

The mean values of the soil properties; bulk density, porosity, texture and gravel content were estimated, and the paired t-test was used to compare them (at $p < 0.05$) between the two depths, 10-20 and 40-50 cm. The SAS software (v 9.0) was used for the analyses.

Soil Property Variability Mapping

Since the soil samples were collected according to a grid layout, grid surface was created separately for each estimated soil parameter by adopting the grid data interpolation method (Kriging) using the GIS software. This method was used in the present study because “Kriging” is the most common and widely-used grid interpolation method for similar kind of studies (Dreskovic and Samir, 2012). The Q-GIS software was used to construct spatial variability maps for soil bulk density, soil porosity, texture and gravel content.

RESULTS AND DISCUSSION

Bulk Density

The bulk density values ranged from1.06 gcm^{-3} to 2.15 gcm^{-3} at 10-20 cm soil depth and from 1.07 gcm^{-3} to 2.18 gcm^{-3} at 40-50 cm depth with averages of 1.68 gcm^{-3} and 1.69 gcm^{-3} respectively. The mean soil bulk density at 10-20cm depth was lowerthan that at 40-50 cm depth. There was no significant difference ($P > 0.05$) in bulk density values between the two depths. A study carried out by Seneviratne (1993) also reported that bulk density values were within the range from 1.62 gcm^{-3} to 1.74 gcm^{-3} with an average of 1.68 gcm^{-3}. The optimum range of the bulk density of soil for cultivation of sugarcane is between 1.3 gcm^{-3} and 1.4 gcm^{-3} (Trouse and Humbert, 1961). Out of the 182 soil samples analysed, only 6 samples were within this optimum range. The bulk density of 97% of the soil samples was higher than 1.4 gcm^{-3}. Figure 1 shows the spatial variation of soil bulk density at 10-20 and 40-50 cm soil depths.

The high bulk density in sub-surface soils

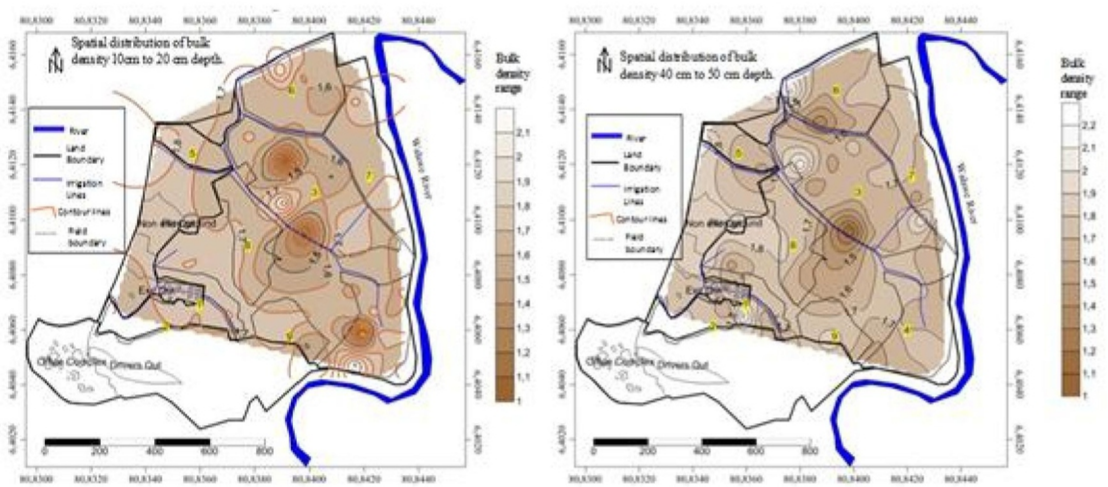

Figure 1.Spatial variation of soil bulk density (gcm^{-3}) in sugarcane research farm at Uda Walawe

may occur due to compaction as a result of the use of heavy machinery for land preparation, cane transportation and other agronomic operations. Also the leachate in the deeper soil layers (40-50cm) (Joshua, 1988) belong to the B-2 sub horizon of RBE soil (Mapa et al., 2009) has a considerable risk to form heavy soils. Somapala (1991) reported that clay and fine sand together with leachate leads to create cementing action in subsurface layer resulting high bulk density. This type of cemented soil layer usually has bulk density varying from 1.6 gcm^{-3} to 2.05 gcm^{-3} with an average of 1.57 gcm^{-3} (Joshua,1988) which is significantly high compared to that in the naturel forest soil available in the same climate. The presence of a compacted layer in root zone soil limits root development, and hence, land preparation practices should be planned accordingly. The bulk density of sugarcane-growing soils could increase further if the land is prepared during wet periods as the soil reaches its maximum compaction limit under moist conditions. Therefore, land preparation activities using heavy machinery should be avoided during rainy seasons. The soil bulk density values beyond 1.7 gcm^{-3} significantly reduces the sugarcane root growth (Kong, 1968) and has been found to be one of the major reasons for low ratoon crop productivity (Trouse, 1961).

Soil Porosity

Soil porosity ranged from 19% to 58% at 10-20 cm depth and from 15% to 55% at 40-50 cm soil depth with average values of 35% and 34% respectively. But, there was no significant difference in mean porosity values between 10-20 cm and 40-50 cm soil depths. However, there was a strong negative correlation ($\alpha = 0.05$) between soil porosity and bulk density values at 10-20 cm and 40-50 cm depths as shown by the correlation coefficient values of -0.91 and -0.87 respectively. Figure 2 shows the spatial variation of soil porosity in the study area.

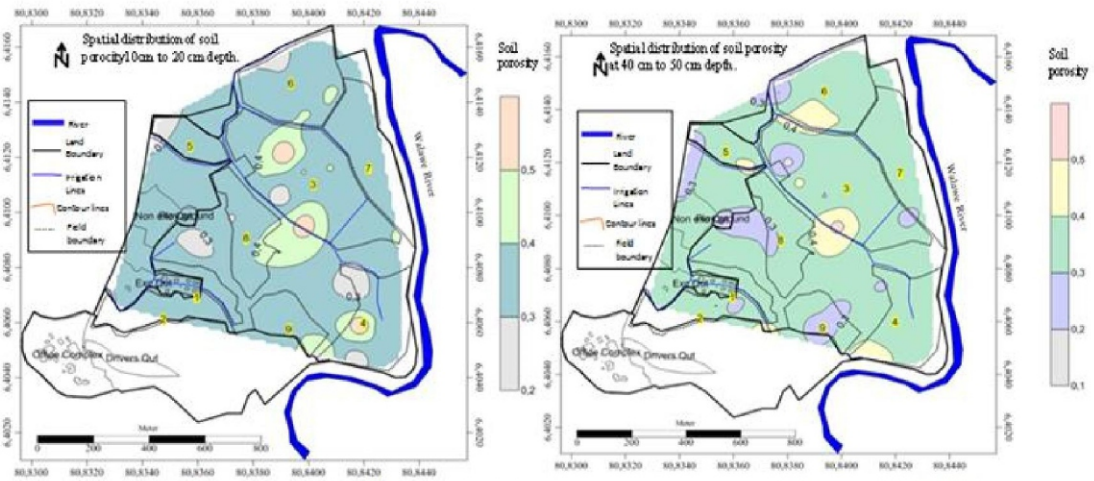

Figure 2. Spatial variation of soil porosity (v/v) in sugarcane research farm at Uda Walawe

According to Figure 2, the porosity values were low in most locations of the study area. Sugarcane crop requires soil porosity higher than 50% for achieving its maximum growth. Out of the 182 soil samples analysed, only 4 samples were within the favourable range. This is a good indication for the presence of soils with high bulk density. Out of the 182 samples, the porosity of 82% of soil samples were between 30-50%, and it was significantly lower than the optimum range required for the growth of sugarcane. Small volume of total pore spaces reduces soil aeration, affecting gas exchange between soil pore spaces and atmosphere. Adding organic matter, such as compost and farmyard manure, mulching and green manure cropping and fallowing will help to improve soil porosity. Sugarcane crop residues and trash and gliricedia leaves are possible mulching materials. Since the 10-20 cm layer shows lower porosity than 40-50 cm layer (Figure 2), the permeability of the top-soil horizons was also lower. This condition restricts infiltration and causes high surface run-off not only with heavy rains but even with light showers. Irrigation efficiency also reduces with less permeable soils. Therefore, it is advisable to practise deep tilling to improve the water adsorption into the soils, increase infiltration, minimise the surface run-off and reduce the risks of soil erosion.

Soil Texture

Sugarcane can be successfully grown on diverse soil types ranging from sandy soils to clay loams and heavy clays, but it grows well in deep, well-drained soils with medium and high fertile sandy loam (SL) soil (Tu Khao, 2007). According to Figure 3, most of the areas of the sugarcane research farm was characterised by sandy clay-loam soil texture category (USDA) and was predominant in both depths. Loamy sand (LS) and sandy loam (SL) soils were also found in several locations but in some limited areas in both10-20 cm and 40-50 cm depths. According to the USDA soil texture class, soil basic infiltration rates for loamy sand, sandy loam, sandy clay-loam and sandy clay soils are 22, 18, 16 and 08 mm/hr respectively. Adding organic matter to improve water-holding capacity and adoption of soil conservation practices, such as, mulching with sugarcane trash and contour farming are the strategies that can reduce surface run-off and soil erosion.

Gravel Content

The gravel content of the soil samples ranged from 0.2% to 65.7 % at the upper depth and from 0.1% to 70.2% at the lower depth with the average valuesof 20.1% and 19.3% respectively (Figure 4). However, there was no significant difference in the gravel contents ($P > 0.05$) between the two depths. Joshua (1988) reported that the gravel content of RBE soils varies between 10% and15% in the surface

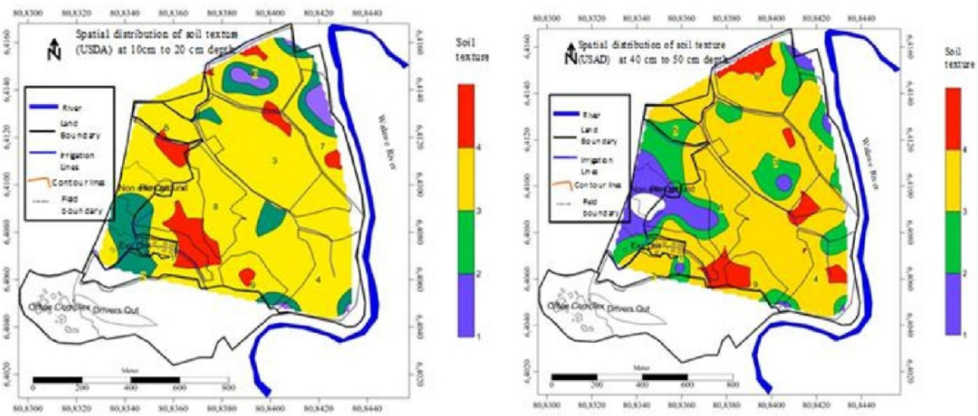

Figure 3: Spatial variation of soil texture: 1-loamy sand, 2- sandy clay, 3- sandy clay loam, 4-sandy loam in sugarcane research farm at Uda Walawe

layers and between 50% and70% in the sub-surface layers. In this case, the top-soil layer has contained high percentage of gravels at about 20% on gravimetric basis. As a consequence of erosion for a long period, sub-surface soil layers have become exposed. Similar results have been observed by Witharama *et al*. (2007) in sugarcane-growing soils at Sevanagala. Therefore, soil conservation practices should be followed, particularly in the upper part of the terrain.

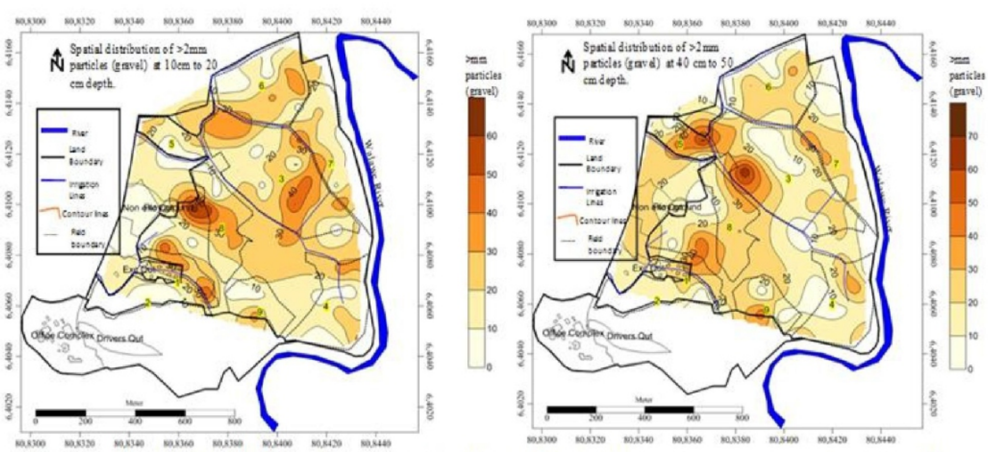

Figure 4: Spatial distribution of gravel content (%) of the soils in sugarcane research farm at Uda Walawe

CONCLUSIONS

The soil property parameters estimated and their maps developed for the sugarcane research farm in Uda Walawe are helpful to determine suitable land preparation methods, and agronomic, soil conservation and water management practices that have to be followed in sugarcane cultivation.

Because of the high bulk density with low porosity particularly in the south-western part and some middle parts of the study area, adoption of the adequate soil tillage practices and incorporation of organic matter to soil is required to improve bulk density, porosity and infiltration to favourable levels.

The study area was predominantly with sandy clay-loam soil in texture; 88% in the upper depths and 79% in the lower depths. Although sugarcane has an ability to thrive well in a wide range of soil texture types, sandy loam is the best for growing sugarcane. The sandy loam soil was found only about 7% and 11% respectively at 10-20 and 40-50cm depths.

The presence of high gravel percentage in the top most layers in high-elevated areas gives evidence that this soil has got exposed to soil erosion for a long period. Soil conservation practices, like improving surface drainage network, avoiding land preparation during rainy seasons and proper mulching are proposed as the possible methods to minimise soil erosion.

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