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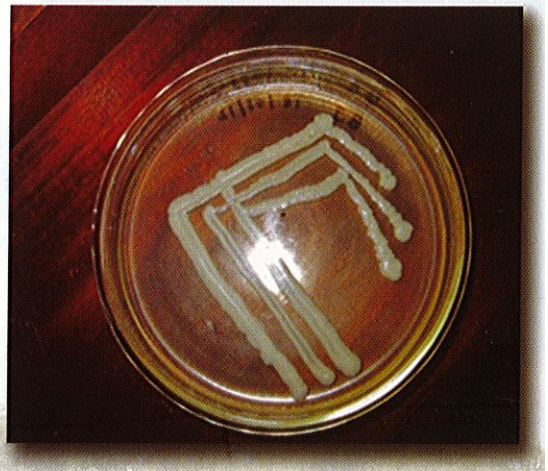

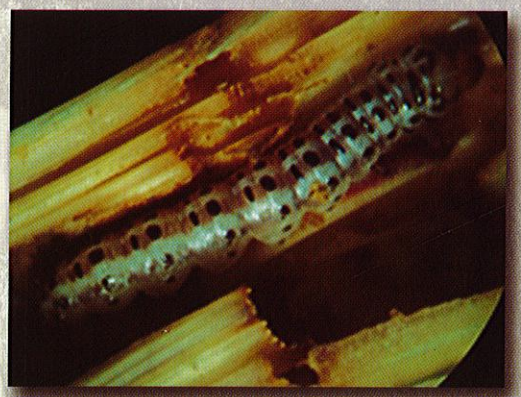

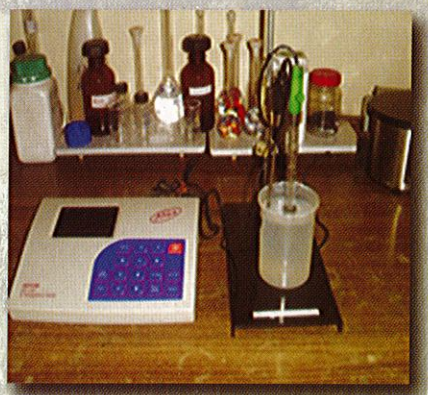

Sugarcane Research Institute, Sri Lanka

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Sugarcane Sri Lanka

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Contents

Adaptability of Some Sugarcane Varieties in Different Environments in Sri Lanka

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ABSTRACT

This study evaluated the genotype-environment interaction (GEI) of fourty sugarcane varieties in five major sugarcane-growing environments in Sri Lanka using Additive Main effects and Multiplicative Interaction (AMMI) models to identify their adaptability to recommend the most adaptable varieties for cultivation. AMMI models were used to identify the relative magnitude and significance of genotypes, environments and GEI with respect to the cane yield, sugar yield and Pure Obtainable Cane Sugar (POCS). Further partitioning of the GEI was done using AMMI model and AMMI 1 and AMMI 2 biplots were used to distinguish the response of genotypes across environments for identifying the most adaptable sugarcane genotypes. The effects of genotype, environment and GEI were highly significant for cane yield, sugar yield and POCS. AMMI analysis captured 72%, 61% and 80% GEI variation of cane yield, sugar yield and POCS, respectively. The genotypes SL 89 2227 and SL 83 06 performed consistently well in terms of both cane and sugar yields in all environments and were identified as general adaptable varieties with high cane and sugar yields. The commercial variety Co 775 was proven to be a generally adaptable genotype with average cane and sugar yields. The commercial varieties SL 88 116, SL 89 1673 and SL 92 4918 were identified as generally adaptable genotypes for cane and sugar yields with higher response in irrigated environments. The genotype SL 71 30 was identified as a specifically adaptable variety to rain-fed environments with respect to cane and sugar yields.

Keywords: Adaptability, AMMI models, Biplot, Genotype – Environment Interaction, Sri Lanka, Sugarcane

INTRODUCTION

Sugarcane cultivation in Sri Lanka is mainly confined to five agro-ecological zones, *viz.* dry zone low country 1 and 2 (DL_1 and DL_2), intermediate zone low country 1 and 2 (IL_1 and IL_2) and intermediate zone mid country 2 (IM_2) in the southern and eastern parts of the island. In the intermediate zone, sugarcane is cultivated predominantly under rain- fed conditions while in the dry zone both irrigated and rain-fed farming are practised (Mettananda, 1990).

Selection of sugarcane varieties that are giving consistently high cane and sugar yields for growing in those different agro-ecological zones has therefore, become a necessity in improving the country's overall sugarcane and sugar production by achieving the maximum productivity determined by the varieties in particular environments. Achieving the maximum possible productivity in each of the location by growing the most suitable sugarcane variety/varieties utilises the resources at the particular environment most effectively and efficiently, and it helps Sri Lanka to move towards a greener cane sugar industry.

The importance of testing the yield of crop genotypes over a wide range of environments has long been recognised by breeders and agronomists (Sharma and Bharaj, 1983; Sudhama Mohan and Rao, 1983; Kang and

Miller, 1984) as varietal ranking determined by the yield differs greatly across environments. This differential genotypic response to environments is caused by genotype-environment interaction (GEI), and the presence of GEI is a major concern to the sugarcane breeders, since large interactions reduce the gains from clonal selection and complicate identification of superior genotypes (Rea and Vieira, 2002). Therefore, measuring GEI is of vital importance in the determination of genotypes with adaptation to the target environments (Romagosa *et al.*, 1993; Delacy *et al.*, 1990; Annicchiriarico, 1997).

Sing and Khan (1997) selected sugarcane genotypes for different environments in India using the methods proposed by Eberhart and Russell (1966) and Yau and Hamblin (1994). Additive main effects and multiplicative interaction (AMMI) models had been successfully applied in sugarcane for GEI analysis in India and Mauritius with respect to cane and sugar yields in varietal stability and adaptability testing (Srivastava *et al.*, 1999; Bissessur *et al.*, 2001). In Sri Lanka, Basnayake (1988) conducted a sugarcane varietal adaptability experiment under irrigated conditions using six genotypes in six environments. His inferences on varietal stability and adaptability cannot be applied at present since there are 17 commercial sugarcane varieties grown in Sri Lanka under irrigated and rain-fed conditions in five agro-ecological zones. Moreover, there are many promising varieties which have been developed through breeding and selection and imported from other countries and collected by local germplasm expeditions for testing their suitability for growing in those diverse environments.

Frip and Caten (1971) pointed out that inclusion of a fairly large number of genotypes and sufficient number of sites representing diverse environments in an adaptability study facilitates obtaining accurate data for subsequent stability analysis. Therefore, testing of a fairly large number of genotypes at sites representing most of sugarcane-growing conditions in Sri Lanka was identified by the Sugarcane Research Institute as an important prerequisite for the development of varieties for commercial cultivation. This paper concerns with the assessment of genotype-environment interactions and adaptability of 40 sugarcane genotypes across five major sugarcane growing environments in Sri Lanka using AMMI model.

MATERIALS AND METHODS

Varieties, locations and experiments

Fourty sugarcane varieties selected for this experiment (Table 1) represented 15 locally-bred, 06 locally-collected and 19 imported varieties. The variety Co 775 was considered as the standard genotype. These fourty varieties were evaluated for their yield performance based on plant crop data collected from five adaptability trials conducted, separately at Uda Walawe, Sevanagala, Pelwatte, and Siyambalanduwa (Table 2). All these field experiments were conducted in the agro-climatic zone DL1. The trials were laid out using the Randomised Complete Block Design (RCBD) at each site. The experimental plots consisted of 10m-long five rows spaced at 1.37m. These field experiments were maintained by using standard management practices. Cane weight of three middle rows in the plots were used to estimate cane yield. Randomly-selected twelve millable stalks from middle three rows were used to estimate Pure Obtainable Cane Sugar (POCS). Sugar yields were estimated by using POCS and cane yield.

Analysis of data

Combined analyses of variance for cane yields, POCS and sugar yields of 40 sugarcane genotypes tested across five environments were performed using AMMI models. AMMI models used ANOVA approach to study

Table 1 The sugarcane varieties tested in locational experiments

No.	Genotype	Country of origin	No.	Genotype	Country of origin
Imported Genotypes			**Locally-bred Genotypes**		
1	AKOKI 22	Indonesia	20	SL 71 03	Sri Lanka
2	CP 72 1210	U.S.A.(Canal point)	21	SL 71 30	Sri Lanka
3	H 44 2772	U.S.A. (Hawaii)	22	SL 83 06	Sri Lanka
4	H 44 3098	U.S.A. (Hawaii)	23	SL 86 13	Sri Lanka
5	H 59 3775	U.S.A. (Hawaii)	24	SL 88 116	Sri Lanka
6	H 68 1158	U.S.A. (Hawaii)	25	SLT 88 238	Sri Lanka
7	H 70 0144	U.S.A. (Hawaii)	26	SL 89 111	Sri Lanka
8	H 78 1207	U.S.A. (Hawaii)	27	SL 89 1362	Sri Lanka
9	H 79 3949	U.S.A. (Hawaii)	28	SL 89 1429	Sri Lanka
10	HINAHINA	Indonesia	29	SL89 1673	Sri Lanka
11	M 438 59	Mauritius	30	SL 89 2227	Sri Lanka
12	ONO	Fiji	31	SL 89 309	Sri Lanka
13	PH 86 144	Philippine	32	SL 91 4295	Sri Lanka
14	PS 42	Indonesia	33	SL 92 4918	Sri Lanka
15	PS 52	Indonesia	34	SL 92 5588	Sri Lanka
16	PS 57	Indonesia	**Locally-collected Genotypes**		
17	ROC 09	Republic of China	35	SLC 92 24	
18	Co 775	India	36	SLC 92 27	
19	SLI 121	Taiwan	37	SLC 92 28	
			38	SLC 92 37	
			39	SLC 92 90	
			40	SLC 92 91	

Table 2 Locations and the growing conditions of the field experiments.

Location	Latitude and Longitude	Growing condition
Pelwatte (PERF)	6.4 N, 80.94 E	rain-fed
Sevanagala (SEIR)	6.36 N, 80.93 E	irrigated
Siyambalanduwa (SIRF)	6.9 N, 81.55 E	rain-fed
Uda Walawe (UDIR)	6.21 N, 80.48 E	irrigated
Uda Walawe (UDRF)	6.21 N, 80.48 E	rain-fed

main effects of genotypes and environments and a principal component analysis (PCA) for the residual multiplicative interaction between genotypes and environments. The resulting interaction PCA scores (IPCA) for genotypes and environments were used to construct the AMMI biplots using the following linear model (Gauch 1992):

$$Y_{ikr} = \mu + \tau i + \beta_k + \alpha_{r(\beta)} + \Sigma_n \tau_n \Gamma_{in} \delta_{kn} + \sigma_{ik} + \varepsilon_{ikr} \quad \ldots\ldots(1)$$

Where, Y_{ikr} is the trait value of the i^{th} genotype in the r^{th} replicate of k^{th} environment , μ is the grand mean, τ_i is the genotype deviation (i.e., genotype mean - grand mean), β_k is the environmental deviation, $\alpha_{r(\beta)}$ is replicate effect, τ_n is the singular value for PCA axis, Γ_{in} and δ_{kn}, are the genotype and environment eigen vectors for axis n and σ_{ik} is the residual in the AMMI model when all the PCA axes are not used.

The number of PCA axes to be retained in the model was judged based on the significance of those PCA axes determined by F-test (Gauch 1988, 1992). The ε_{ikr} was the error term or random variation. The eigen vectors were scaled as the unit vectors (i.e. $\Sigma_i\Gamma_i^2 = \Sigma_i\Gamma_k^2 = 1$). AMMI performed principal component analyses (PCA) for each genotype x environment matrix of the characters that were analysed (i.e., cane and sugar yields). The PCA of AMMI partitioned GEI into several orthogonal axes called interaction PCA axes (IPCA). IPCAs were ordered as IPCA1> IPCA2>,...> IPCAn, where the relative contribution of the first IPCA was greater than IPCA 2, etc. AMMI models were named as AMMI1, AMMI2....and AMMIn depending on the number of IPCA axes (n) used in the model. AMMI1 with IPCA 1 and AMMI 2 with IPCA 1 & IPCA 2 were used in this study for the interpretations.

AMMI 1 biplots were generated by plotting IPCA 1 scores of the environments and genotypes against main effects (i.e., cane and sugar yields). The genotypes with high or average yield and IPCA 1 value close to zero showed general adaptation to the tested environments. A large genotypic IPCA 1 score reflects more specific adaptation to environments with IPCA 1 score of the same sign.

AMMI 2 biplots were derived by plotting the genotypes and environment scores of the first two multiplicative terms ($IPCA_1$ and $IPCA_2$). The AMMI biplots produced in this manner were used to display the variability of genotypes and GEI, i.e. the selection of high-yielding, widely-adapted genotypes suited for growing in all environments.

RESULTS AND DISCUSSION

Variation of cane yield

The results of the combined analyses of variance (ANOVA) for cane yield of the 40 sugarcane genotypes evaluated across five environments are presented in Table 3a. It indicated highly significant differences ($P < 0.01$) in genotypes, environments and genotypes-environment interaction for all the variables. When the GEI was further partitioned to the IPCA axes, the F-tests showed significant difference ($P < 0.05$) for the first two IPCA axes and were not showed significant differences ($P < 0.05$) for the third and fourth IPCA (Table 3a). The first and second IPCA axes explained 38% and 34% variability of the total GEI variation, respectively and the cumulative effects of IPCA 1 and IPCA 2 axes explained 72% variation of GEI.

Variation of POCS

The ANOVA indicated highly significant effects ($P < 0.001$) of genotypes, environments, and GEI with regard to POCS. The F-tests indicated significant differences ($P < 0.05$) between the first two IPCA axes (Table 3b). The first and the second IPCA axes explained

Table 3a The results of the combined analysis of variation of cane yield

Source	Df	SS	MS		% of GEI explained
Genotypes	39	67386.69	1727.86	***	
Environments (Env)	4	118212.04	29553.01	***	
Genotypes x Env (GEI)	156	57111.30	366.10	***	
IPCA 1	42	21477.64	511.37	*	38
IPCA 2	40	19659.56	491.49	*	34
Residual	74	15974.08	431.47		
Pooled error	570	82296.46	144.38		

* and *** denotes significant differences at probabilities 0.05 and 0.001, respectively.

Table 3b The results of the combined analysis of variation of POCS

Source	df	SS	MS		% of GEI explained
Genotypes	39	1599.696	41.02	***	
Environments (Env)	4	946.408	236.60	***	
Genotypes* Env (GEI)	156	768.1	4.92	***	
IPCA 1	42	326.055	7.76	**	42
IPCA 2	40	212.136	5.30	*	28
Residual	36	229.90	3.10		
Pooled error	570	1176.28	2.06		

*, **, *** denotes significant differences at probabilities 0.05, 0.01 and 0.001, respectively.

42% and 28% of variability of total GEI variation, respectively. Therefore, the cumulative effects of IPCA 1 and IPCA 2 axes explained 80% variation in GEI.

Variation of sugar yields

None of the IPCA axes for sugar yield of the varieties tested were significantly different at P < 0.05 level (Table 3c).

The first and the second IPCA axes explained 33 % and 28 % variation of sugar yield out of the total GEI variation, respectively. IPCA 1 and IPCA 2 together explained 61 % variation of GEI though they were not significantly different.

Evaluation of varietal adaptability

Cane yield

Figure 1 shows the biplot of IPCA 1 against mean cane yield. It showed that the variety SL 89 2227 was the most productive and stable genotype followed by H 44 3098, SLC 92 91, SL 83 06, SLT 88 238, SLC 92 28, and SLC 92 27. The varieties SL 92 4918, SL 89 1673, PS 57, SL 88 116 and Co 775 have shown stability with medium level of productivity. The biplot indicated the varieties SLC 92 90, SL 71 30 and SL 89 111 were least stable with moderate yields. The variety H 68 1158 was a stable genotype with low productivity. Among the locally-collected varieties, five out of six, namely, SLC 92 24, SLC 92 27, SLC 92 28, SLC 92 37 and SLC 92 91 showed significantly higher mean cane yields than the standard Co 775.

The best environment for growing the tested varieties was Sevanagala under irrigation (SEIR) and it was followed by Uda Walawe under irrigation (UDIR). These two irrigated environments showed less interaction with genotypes when compared to rain-fed environments, i.e., Pelwatte - rain-fed (PERF) and Siyambaladuwa - rain-fed (SIRF). The environment SIRF showed very high GEI followed by PERF. It was observed that the genotypes grown in these two environments were subjected to severe drought during the

Table 3c The results of the combined analyses of variation of sugar yield

Source	df	SS	MS		% of GEI explained
Genotypes	39	1163.068	29.82	***	
Environments (Env)	4	2238.896	559.72	***	
Genotypes* Env (GEI)	156	821.74	5.76	***	
IPCA 1	42	267.0276	6.3578		33
IPCA 2	40	226.35	5.65875		28
Residual	74	328.36	4.43		
Pooled error	570	1509.15	2.6476376		

*** denotes significance at 0.001 probability level.

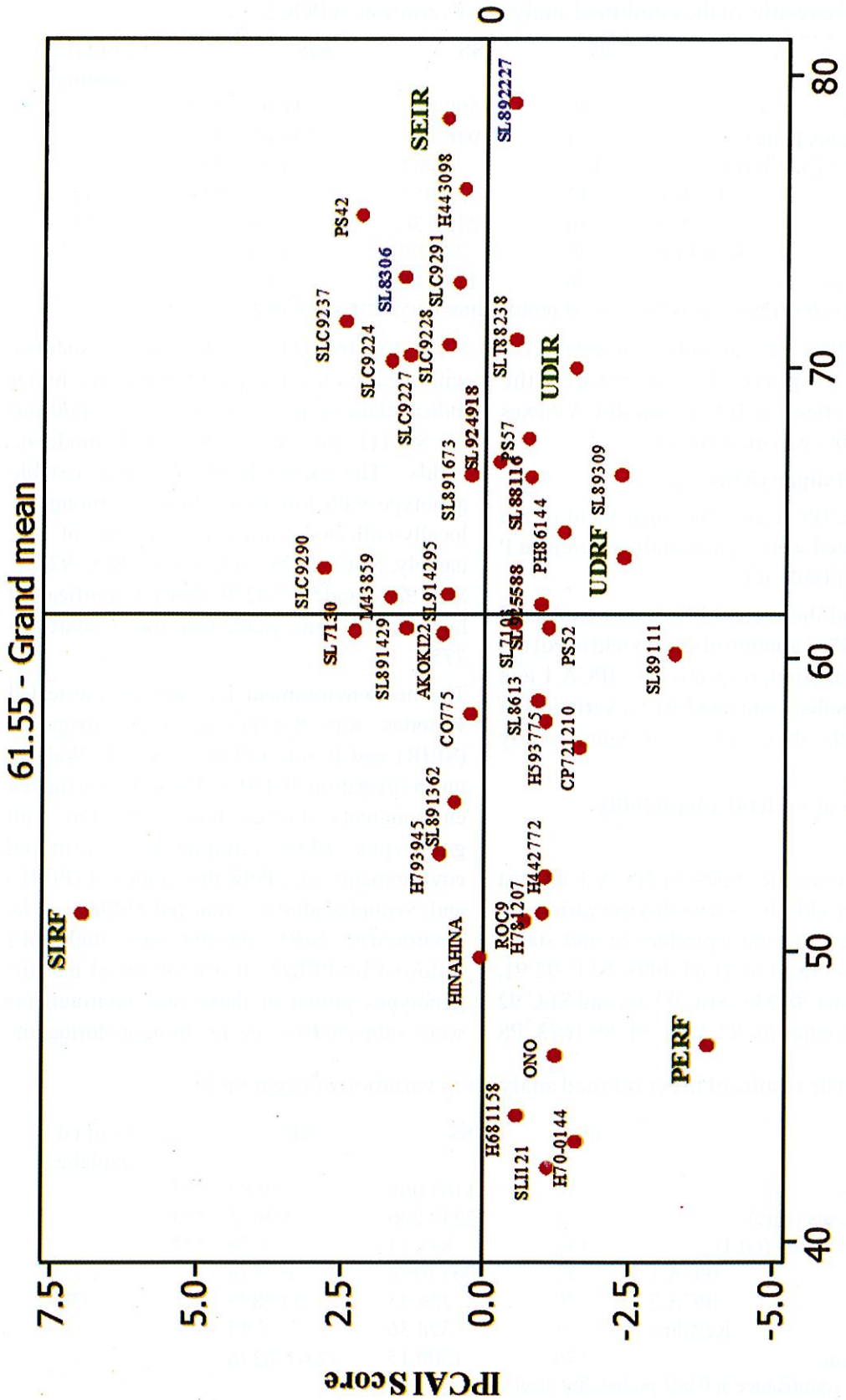

Figure 1 IPCA 1 scores for genotypes and environments plotted against the mean cane yield

grand growth stage (5-9 months of age). AMMI 2 biplot generated using the first two IPCA scores of cane yields of the 40 genotypes in 5 environments are shown in Figure 2. The biplot showed a clear association between genotypes and environments. According to these results, the rain-fed environments PERF and SIRF were the most discriminating environments for the varieties as indicated by longest distance between its markers and the origin. UDIR and UDRF environments showed similar interactions. The trial conduced at Uda Walawe under rain-fed (UDRF) conditions received adequate rainfall during the critical growth stages of the crop (tillering and grand growth stage). This might cause the similarity in behavior of these two environments. The irrigated environment at Sevanagala (SEIR) was more discriminating for the varieties than the Uda Walawe – irrigated (UDIR) environment.

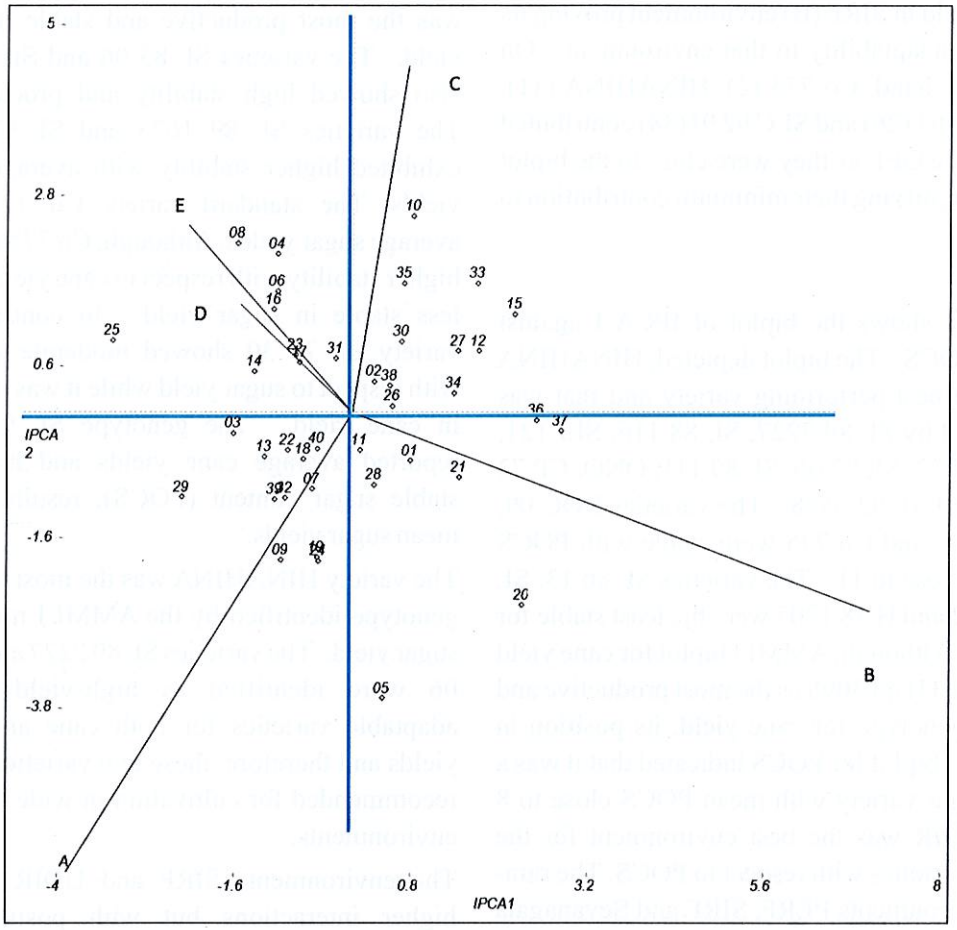

Figure 2 AMMI 2 interaction biplot of 40 genotypes over five environments for cane yield. Model fit = 72% of GEI SS. The angles and the projection of vectors indicate the association among environments. A= PERF B= SIRF C= SEIR D= UDIR E=UDRF

Legends for varieties are as follows;

1	AKOKI22	9	H781207	17	PS57	25	SL89 111	33	SLC9224
2	Co 775	10	H793945	18	ROC9	26	SL891362	34	SLC9227
3	CP721210	11	HINAHINA	19	SL7103	27	SL891429	35	SLC9228
4	H442772	12	M43859	20	SL7130	28	SL 89 1673	36	SLC9237
5	H443098	13	ONO	21	SL8306	29	SL89309	37	SLC9290
6	H593775	14	PH86144	22	SL8613	30	SL914295	38	SLC9291
7	H681158	15	PS42	23	SL88116	31	SL924918	39	SLI121
8	H 70 0144	16	PS52	24	SL 89 2227	32	SL925588	40	SLT88238

The genotypes that are further away from the biplot origin contributed more to the GEI. They were H 79 3945(10), SLC 92 24 (33), SL 7130 (20), H 44 3098 (5), SL 89 309 (29), SL 89 111 (25), H 44 2772 (4) and H 70 144(8). Such genotypes with high IPCA scores had an ability to react positively with the environments with similar IPCA scores (specific adaptability). Accordingly, genotype SL 7130 (20) showed similar interactions with SIRF environment.

The variety SL 7130 (20) reported the highest mean yield in SIRF (B) environment proving its specific adaptability to that environment. On the other hand, Co 775 (2), HINAHINA (11), SL 89 1362 (26) and SLC 92 91(38) contributed less to the GEI. as they were close to the biplot origin signifying their minimum contribution to GEI.

POCS

Figure 3 shows the biplot of IPCA I against mean POCS. The biplot depicted, HINAHINA was the best-performing variety and that was followed by SL 89 2227, SL 88 116, SLI 121, AKOKI 22, SL 83 06, SL 89 111, ONO, CP 72 1210 and SL 92 5588. The varieties ROC 09, SL 71 03 and Co 775 were stable with POCS values close to 11. The varieties SL 86 13, SL 89 1362 and H 78 1207 were the least stable for POCS. Although, AMMI I biplot for cane yield identified H 44 3098 as the most productive and stable genotype for cane yield, its position in AMMI I biplot for POCS indicated that it was a low-sugar variety with mean POCS close to 8 %. UDIR was the best environment for the tested varieties with respect to POCS. The rain-fed environments PERF, SIRF and Sevanagala – irrigated environment (SEIR) are with similar IPCA 1 scores while UDRF is with the highest IPCA 1 scores.

AMMI 2 biplots generated using the first two IPCA scores of POCS are shown in Figure 4. The varieties that are further away from the biplot origin contributed more to GEI. These varieties were H 68 1158 (7), H 78 1207(9), H 59 3775 (6), PS 52 (16), SL 86 13 (22), SL 89 1362 (27) and they showed highest contribution to GEI. The genotype SL 92 4918 contributed less to GEI as it was close to the biplot origin signifying its minimum contribution to GEI.

Sugar yield

Figure 5 illustrates the IPCA 1 scores for genotypes and environments plotted against the mean sugar yield for varieties and environments, respectively. AMMI1 biplot (Figure 5) shows that the variety SL 89 2227 was the most productive and stable in sugar yield. The varieties SL 83 06 and SL 88 116 also showed high stability and productivity. The varieties SL 89 1673 and SL 92 4918 exhibited higher stability with average sugar yields. The standard variety Co 775 gave average sugar yields. Although, Co 775 showed higher stability with respect to cane yield, it was less stable in sugar yield. In contrast, the variety SL 71 30 showed moderate stability with respect to sugar yield while it was unstable in cane yield. The genotype SL 92 5588 reported average cane yields and high and stable sugar content (POCS), resulting high mean sugar yields.

The variety HINAHINA was the most unstable genotype identified by the AMMI I model for sugar yield. The varieties SL 89 2227 and SL 83 06 were identified as high-yielding and adaptable varieties for both cane and sugar yields and therefore, these two varieties can be recommended for cultivation in wide range of environments.

The environments SIRF and UDIR showed higher interactions but with positive and negative signs of IPCA scores, respectively. The environment PERF showed almost zero IPCA scores with respect to sugar yields. Unlike for cane yield, the interactions reported by environments appeared to have no relationship with rainfall or irrigation. This may be due to non-significant IPCA 1 axis for sugar yields compared to cane yields.

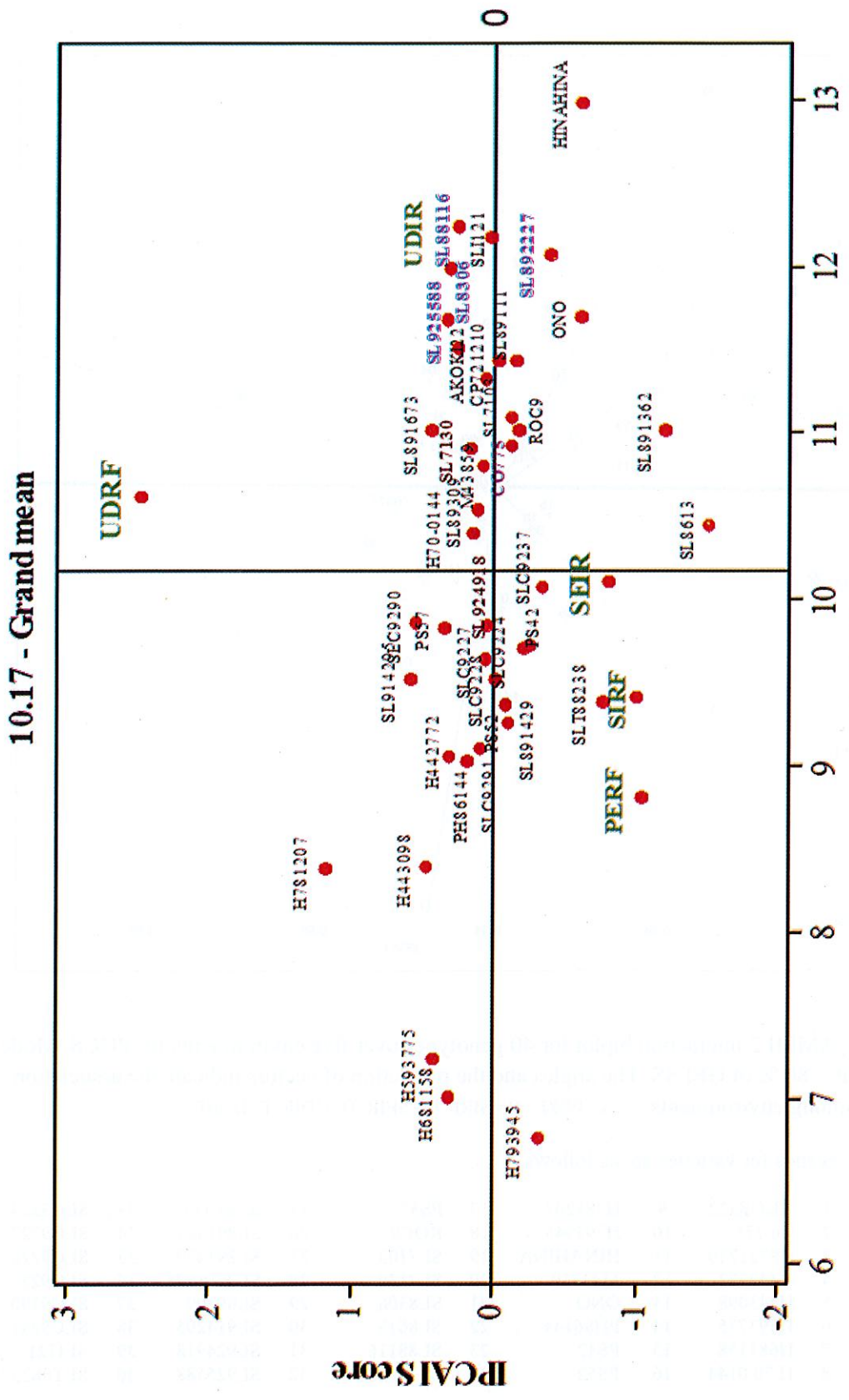

Figure 3 IPCA 1 scores for genotypes and environments plotted against POCS

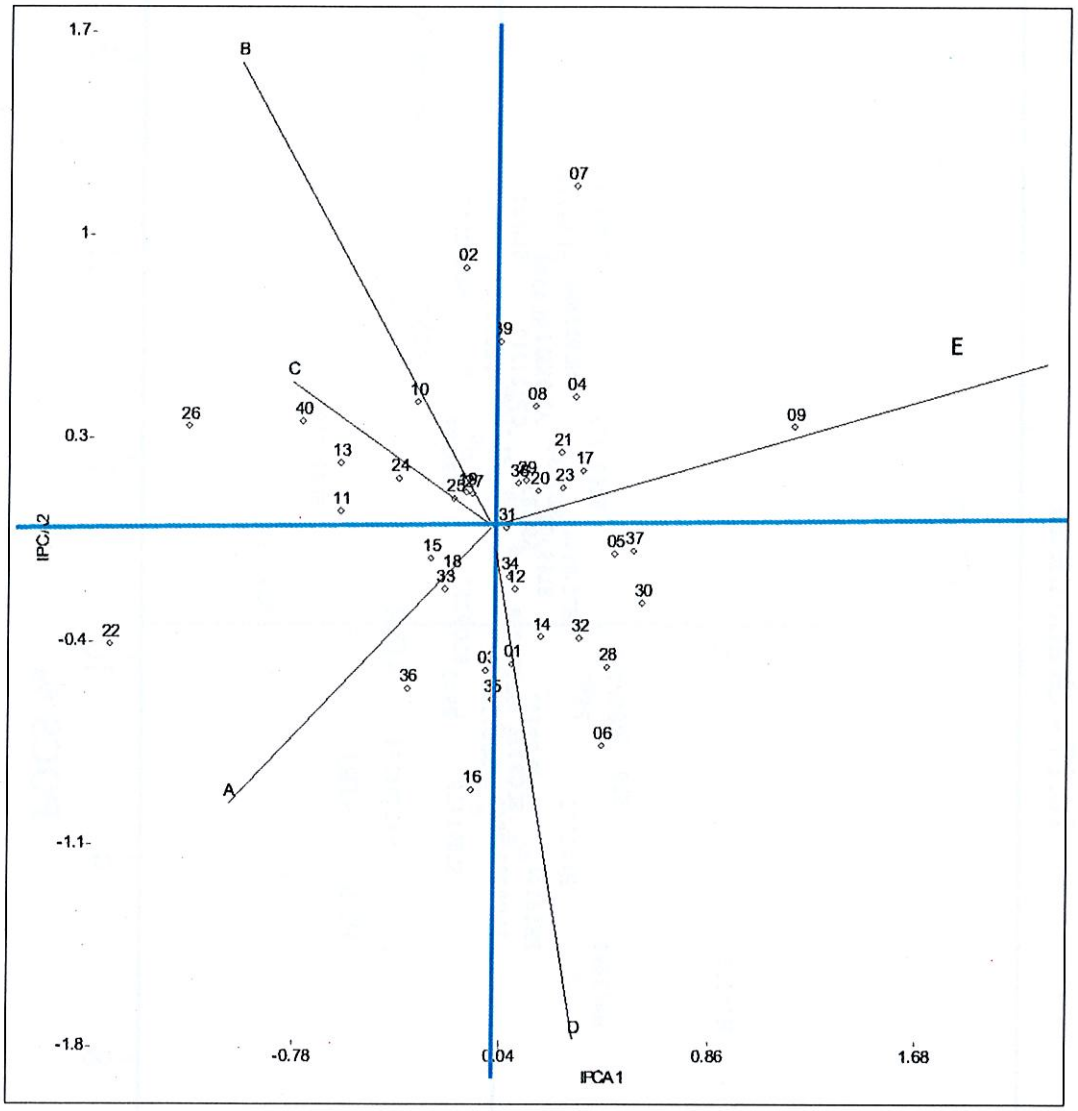

Figure 4 AMMI 2 interaction biplot for 40 genotypes over five environments for POCS. Model fit = 80 % of GEI SS. The angles and the projection of vectors indicate the association among environments. . A= PERF B= SIRF C= SEIR D=UDIR E=UDRF

Legends for varieties are as follows;

1	AKOKI22	9	H781207	17	PS57	25	SL89 111	33	SLC9224
2	Co 775	10	H793945	18	ROC9	26	SL891362	34	SLC9227
3	CP721210	11	HINAHINA	19	SL7103	27	SL891429	35	SLC9228
4	H442772	12	M43859	20	SL7130	28	SL 89 1673	36	SLC9237
5	H443098	13	ONO	21	SL8306	29	SL89309	37	SLC9290
6	H593775	14	PH86144	22	SL8613	30	SL914295	38	SLC9291
7	H681158	15	PS42	23	SL88116	31	SL924918	39	SLI121
8	H 70 0144	16	PS52	24	SL 89 2227	32	SL925588	40	SLT88238

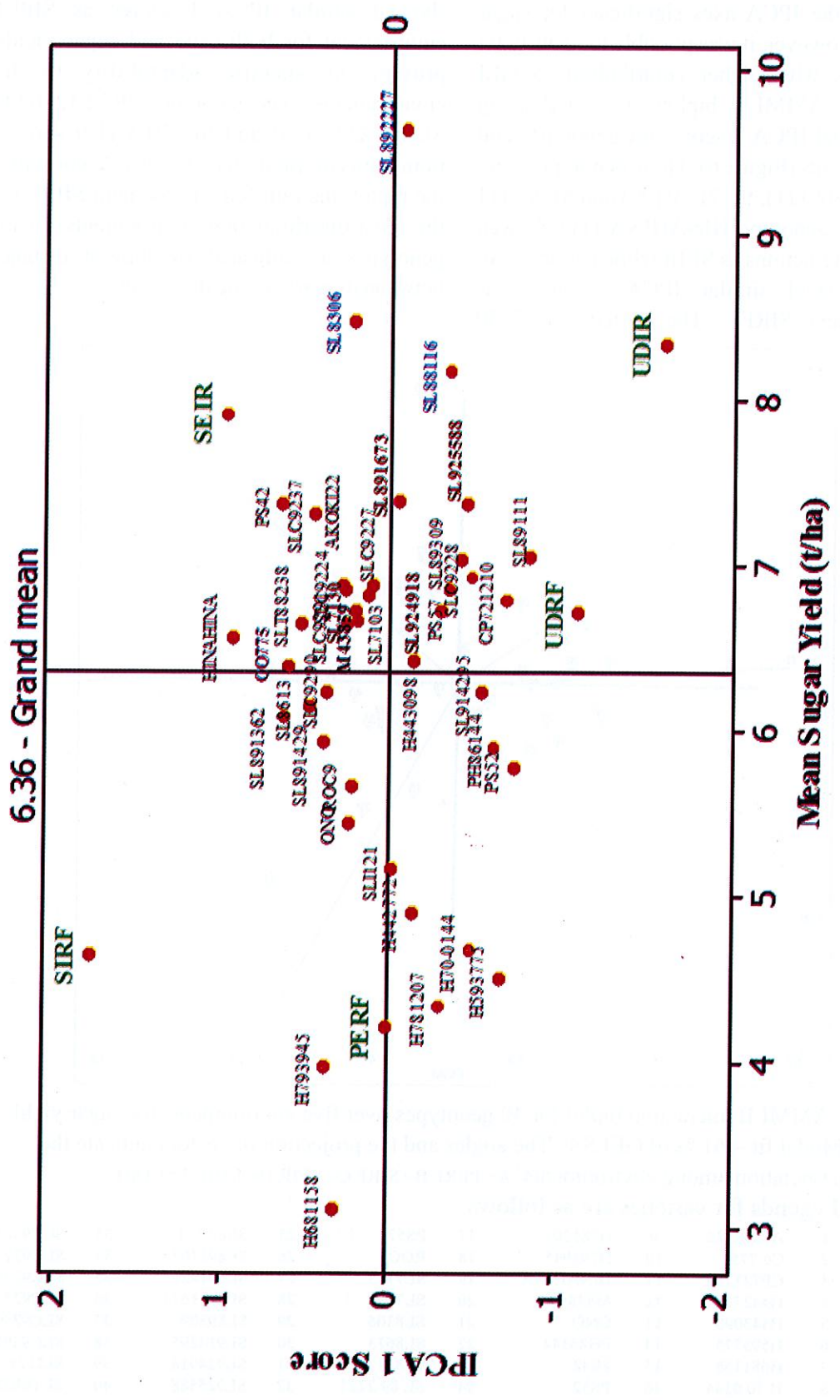

Figure 5 IPCA 1 scores for genotypes and environments plotted against the mean sugar yield for genotypes and environments, respectively

None of the IPCA axes significant for sugar yields. However, it was possible to identify 03 genotypes with higher contribution to GEI using the AMMI 2 biplots generated using IPCA 1 and IPCA 2 scores for genotypes and environments (Figure 6). These genotypes were HINAHINA (11), SL 71 30 (20) and SL 89 111 (25). The genotype HINAHINA (11) showed similar interactions as SEIR while genotype SL 7130 showed similar IPCA 2 scores as environment SIRF. The variety SL 7130 showed similar IPCA 1 scores as SIPRF environment for both cane and sugar yields, proving its specific adaptability to dry environments. The genotypes CP 72 1220 (4), SL 89 2227 (24) and SL 7103 (19) showed minimum contribution to the GEI. According to the biplot, the rain-fed environment SIRF was the most discriminating environments for the genotypes as indicated by longest distance between its markers and the origin.

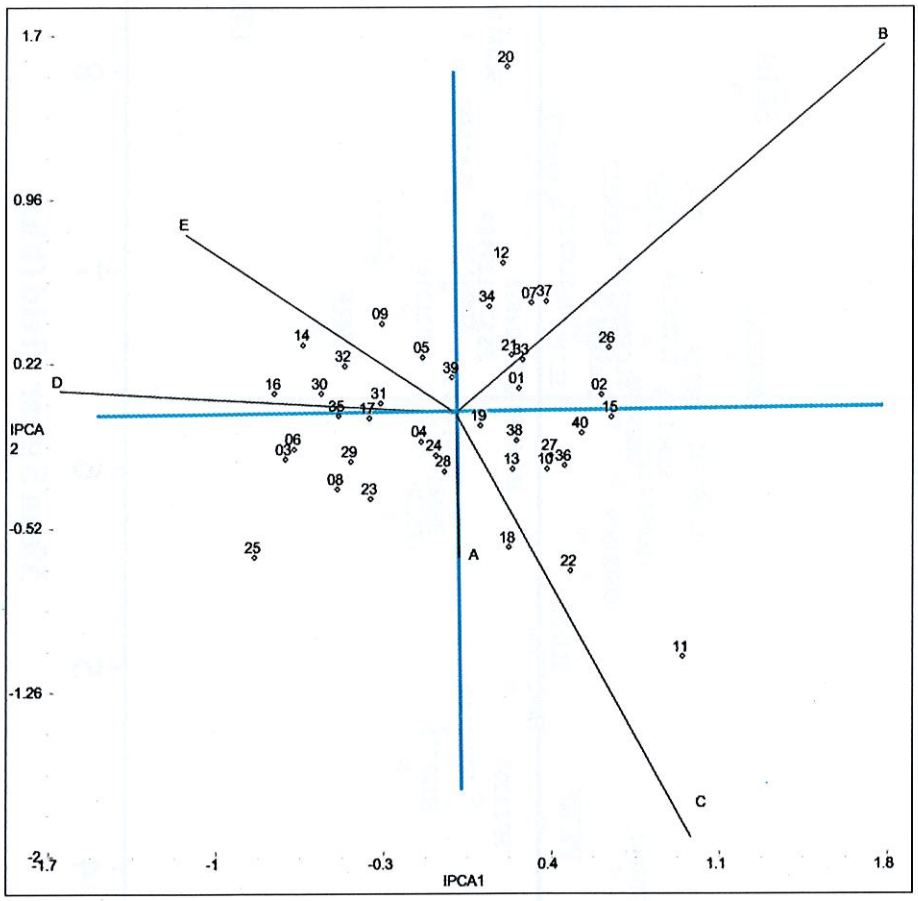

Figure 6 AMMI II interaction biplot for 40 genotypes over five environments for sugar yield. Model fit = 61 % of GEI SS. The angles and the projection of vectors indicate the association among environments. A= PERF B= SIRF C= SEIR D= UDIR E=UDRF

Legends for varieties are as follows;

1	AKOKI22	9	H781207	17	PS57	25	SL89 111	33	SLC9224
2	Co 775	10	H793945	18	ROC9	26	SL891362	34	SLC9227
3	CP721210	11	HINAHINA	19	SL7103	27	SL891429	35	SLC9228
4	H442772	12	M43859	20	SL7130	28	SL 89 1673	36	SLC9237
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6	H593775	14	PH86144	22	SL8613	30	SL914295	38	SLC9291
7	H681158	15	PS42	23	SL88116	31	SL924918	39	SLI121
8	H 70 0144	16	PS52	24	SL 89 2227	32	SL925588	40	SLT88238

Conclusions

The variety Co 775 which is the widely-grown commercial variety in Sevanagala, was identified as the variety with average yields and wide adaptability. Therefore, this variety can be recommended for growing in all the environments. However, average yields are expected from Co 775. The genotypes SL 83 06 and SL 89 2227 were identified as the best high- yielding genotypes with general adaptability for both cane and sugar yields and can be recommended for growing in all the environments expecting high yields. Commercial genotypes SL 88 116, SL 89 1673 and SL 92 4918 were identified as generally adaptable genotypes for cane and sugar yields with high response to irrigated environments, and therefore, they can be recommended for growing under irrigation expecting very high yields. The variety SL 92 5588 was found to be a genotype with average cane yield and with high sugar yields since this variety has shown high and stable sugar content (POCS) and can be recommended for all environments expecting high sugar yields. Genotype SL 71 30 was identified as specifically adaptable genotype to rain-fed environments and is recommended for cultivation in all environments under rain-fed conditions.

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Optimising Planting Schedules of Sugarcane for Saving Irrigation Water in Sevanagala and Uda Walawe, Sri Lanka

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ABSTRACT

An analysis was carried to determine the most appropriate planting time in terms of minimum use of irrigation water for sugarcane cultivation at Sevanagala and Uda Walawe. Agro-meteorological data collected from 1984 to 2012 were used for this analysis. Monthly effective rainfall, crop water requirement, irrigation requirements and rainfall usage by the crop were assessed. The annual average rainfall at Sevanagala and Uda Walawe from 1984 to 2012 was1453 mm and 1532 mm respectively. The respective effective rainfall levels were 896 mm and 960 mm. The estimated annual average crop water requirement of sugarcane at Sevanagala and Uda Walawe were1421mm and 1397 mm respectively. With the change of planting date from January to December, it varied from 1385 mm to 1455 mm at Sevanagala and from 1352 mm to 1441 mm at Uda Walawe. The study revealed that when the crop was planted 10thJanuary to coincide with the first rainy season of the year, the total estimated annual irrigation water requirement in both locations was at minimum; 685 mm for Uda Walawe and 700 mm for Sevanagala. Similarly, when the crop was planted on 30th June, the grand growth period of sugarcane plant coincided with the second rainy season, and hence, the total estimated annual irrigation water requirement was at minimum in both locations; 619 mm for Uda Walawe and 649 mm for Sevanagala. Thusplanting sugarcane on 10thJanuary and 30thJune makes possible minimising the utilisation of limited available irrigation water by maximising the usage of rainfall at Sevanagala and Uda Walawe.

Keywords: Crop water requirement, Effective rainfall, Evapo-transpiration, Irrigation, Sri Lanka, Sugarcane

INTRODUCTION

Commercial cultivation of sugarcane in Sri Lanka is carried out in dry and intermediate zones where annual rainfall varies from 1500 mm to 1700 mm and 1750 mm to 2500 mm respectively with a bimodal pattern which has two rainy periods (Shanmugnathan, 1990). The first rainy period starts with the first inter-monsoonal rainfall from mid of March and continues till May. The second rainy season starts with the onset of second inter-monsoon and ends with the north-east monsoon from mid September to January. With this rainfall pattern, supplementary irrigation is required during dry months when crop water requirement cannot be supplied with rainfall for optimum growth (Shanmugnathan, 1990, Aloysius & Zubair, 1999). Rain fed-cultivation of sugarcane normally produces a low yield, and is about half of irrigated yield at Uda Walawe (De Silva, 2011). Even though Sevanagala (irrigated sector) and Uda Walawe sugarcane plantations are managed with irrigation supply at a rate of 151,000 m^3/day from Uda Walawe reservoir (Maaike, 2002), the frequency of water cut-offperiods have shown an increasing trend in the recent past. This leads to reduce not only potential yields of sugarcane but also total extent of irrigable land. Thus, adoption of irrigation water-saving practices has become important to increase cane yield as well as cropped area.

In general, net irrigation water requirement of a crop (In) is determined by effective rainfall (Pe) and crop evapo-transpiration (ETc) in a particular month. The length of a normal crop cycle of sugarcane under irrigation in tropical area is about 12 months (Wyseure, *et.al*, 1992) and crop water requirement (CWR) is 1200-1500 mm (Glyn,2004) per annum. The CWR depends on the local climatic conditions and the variety (FAO, 2002). Crop coefficients used to estimate crop evapo-transpiration varies from 0.4 to 1.25 (FAO, 1984), and accordingly the crop water requirement of different growth stages also vary. By planting sugarcane to coincide the growth stage where the crop water requirement is high and manipulation of other agronomic practices, the available rain water could be maximally utilised. This makes possible reduction of demand for irrigation. Commercial planting under irrigation can be carried out year around, and hence, planting date can easily be shifted to minimise the irrigation demand. The reduction of irrigation water use enhances the productivity of water, and hence, the sustainability of sugarcane farming under irrigation. This study was carried out to find out the best sugarcane planting dates in the two rainy periods aiming at minimising the irrigation water demand of sugarcane crop at Sevanagala and Uda Walawe.

MATERIALS AND METHODS

The maximum and minimum temperatures, relative humidity, wind velocity, bright sunshine hours and rainfall during the last 29 years from 1984 to 2012 collected at weather stations in Lanka Sugar Company Limited, Sevanagala (6°23'47"N, 80°54'45"E) and Sugarcane Research Institute, Uda Walawe (6°24',32"N; 80°50',23"E) were used for this analysis. These two agro- meteorological stations are located at a distance of 8.14km. The Uda Walawe and Sevanagala sugarcane lands are located in DL_{1a} and DL_{1b} agro-ecological zones, respectively.

Crop water requirement (CWR), which is equal to crop evapo-transpiration was estimated by multiplying reference evapo-tratspiration (ET_o) values with crop factor (Joss, 2009). The reference evapo-transpiration values were estimated based on agro-climatic data in Sevanagala and Uda Walawe using the Modified Penman method (FAO, 1984).

The reference evapo-transpiration (ET_0) was estimated with the following equation (Equation 1) (FAO, 1984) using CROPWAT software v 8.

$$\mathbf{ET_0 = C\ [W.Rn + (1-w).\ f\ (U).\ (ea - ed)]} \qquad \text{Equation 1}$$

where, Rn = net radiation in equivalent evaporation expressed as mm/day, W=temperature of altitude related factor, f(U) = wind-related function, ea–ed= vapour pressure deficit (m. bar), C=the adjustment factor (ratio of U day to U night), Rn (0.75-Rns), ea=Saturated vapour pressure (mb), ed=mean actual vapour pressure of the air (mb).

The crop evapo-transpiration of sugarcane crop was estimated by equation (2) shown below (FAO, 1984):

$$\mathbf{ET_c = K_c * ET_o} \qquad \text{Equation 2}$$

where, ET_c – evapo-transpiration, Kc – crop coefficient depending on the crop growth stage, ET_0 reference evapo-transpiration .

The irrigation requirement was determined by field water balance approach (Equation 3). Field water balance (soil moisture deficit or surplus) was calculated for 10-day intervals by subtracting effective rainfall (Pe) from crop-evapo-transpiration (ET_C), assuming evapo-transpiration is the only way of removing water from the root zone soil and no capillary rise takes place from groundwater table. It was assumed that deep percolation loss is zero, since the root–zone depth of sugarcane is considered as 90 cm. The irrigation depth was calculated at 50% moisture depletion level.

$$\mathbf{In = ETc - (Pe + Ge + Wb)} \qquad \text{Equation 3}$$

where, In-net irrigation requirement, ETc – crop evapo-transpiration, Pe- effective rainfall, Ge- ground water contribution, Wb- soil moisture level before irrigation.

The effective rainfall (Pe) in Sevanagala and Uda Walawe was determined according to the FAO/AGLW formula (FAO, 1984).

Field water balance analysis showed excess rainfall in some months and deficits in others. Even though excess water is available, plants consume only the fraction equal to crop evapo transpiration. Accordingly, the amount of rainfall that could be utilised by the crop ($RF_{utilise}$) can be calculated as follows:

If, effective rainfall (Pe) ⩽ Crop evapo-transpiration (ET_{Crop}) then,

$\mathbf{RF_{utilise} = Pe}$

Else,

$\mathbf{RF_{utilise} = ET_{Crop}}$

RESULTS AND DISCUSSION

Rainfall and effective rainfall

Sevanagala and Uda Walawe areas received an annual average rainfall of 1452.7 mm and 1531.6 mm respectively with a unique bimodal pattern of distribution in *Yala* (March to May) and in *Maha* seasons from September to January (Figure 1).

The estimated monthly effective rainfall (*Pe*) for sugarcane crop of Sevanagala and Uda Walawe were 896.2 mm and 959.7 mm respectively (Table 01).

Variations of crop evapo-transpiration and irrigation requirements

The estimated crop evapo-transpiration (ET_c), irrigation requirement (In) and rainfall utilised by the crop ($RF_{utilise}$) varied with the change of planting date (Table 2). Further, variation of irrigation water requirement (In) showed a bimodal pattern (Figure 02) as the pattern of rainfall distribution.

According to the results, the estimated annual crop water requirement varied from 1384.6 mm to1454.8 mm and from 1352.3 mm to 1441.1 mm in Sevanagala and Uda Walawe respectively. The annual average values were 1420.5 mm and 1396.5 mm for Sevanagala and Uda Walawe respectively (Table 2). Moreover, as monthly effective rainfall varied (Table 1), the irrigation water requirement also varied (Figure 2).The analysis showed that planting

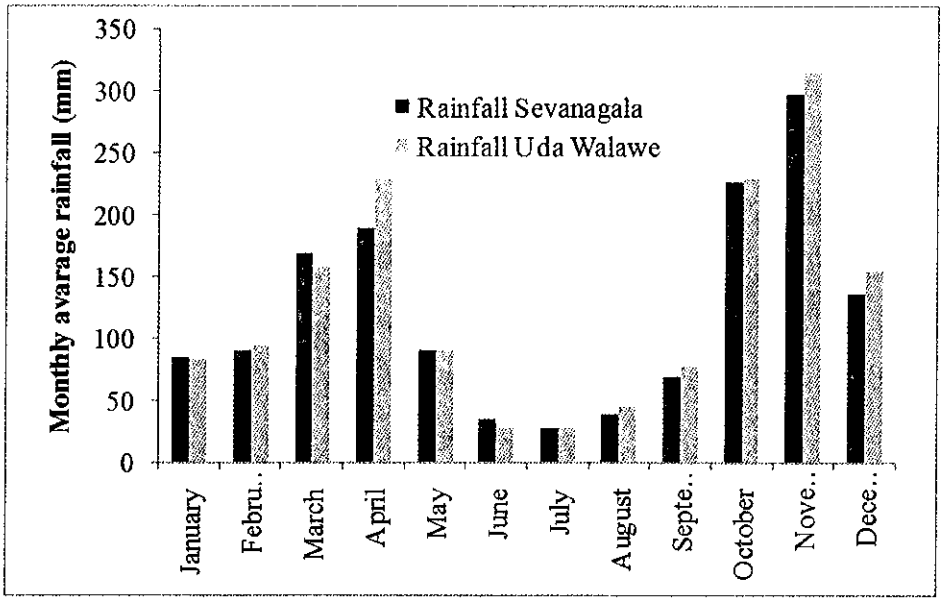

Figure1 Distribution of mean monthly rainfall (from 1984 to 2012) at Sevanagala and Uda Walawe

Table 1 Variation of monthly affective rainfall (mm) in Sevanagala and Uda Walawe

Month	Sevanagala	Uda Walawe
January	43.5	42.5
February	48.6	52.2
March	111.1	102.5
April	127.1	159.4
May	47.8	48.6
June	10.6	6.0
July	6.1	6.0
August	13.6	16.9
September	31.6	37.6
October	157.4	159.4
November	214.2	228.6
December	84.6	100.0
Total	896.2	959.7

June which resulted in a minimum irrigation water requirement for a total crop cycle. The analysis for Sevanagala showed the irrigation requirement has reduced to 700.4 mm/year when planting was done on 10th January and to 649.3mm/year if planted on 30th June. For Uda Walawe, these two minimum irrigation water requirement levels were at 685.2 mm/year and 619.1mm/year respect to planting on10th January and 30th of June .The grand growth period which has a maximum daily crop evapo-transpiration starts at 95 days after planting. If planting is done on the 10th of January, the maximum amount of rainwater can be utilised by the crop during this grand growth period, which starts on 6th of April. At this time, *Yala* rainy season is well established. If planting is done on 30th June, the grand growth period starts from 3rd of October. Usually, the 2nd inter-monsoonal rainfall for Sevanagala and Uda Walawe area starts in late September (Figure 1). The *Maha* rainfall continues till end of December for a period of three and a half months. Hence, the maximum amount of rainwater can be utilised by the crop during this period. Starting the planting on 30th of June facilitates the grand growth period of sugarcane crop to coincide with this heavy rainy season that has adequately available soil moisture. Considering the fraction of rain water used, month of January and (1st planting season) and from June to July (for 2nd planting season) are most suitable for planting sugarcane in both Sevanagala and Uda Walawe areas.

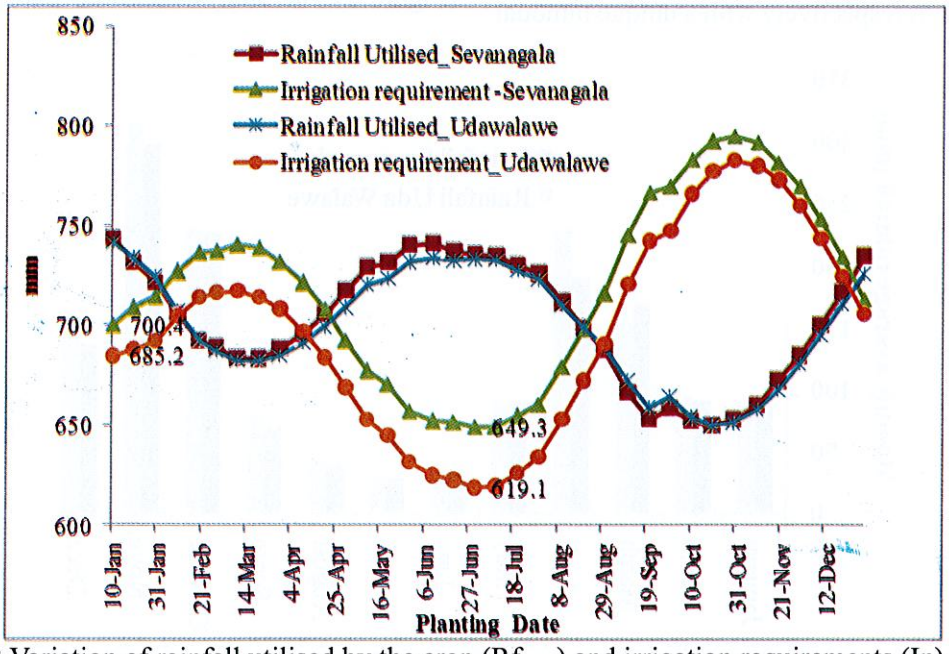

Figure 2 Variation of rainfall utilised by the crop ($Rf_{utilise}$) and irrigation requirements (In) for a 12-month crop cycle at Sevanagala and Uda Walawe

Table 2 Variation of the estimated crop evapo-transpiration (ET_c), rainfall utilised by the crop ($Rf_{utilise}$) and irrigation requirement (In) for a crop cycle of sugarcane at Sevanagala and Uda Walawe

	Sevanagala			Uda Walawe		
Planting date	ET_{crop} (mm/yr)	Rainfall utilised(mm/year)	Irrigation requirement (mm/yr)	ET_{crop} (mm/yr)	Rainfall utilised (mm/yr)	Irrigation requirement (mm/yr)
10-Jan	1444.3	743.9 #	700.4 *	1426.4	741.2 #	685.2 *
20-Jan	1440.6	732.0	708.6	1421.4	733.1	688.3
30-Jan	1436.5	721.9	714.6	1416.3	723.9	692.4
10-Feb	1432.4	705.7	726.7	1411.2	706.3	704.9
20-Feb	1429.1	692.4	736.7	1407.0	692.5	714.5
28-Feb	1426.8	689.4	737.4	1403.7	686.9	716.8
10-Mar	1424.4	684.0	740.4	1400.0	682.4	717.6
20-Mar	1422.4	683.4	739.0	1396.7	682.2	714.5
30-Mar	1420.7	688.8	731.9	1393.4	684.8	708.6
10-Apr	1417.3	696.0	721.3	1388.2	691.1	697.1
20-Apr	1414.1	705.8	708.3	1383.4	699.2	684.2
30-Apr	1410.4	717.6	692.8	1378.2	708.8	669.4
10-May	1406.7	729.4	677.3	1373.6	720.2	653.4
20-May	1402.5	732.0	670.5	1368.6	723.3	645.3
30-May	1398.0	740.8	657.2	1363.6	731.4	632.2
10-Jun	1393.1	741.1 #	652.0	1358.8	733.5 #	625.3
20-Jun	1388.9	737.4	651.5	1355.1	732.2	622.9
30-Jun	1385.3	736.0	649.3 *	1352.3	733.2	619.1 *
10-Jul	1384.6	735.2	649.4	1352.4	732.7	619.7
20-Jul	1384.8	730.4	654.4	1353.8	727.4	626.4
30-Jul	1386.4	726.0	660.4	1357.0	722.9	634.1
10-Aug	1391.1	711.9	679.2	1363.5	710.1	653.4
20-Aug	1396.9	698.8	698.1	1371.0	698.4	672.6
30-Aug	1403.8	688.0	715.8	1380.0	689.4	690.6
10-Sep	1411.9	666.4	745.5	1381.5	700.3	720.7
20-Sep	1419.9	653.2	766.7	1401.0	658.5	742.5
30-Sep	1428.0	658.5	769.5	1411.3	663.8	747.5
10-Oct	1435.3	652.3	783.0	1419.8	653.7	766.1
20-Oct	1442.2	650.2	792.0	1427.5	649.8	777.7
30-Oct	1448.3	653.4	794.9	1434.3	651.3	783.0
10-Nov	1452.0	660.5	791.5	1438.4	658.2	780.2
20-Nov	1454.1	672.6	781.5	1440.6	667.3	773.3
30-Nov	1454.8	685.0	769.8	1441.1	680.7	760.4
10-Dec	1453.5	700.2	753.3	1439.0	695.1	743.9
20-Dec	1451.1	717.0	734.1	1435.6	710.8	724.8
30-Dec	1448.0	735.0	713.0	1431.5	725.8	705.7

Note: "maximum rainfall use" and "minimum irrigation requirement" are demarcated in # and *

Conclusion

The findings of this study could be used as a guideline to plan planting program for efficient utilisation of limited available irrigation water by maximum utilisation of rainfall. However, this finding was merely based on the estimated values using climatic data of the area. Further studies based on field trials have to be carried out for a better understanding of performance of new planting schedules in respect of yields, sugarcane quality, sugar recovery percentages and pest and disease incidence, etc.

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An Assessment of Major Pests of Sugarcane in Sri Lanka

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ABSTRACT

All sugarcane varieties grown in commercial plantations of Sri Lanka are attacked by different pest species with different infestation levels. Regular monitoring of the population levels of these pests and their natural enemies and their damage on the crop is required to adopt control measures to minimise crop losses. Therefore, field surveys were conducted in Uda Walawe, Sevanagala, Pelwatte, Hingurana, and Passara from January to December 2013 to assess the damage levels of internode borer, shoot borers and termites. In addition, the populations of woolly aphid alone with the natural predators were also studied in the same year in Passara. Four sugarcane fields of 0.5 ha each were selected randomly from each location on each sampling day, and three plots with size of 25m x 10m were selected randomly from each field for collecting data. The total number of internodes and the number of internode borer infested fresh internodes of 100 randomly-selected plants, the number of total plants and the number of shoot borer-infested plants and the termite-infested plants in each plot were collected at monthly intervals. The analysis of variance was carried out. No severe damages of internode borer, shoot borers and termites were recorded during 2013. But their damages were comparatively high during the dry months of the year, i.e., from February to March and from June to September. High to moderate infestations of woolly aphid were recorded in Passara area throughout the year. The natural predators of woolly aphid, *Dipha aphidivora, Micromus* sp. and *Eupeodes* sp. were also reported throughout the year in Passara area. A sudden outbreak of any of these pests can be occurred at any time, and therefore, regular monitoring is essential to avoid such outbreaks.

Keywords: Internode borer, Shoot borers, Sri Lanka, Sugarcane, Termites, Woolly Aphid

INTRODUCTION

Utilisation of varietal resistance is the most suitable practical method for the management of pests in sugarcane plantations. However, there are several constraints to identify sources of resistance and to breed varieties resistant to pests (Mukunthan, 2002). In order to identify the varietal response to pests, all high-yielding varieties developed by the Sugarcane Research Institute (SRI), Sri Lanka, are inspected for pest infestations under natural environmental conditions in sugarcane-growing areas of the country. Those varieties detected to be highly susceptible to pest damages will not be recommended for commercial cultivation.

All sugarcane varieties grown in commercial plantations are attacked by a number of pest species and Integrated Pest Management (IPM) approaches are adopted to minimise these pest damages (Kumarasinghe, 1999). Regular monitoring of pest infestations is essential to avoid pest outbreaks (Dent, 1993). The surveys conducted by SRI in commercial sugarcane-growing areas of Sri Lanka revealed that Sugarcane Woolly Aphid (SWA) (*Ceratovacuna lanigera,* Homoptera: Aphididae), Internode Borer (INB) (*Chilo sacchariphagus indicus,* (Lepidoptera:

Pyralidae), Pink Borer; *Sesamia inferans* Lepidoptera: Noctuidae; one of two major shoot borer species of sugarcane in Sri Lanka, and Termites (Isoptera) are the major pests of sugarcane. Several natural enemies of sugarcane pests have been identified in Sri Lanka, which helps to keep the pest population levels below threshold levels. So far, six species of natural predators of SWA; *Dipha aphidivora* (Lepidoptera: Pyralidae), *Micromus* sp.(Neuroptera: Hemorabiidae), *Eupeodes* sp. (Diptera: Syrphidae), *Micraspis discolor* (Coleoptera: Coccinelidae), *Synonycha* sp. (Coleoptera: Coccinelidae) and *Micraspis allardi* (Coleoptera: Coccinelidae) have been identified from sugarcane plantations in Sri Lanka (Wanasinghe *et al.*, 2012). Regular assessment of population levels of these pests and their natural enemies and their damage intensity on the crop is required to provide information for screening and selecting sugarcane varieties tolerant to these pests and to advise sugar companies and farmers for adopting the most suitable control measures to minimise crop losses while protecting the sugarcane-growing environment for sustainable sugarcane production.

This study was undertaken with the following objectives:

i. to assess the spatial and temporal variation of damage intensity of internode borer (INB), shoot-borer and termites in sugarcane plantations in Sri Lanka.
ii. to analyse the population densities of SWA and its natural predators in Passara area.

MATERIALS AND METHODS

Study locations

Field surveys were conducted in five locations; research farm at Uda Walawe and commercial sugarcane plantations at Sevanagala, Pelwatte, and Hingurana in the dry zone (annual rainfall 1,300 – 1,600mm) and Passara in the intermediate zone (annual rainfall 1,750 – 2,500mm) of Sri Lanka from January to December 2013. The climate is characterised by a bi-modal rainfall distribution pattern where nearly two-thirds of rainfall is received during September to January or *Maha* season. There is a small peak during March to May or *Yala* season but the rainfall is erratic. The rain-fed sugarcane is planted during these two rainy periods, i.e., *Maha* and *Yala*. Nearly 50% of sugarcane plantations in Uda Walawe and Sevanagala and all plantations in Hingurana are cultivated under irrigation.

Sampling

Four sugarcane fields, 0.5 ha each, were selected randomly from each location on each sampling day and three plots size of 25m x 10m were selected randomly from each field for collecting information on pest damages. A minimum distance of 0.5 km was maintained between two fields. The application of insecticides for controlling pests was withheld throughout the study period.

Data collection

Damage intensity of INB

The total number of internodes and the number of INB-infested fresh internodes in 100 randomly-selected plants from each plot were recorded at monthly intervals.

Damage intensity of shoot borers

The number of total plants/tillers and the number of shoot borer-infested plants/ tillers (with "*Dead Hearts*") in each plot were recorded at monthly intervals.

Damage intensity of termites

The number of total plants and the number of termite-infested plants in the selected plots in each field were counted at monthly intervals.

Infestation of SWA and its natural predator populations

The number of total plants and the SWA-infested plants and the number of natural

predators were recorded in selected farmer fields at monthly intervals in Passara area. The population levels of three natural predators, i.e., *Dipha aphidivora*, *Micromus* sp. and *Eupeodes* sp on ten randomly-selected SWA-infested plants were counted at monthly intervals to estimate the population of each predator.

Analysis

The percentage damage intensity due to INB, shoot borers, termites, and infestation level of SWA were estimated using the information recorded during the field survey. These percent damage levels were transformed into square root values to have normal distribution. The analysis of variance was carried out to determine the significance of spatial and temporal variation of damage of INB, shoot borers and termites using the SAS software (for Windows 9.0).

RESULTS AND DISCUSSION

Variation of INB, shoot borers and termite damage in different locations

The damage intensities of INB, shoot borers and termites in sampling locations were low, and there was no economic damage recorded during the year 2013 (Table 1). Comparatively very low levels of INB and shoot borer damages were recorded in Passara area. The sugarcane varieties, *Alu UK* and Co 527 grown in Passara observed to be less susceptible to two species of borers. High priority should be given to select sugarcane varieties with low susceptibility to both borer species to avoid build-up of their populations beyond economic threshold levels.

Comparatively high damage incidence of shoot borers was recorded at Hingurana. The experiments conducted to determine the parasitism level of the larval parasitods of borer pests of sugarcane in Sri Lanka revealed that the larval parasitoid of shoot borers *Cotesia flavipes* was absent in sugarcane plantations at Hingurana (Unpublished data). The lack of larval parasitoid could be one of a reasons for the higher population level of shoot borers at Hingurana, in addition to the presence of paddy fields adjacent (host plants of *Sesamia inferans*) to sugarcane fields. Furthermore, all the shoot borer-infested fields at Hingurana were highly infested with graminae weeds due to poor weed management practices, and *S. inferans* larvae were observed in these weeds having 'dead-heart symptom'. Those weeds provide conditions conducive for rapid multiplication and spread of the shoot borer. Nine species of grasses in local cane fields have been recorded as collateral hosts for the *Sesamia inferans,* and they provides more congenial conditions for egg laying and for the survival of the first two larval instars before attacking cane (Rajendra, 1979).

Table 1 Damage intensities (Means± SE) of INB, shoot borers and termites in different study locations during 2013.

Type of pest	Uda Walawe	Sevanagala		Pelwatte	Hingurana	Passara
		Rain-fed	Irrigated			
INB	3.44 ±2.61a	3.89 ±2.27a	1.09 ±0.94b	3.21 ±1.87a	2.89 ±1.74a	0.49 ±0.8b
Shoot borers	0.19 ±0.04a	0.15 ±0.03ab	0.11 ±0.07b	0.20 ±0.06a	0.21 ±0.09a	0.09 ±0.03b
Termites	0.14 ±0.04a	0.10 ±0.06a	0.00 ±0.01b	0.03 ±0.02b	0.02 ±0.02b	0.11 ±0.04a

Note: Means in a row with the same letter are not significantly different at 0.05 probability level.

According to the results, the damage incidences of termites in plantations under rain-fed conditions were higher than those under irrigated conditions. Farmers and industries with rain-fed cultivations should give high priority to manage the damages of termites during the dry season. Since chemical application is harmful to the environment, addition of compost or manure, sowing green manure crops, removal of queen, crop rotation, use of maize cobs for mechanical control, use of plant parts and plant extracts such as leaves and seeds of neem tree, latex of *Calotropis* plant, etc. are some of the most preferred methods (Ahmed *et al.*, 2008; Upadhyay, 2013).

Temporal variation of pest damages

***Damage intensity levels of INB*:** The highest intensity of INB damage in all locations was recorded from June to September 2013 that coincide with the dry period (Figure 1).

Borers cause significant crop loss during dry periods of every year in all commercial plantations in Sri Lanka. During this study, the highest percentage damage was nearly 9% in the month of August at Sevanagala rain-fed sector. The action threshold for the INB in Sri Lanka has been estimated at 13-15% bored internodes on the cane variety Co 775 at the age of 4-5 months (Seneviratne *et al*, 2001). The damage levels found in the surveyed plantations in different locations during the year 2013 were below the action threshold level (from 0.49 to 3.89%).The presence of natural enemies and the use of correct management practices may be the reason for the low level of damages of INB.

***Damage intensity of shoot borers*:** The highest percentage damage intensity levels of shoot borers in all locations were recorded in the first and the third quarters of the year that coincide with the dry periods (Figure 2).The recommended management practices should be followed to reduce the crop losses due to shoot borers during those time periods. Maintenance of weed-free plantations, conservation of natural enemies (Kumarasinghe, 1999), removal of infested plants, trash mulching, light earthing-up, sprays of granulosis virus of shoot borers with a dose of 10^7- 10^9 IB/ml, application of insecticides to soil are adopted to reduce the shoot borer incidences (Srivastava, 2012).

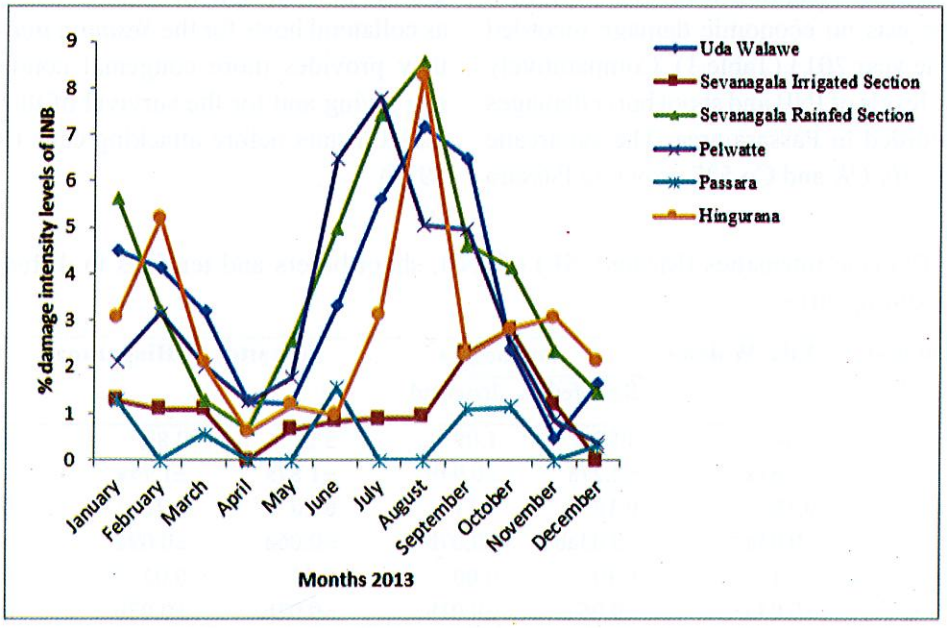

Figure 1 Percentage damage intensity of INB in different study locations of Sri Lanka during 2013

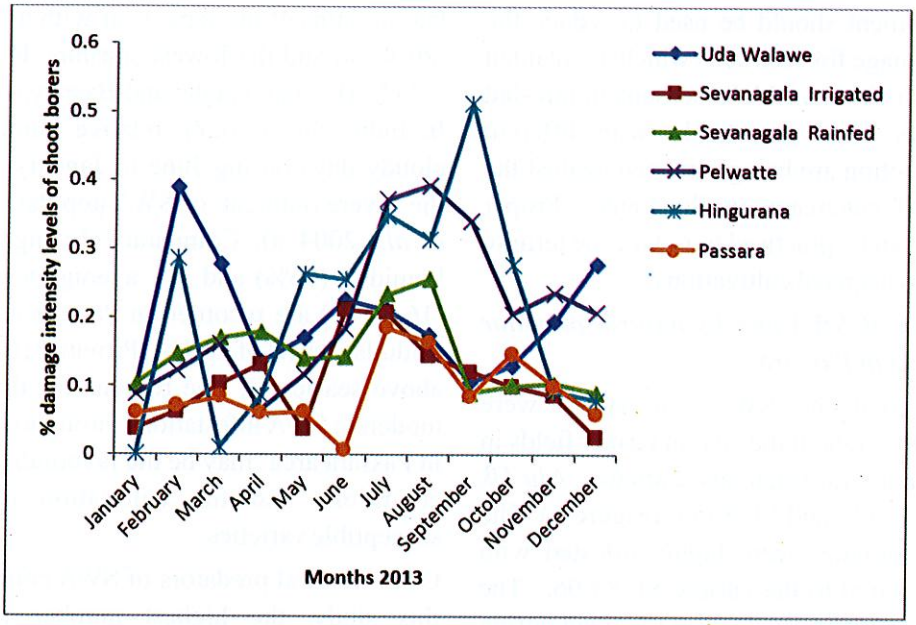

Figure 2 Percentage damage intensity levels of shoot borers in different study locations in year 2013

Damage intensity of termites: The highest damage intensity levels of termites were recorded from February to April and from September to October 2013 that coincide with the dry periods (Figure 3).Termites attack to any growth stage of the sugarcane crop, and a field study in the research farm, Uda Walawe showed that the planted seed setts were more susceptible to termite attacks than the other growth stages (Unpublished data, 2014). Suitable recommended insecticides as

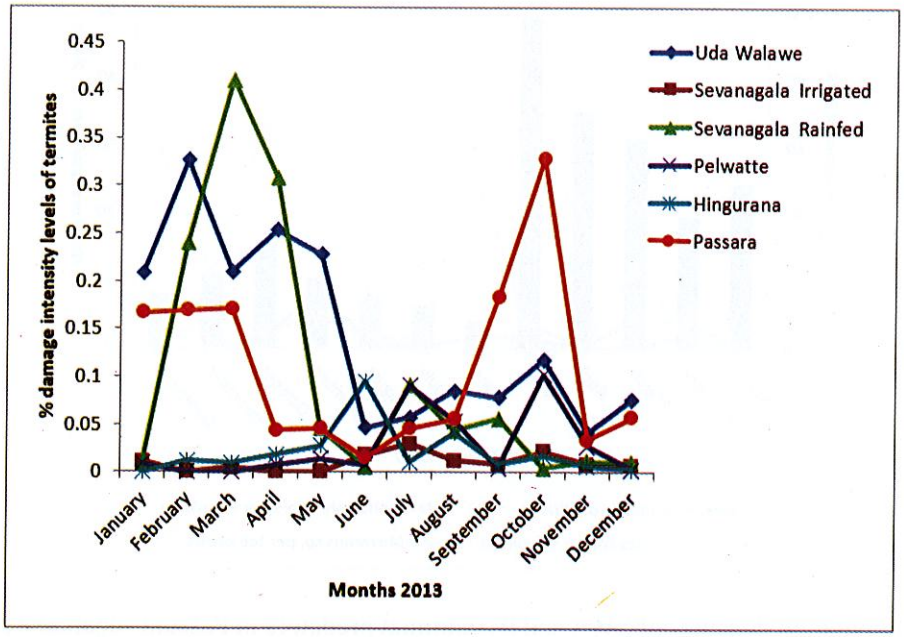

Figure 3 Percentage damage intensity levels of termites in different study locations in Sri Lanka during 2013

a sett treatment should be used to reduce the termite damage for seed setts which are planted during both *Yala* and *Maha* seasons in rain-fed cultivations. Three insecticides with different modes of action are being screened against the termites of sugarcane in Sri Lanka. Proper irrigation can be practised to reduce the termite damages in irrigated cultivations.

Infestation of SWA and its natural predator populations in Passara

High to moderate SWA infestations were recorded throughout the year in farmer fields in Passara area with sugarcane varieties, A*lu Uk* (Local), Co 527 and SL 83 06 (Figure 4). The first two varieties were highly infested with SWA compared to the variety SL 83 06. The highest infestation levels were recorded during the first five months of the year. SWA was first reported in sugarcane plantations in Badulla district in January 2006 (Kumarasinghe, 2007),and the subsequent outbreaks in other sugarcane plantations were recorded during the later months of the same year with highest RH (80-82%) and the lowest sunshine hours (3.2-3.75 h) (Kumarasinghe and Basnayake, 2009). In India, the morning relative humidity and cloudy days during June to January favoured the severe outbreak of SWA populations (Patil *et al.*, 2004 a). Comparatively high relative humidity (86%) and low average temperature (16-30 ^{0}C) are recorded in Passara area in the Badulla district of the Uva Province (670-690 m above sea level). The reasons for the high to moderate SWA infestations throughout the year in Passara area may be the favourable weather conditions and the cultivation of highly susceptible varieties.

Of the natural predators of SWA considered in this study, the highest number of *Dipha aphidivora* was recorded in the month of June (49 per ten plants) and the highest number of *Micromus* sp. and *Eupeodes* sp were recorded in the month of September (54 and 17 larvae per ten plants respectively). The number of

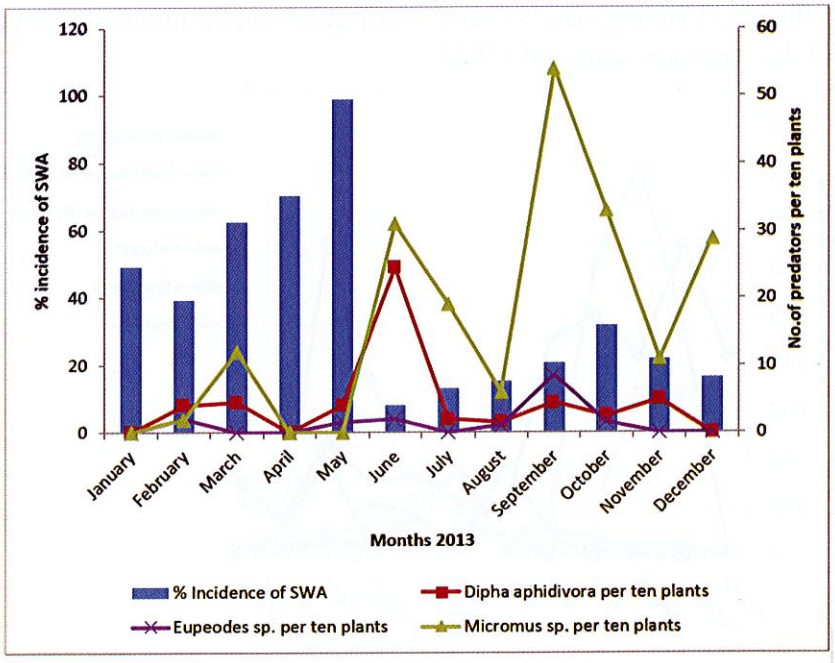

Figure 4 Population densities of SWA and its common predators in Passara sugarcane plantations recorded during 2013

coccinellid beetles was not considered in this analysis as those coccinellid beetles showed an uneven distribution pattern with low relative abundance during the study period. Peak populations of predators were detected during the periods with low population levels of SWA. Accordingly, natural enemies have helped to reduce SWA populations, but the efficiency of the predators was not sufficient to control the high SWA populations throughout the year. However, in other sugarcane-growing areas, SWA can be successfully controlled with the predators (Unpublished data from field experiments). Therefore, augmentation and conservation programmes should be continued to increase the population levels of the predators of SWA in Passara area.

Conclusions

Severe damages of INB, shoot borers and termites were not recorded during the year 2013 in commercial sugarcane plantations in Sri Lanka, and sugarcane was more prone to these pest attacks during the dry months of the year.

Infestations of SWA were detected in farmer fields at Passara throughout the year with peak levels from March to May. The identified natural predators of SWA were observed in the sampling locations, and they have helped to reduce SWA populations, but their efficiency was not sufficient to control the high populations of SWA throughout the year.

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Evaluation of Some Brazilian Sugarcane Varieties for Resistance to Leaf Scald Disease Pathogen in Sri Lanka

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ABSTRACT

Identification of resistant parent clones of sugarcane (*Saccharum spp hybrid*) for leaf scald disease caused by *Xanthomonas albilianeans* is required to produce resistant varieties for commercial cultivation. The present study investigates the resistance of some Brazillian sugarcane varieties against leaf scald disease. Three-budded setts of eleven sugarcane varieties imported from Brazil with wide genetic variation along with the standard varieties were planted in one-metre plots in three replicates in Randomised Complete Block Design to evaluate their reaction to sugarcane leaf scald disease. Three-month old plants were inoculated with the inoculum extracted from the leaf tissue of the diseased plants mixed with leaf scald disease-causing bacterial broth culture according to the standard "Aluminium cap" technique. The disease incidence was recorded at one-month intervals from 30 days after inoculation of the bacterium up to ten months. The percentage disease incidence was calculated and the ratings of the resistance levels were assigned for the test varieties based on the ratings of the standard varieties. The results revealed that the variety SP 89 1115 was resistant to leaf scald disease and while the others were susceptible to the disease. This variety could be used for sugarcane crop improvement program to improve the resistance of the varieties to leaf scald disease in sugarcane.

Keywords: Leaf scald disease, Resistance, Sri Lanka, Sugarcane

INTRODUCTION

Leaf Scald Disease (LSD) is one of the two major bacterial diseases in almost all sugarcane-growing areas in the world including Sri Lanka. The disease is caused by a gram negative bacterium, *Xanthomonas albilianeans* (Ashby, 1929 and Dowson, 1943). It colonises in the vascular system of leaves, stems and roots, and has a significant effect on reducing cane yield (Pan *et al.*, 2004) and the quality of juice (Martin and Robinson, 1961).This disease can cause extensive yield losses in highly susceptible varieties through death of stalks and poor ratooning. It has caused severe losses in *Saccharum offinarum* L. cultivars that were grown in the world until the early part of the twentieth century. The losses have been reduced after the introduction of inter-specific hybrids of *Saccharum* that were resistant to LSD (Hoy and Grisham, 1994).

A great concern with this disease is that the bacterial pathogens can exist for extended period of time in seemingly healthy plants. Since sugarcane is a vegetatively-propagated crop, the pathogens can be readily spread between fields, regions and even countries (Pan *et al.*, 2004). The first documented note on this disease in Sri Lanka was from Kantale, Gal Oya and Walawe in 1961(Egan, 1961).

As the LSD can cause complete crop loss in highly susceptible varieties (Rott and Devis, 2000), breeding for resistant varieties has been the most-adopted strategy for managing the disease. In order to facilitate the directional breeding for LSD resistance, the screening of the sugarcane varieties for their

reactions to this disease is of great importance to avoid crosses between susceptible parent clones to reduce the number of susceptible clones coming through the crop improvement program. This is useful to avoid the releasing of disease susceptible/less tolerant varieties into the commercial plantations, and thereby, to reduce the disease in sugarcane plantations. In this study, an assessment of the reaction of some imported sugarcane varieties from Brazil to LSD was made to identify the resistant/tolerant parent clones to recommend them for sugarcane crop improvement for LSD.

MATERIALS AND METHODS

A field experiment was carried out at the research farm of the Sugarcane Research Institute, Uda Walawe, where the annual average rainfall is about 1450 mm during 2009 - 2010 using the varieties, SP 83 2847, SP 85 3877, SP 86 155, SP 87 365, SP 87 369, SP 89 1115, SP 90 1107, SP 90 1638, SP 90 3414, SP 90 3723 and SP 91 1047 imported from Brazil with a wide genetic variation. Three-budded setts of these varieties were planted along with the standard varieties, namely, Co 997, Triton, Trojan, Co 740, Q 68, Co 775 and Co1001 in one-metre row plots in three replicates in Randomised Complete Block Design to evaluate the resistance of the varieties to LSD.

To inoculate the plants, the bacterium was isolated from the infected leaves with white/cream colour streaks on Wilbrinks medium with slight modifications proposed by Davis *et al.*(1994). The medium contains Sucrose 10.0 g, peptone 5.0 g, yeast extract 5.0 g, K_2HPO_4 0.5 g, $MgSO_4.7H_2O$ 0.25 g, Na_2SO_3 0.05 g, Agar 15.0g distilled water 1 L supplement with KBr (5 g/L),Cephalexin (25 mg/L) and Nivobiocin (30 mg/L).The leaf segments were surface sterilised in 0.1 % cholox for 1 min, washed twice in sterile distilled water. They were transferred to 70 % alcohol for 30 seconds and again washed twice with sterile distilled water. The swabbed leaf segments were transferred to the medium and incubated for 144 hours at 28^{0}C. Single colonies were then serially sub cultured on respective medium to get pure cultures. After getting pure cultures, the bacterium was transferred to Wilbrink broth. The bacterium in 250ml of broth was cultured for two days under shake flask culture-shaken for two days at 150 rpm. This broth culture was mixed with 500 ml of the inoculum which was freshly prepared by grinding disease symptoms bearing leaves. Three-month old randomly-selected ten plants from each variety were decapitated and inoculated with 5ml of the above suspension according to the standard "Aluminium cap" technique (Koike, 1965).

The disease incidence was recorded at one-month intervals from 30 days after inoculation of the bacterium up to ten months. Then the average observed disease percentage was obtained for each variety by calculating the arithmetic average of the percentage disease incidence measured in three replicates. Then a calibration curve was drawn and its equation was derived on the average observed disease incidence (Y) and the previously-assigned leaf scald disease ratings for the standard varieties (X) (SRI, 2009). A graph was also drawn to compare the behaviour of the standard varieties according to their known rating and the behaviour of the same standard varieties based on the field observations. By referring the derived calibration curve, disease ratings for the test varieties were obtained based on their observed disease incidences.

RESULTS AND DISCUSSION

The calibration curve derived using the standard varieties is shown in Figure 1.The equation derived for the calibration curve was $Y = 4.822 - 3.5510X + 1.529X^2$; ($R^2$=98 %) where Y is the percentage disease incidence observed and X is the leaf scald disease rating previously assigned.

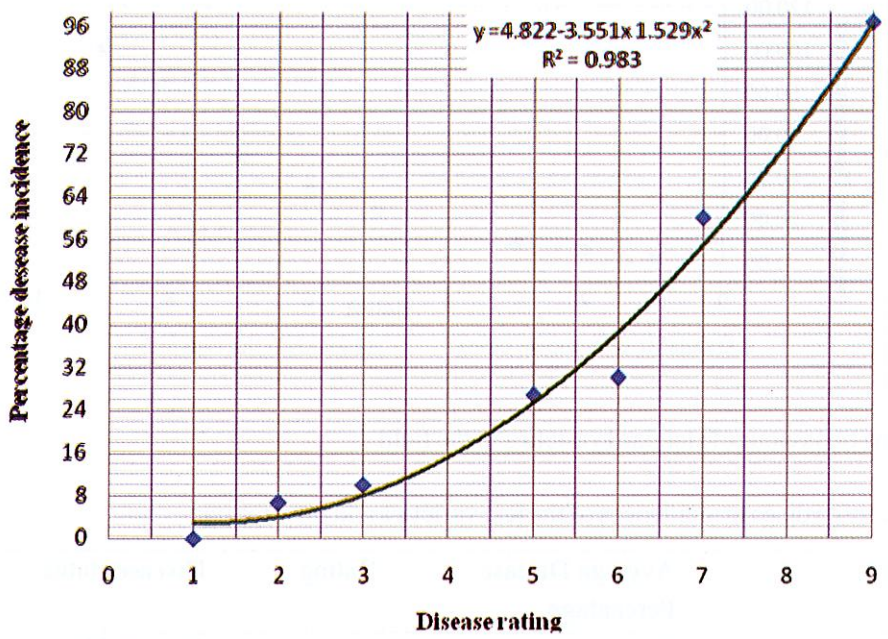

Figure 1 The calibration curve established for leaf scald disease

The currently-used standard varieties and their observed and estimated disease incidences and the estimated ratings based on the calibration equation are summarised in Table 1.

The behaviour of the standard varieties according to their known ratings and that of the same standard varieties based on the field observations are shown in Figure 2.

According to the results, all the standard varieties have shown previously proven disease ratings. There were no much deviations of the standard varieties from their normal behaviour. Therefore, all the test varieties also would have shown their correct reaction to leaf scald disease.

The ratings assigned to each test variety based on their observed disease percentages are summarised in Table 2.

Table 1 The observed and estimated disease incidences and the estimated ratings of standard varieties

Standard variety	Disease percentage	Known rating	Disease status	Observed incidence	Estimated incidence	Estimated rating
Co 997	1.00-3.00	1	HR	0.00	2.84	1
Triton	4.00-6.00	2	R	6.67	3.85	2
Trojan	7.00-9.00	3	R	10.00	7.90	3
Co 740	13.00-25.00	5	MS	26.67	25.12	5
Q 68	26.00-35.00	6	S	30.00	38.29	6
Co 775	36.00-50.00	7	S	60.00	54.50	7
Co 1001	66.00- 100.00	9	HS	96.67	96.04	9

Note: HR- Highly Resistant, R-Resistant, MS-Moderately Susceptible, S-Susceptible, HS - Highly Susceptible

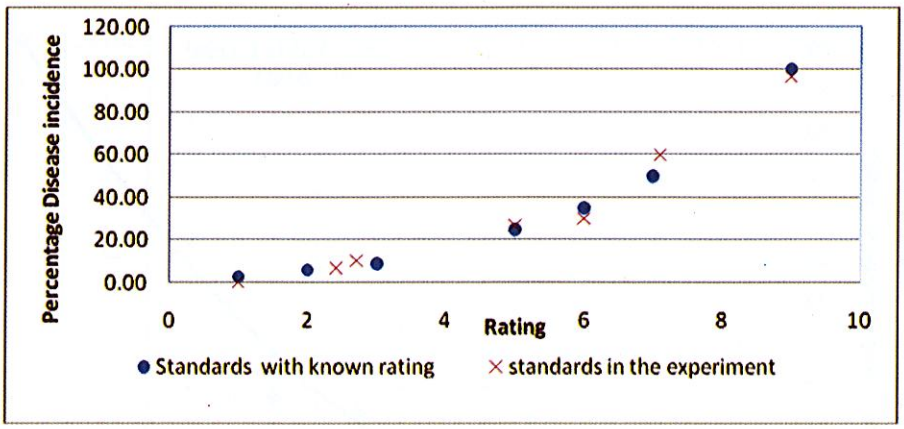

Figure 2 The behaviour of standard varieties in the field

Table 2 Average disease incidences of the test varieties and their ratings

Test variety	Average Disease Percentage	Rating	Disease status
SP 83 2847	82.96	8	Susceptible
SP 85 3877	63.33	7	Susceptible
SP 86 155	100.00	9	Highly susceptible
SP 87 365	53.33	7	Susceptible
SP 87 369	100.00	9	Highly susceptible
SP 89 1115	20.00	4	Resistant
SP 90 1107	93.33	9	Highly susceptible
SP 90 1638	66.67	8	Susceptible
SP 90 3414	53.33	7	Susceptible
SP 90 3723	80.00	8	Susceptible
SP 91 1047	60.00	7	Susceptible

The behaviour of the test varieties and the standard varieties during the experimental period is graphically shown in Figure 3.

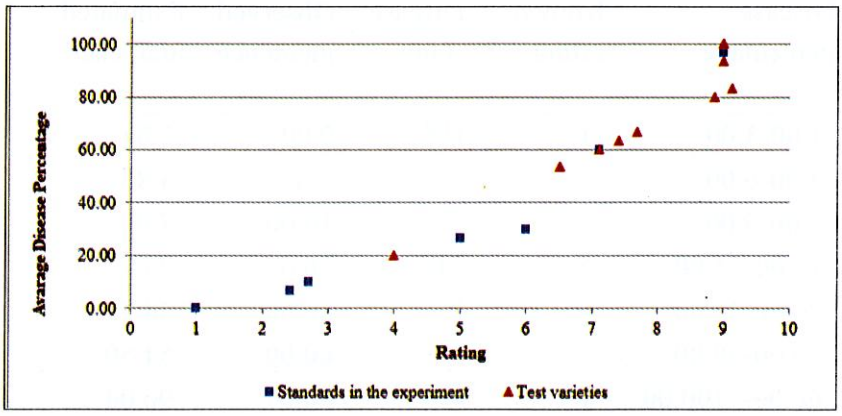

Figure 3 The Behaviour of test varieties and standard varieties in the field

No any test variety has shown a rating lower than 5. Only the variety SP 89 1115 has shown rating of 4, i.e., resistant to LSD. It has recorded a 20 % disease incidence. Furthermore, this variety has showed the same result (a resistant variety) in the gemplasm screening trials in Brazil (Gutierrez and Hoy, 2013) also. All the test varieties, except the variety SP 89 1115, have shown more than 20% disease level during the experimental period. Therefore, those varieties are considered as susceptible to leaf scald disease caused by the local strains of *X. abilianus*.

Conclusion

Based on the results of this study, it can be concluded that the variety SP 89 1115 could be utilised for sugarcane crop breeding program to improve the resistance of the sugarcane varieties to leaf scald disease.

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pH-Buffering Capacities of Sugarcane-growing Soils at Sevanagala, Sri Lanka

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ABSTRACT

No information on the pH-buffering capacities of the sugarcane-growing soils at Sevanagala, Sri Lanka is available to understand the behaviour of the soil after application of fertilisers and amendments. The objectives of the study were to determine the pH-buffering capacities of the sugarcane-growing soils at Sevanagala and pH variations after application of the recommended quantities of ammonium sulphate, urea and vinasse on sugarcane-growing soils at Sevanagala. Thirty composited soil samples from 6 divisions were collected at a depth of 0-15 cm from the surface of sugarcane fields at Sevanagala. The soil samples were treated with different quantities of $Ca(OH)_2$ to establish pH-buffering curves. The soil pH became stable one hour after treatment with $Ca(OH)_2$. Hence, soil samples were incubated for one hour prior to measuring pH to establish buffering curves. After application of ammonium sulphate, urea and vinasse, the change in pH values of selected soils were also determined. The results indicated that the soils in Division 4 and 5 have comparatively high pH-buffering capacities while Division 1 and 3 are with soils having comparatively low pH-buffering capacities. With the application of ammonium sulphate and vinasse to low buffering soils the pH values changed below 5.5 making soils highly acidic. However, Urea application maintained a favourable pH for sugarcane. Hence, precautions should be made when applying ammonium sulphate and vinasse to low buffering soils in Sevangala.

Keywords: Ammonium sulphate, Soil pH-Buffering capacity, Soil pH, Sugarcane, Urea, Vinasse

INTRODUCTION

Soil pH that measures the degree of soil acidity, neutrality and alkalinity of a soil, is an important chemical parameter affecting growth of sugarcane crop through its effect on soil nutrient availability to the crop. A favourable soil pH level is important for maintaining the nutrient composition in the root-soil interface. The ideal range of pH for sugarcane crop is between 5.5 and 7.0 (Calcino, 2010). Deviation of soil pH beyond this range adversely affects the growth of the crop leading to a reduction in yield resulting an economic loss. According to Calcino (2010), sugarcane plant could tolerate soil pH conditions between 5 and 8. Thus, the ability of a soil to maintain the pH levels within favourable levels is an important requirement for sugarcane production.

[1]Acidity is due to excess of H^+ ions over OH^- ions and alkalinity is due to the excess of OH^- ions over H^+ ions.

Soil pH is a measure of the H^+ concentration in the soil solution while the concentration of the H^+ attached to the negatively-charged clay particles and organic matter in soil is measured as pH-buffering capacity (Schroeder, 1984).

Soil pH-buffering capacity is a key indicator of the amount of additive material required to bring soil pH to the preferred level. Further, this reflects its ability to resist changes in pH, and it differs from soil to soil. Also, the soil pH-buffering capacity has a relationship with cation exchange reaction. In cation exchange reactions, functional groups associated primarily with variable-charge minerals, and soil organic matter acts as sinks for hydrogen and hydroxide ions (Helling *et al.,* 1964).

The soil pH-buffering capacity has been used to categorise tea-growing soils in Sri Lanka, and its equilibrium time has been identified as 45 minutes (Liyanage *et al.,* 2011). Continuous monoculture of crops ignoring the importance of pH buffering would lead to deterioration of soil quality, thereby changing pH with addition of external materials, finally to low crop yields. Though sugarcane has been cultivated in Sri Lanka over more than two decades, the soil pH and its buffering capacity of Sevanagala sugarcane-growing soils have not been given due attention. The two nitrogen (N) fertilisers, urea and ammonium sulphate and sugarcane distillery effluent (Vinasse) are added to sugarcane-growing soils Sevanagala at levels beyond the recommendations. Therefore, the objectives of the study are to determine the pH-buffering capacities and characterise the sugarcane-growing soils at Sevanagala accordingly and to identify the relationship between pH-buffering capacities and application of ammonium sulphate, urea and sugarcane distillery effluent (Vinasse) to these soils.

MATERIALS AND METHODS

The Sevanagala sugar mill area of Sri Lanka (6° 40' N, 80° 89' E) located in the command area of the left bank of the Uda Walawe reservoir was selected for the study. It has a total land area of around 4000 ha with sugarcane cultivated under both irrigated and rain-fed conditions. The soils of the area are mainly Reddish Brown Earths accounting for more than 90 %. The area receives an annual rainfall of about 1450 mm and 900 mm of 75 % expectancy with a distinct bi-modal distribution (Punyawardena, 2010).

Two experiments; one for characterisation of sugarcane-growing soils at Sevanagala in relation to pH-buffering capacity, and the other for ascertaining the effect of ammonium sulphate, urea and vinasse application to sugarcane-growing soils with contrasting pH buffer capacities, were conducted.

Site selection and sampling procedure

The sampling was carried out in 2011 and the area covered six main divisions of Sevanagala under sugarcane-growing area namely, 1 to 6 covering both rain-fed and irrigated cultivations with a total extent of 3903 ha (Table 1).

Table 1 Details of the sampling locations at Sevanagala and the samples collected

Division	Extent (ha)	Sampling locations	Samples per location	Prepared composite samples per Division
Division 1	691	5	5	5
Division 2	710	5	5	5
Division 3	730	5	5	5
Division 4	519	5	5	5
Division 5	545	5	5	5
Division 6	708	5	5	5

Soil samples from each division were collected at a depth of 0-15 cm from the surface. The composite soil samples from each of the 6 divisions (Table 1) were stored in labelled polythene bags and transported to the Crop Nutrition laboratory at the Sugarcane Research Institute, Uda Walawe. The soil samples were air dried at room temperature for a week and sieved using a 2-mm sieve.

Determination of soil pH

The pH was measured by standard procedure (Kalra and Maynard, 1991), immersing the combination electrode of the pH meter (model: ADWA 1030) into the supernatant solution prepared using a 1:2.5 soil:water suspension and with or without $Ca(OH)_2$. Two drops of chloroform were added to each suspension to stop microbial activities.

Determination of soil pH-buffering capacity

The following three treatments were tested to determine pH-buffering capacities. Calcium hydroxide ($Ca(OH)_2$) was used as the additive component and treatment 01 had no addition of $Ca(OH)_2$ solution which was considered as the control. Treatment 02 was with an addition of 1 ml of 0.022 M freshly prepared $Ca(OH)_2$ lime solution. The addition of 2 ml of 0.022 M $Ca(OH)_2$ solution was the treatment number 3.

Pre-tests were carried out to determine the incubation duration prior to determination of pH-buffering capacity in soils. The three treatments were incubated, and the pH was measured at 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220-minute intervals in order to determine the equilibrium time required for maximum neutralisation. The pH-buffering curves were established using this equilibrium time, and the pH-buffering capacities of the soils were measured by the slope of the curves.

The cation exchange capacity and organic carbon percentage of the highest and the lowest pH-buffering soils were determined according to standard laboratory procedures to identify their relationships with soil pH-buffering capacity (Kalra and Maynard, 1991).

Effect of Ammonium sulphate, Urea and Vinasse on soil pH

The soils with the lowest (Division 1) and the highest (Division 4) pH-buffering capacities identified from the previous experiment were considered for this experiment. Under laboratory conditions, the experiment was carried out with 10 g of soil from the Divisions, 1 and 4. Then recommended quantities of urea (200 kg/ha), ammonium sulphate (300 kg/ha) and vinasse (40,000 L/ha) were added proportionately to 10 g of the selected soil. The change of soil pH was determined to observe the effect due to fertiliser and vinasse application.

Statistical analysis

Means were calculated where required. The Analysis of Variance was carried out to determine the effect of urea, ammonium sulphate and vinasse on soil pH under low- and high-buffering soils.

RESULTS AND DISCUSSION

Characterisation of sugarcane-growing soils at Sevanagala in relation to pH-buffering capacity

Incubation duration for determination of pH-buffering capacity in soils

The results of the pre-test indicated that the maximum incubation duration to achieve the equilibrium status was 1 hour (Figure 1). Hence, it was decided to incubate the samples for 1 hour in 1:2.5 soil suspension under laboratory conditions prior to measuring pH to establish their buffer curves. This was 15 minutes greater than the equilibrium time taken for tea-growing soils which are usually acidic in nature (Liyanage *et al.*, 2011).

The pH buffer curves were established according to their change in pH with the addition of the three concentrations of lime and are given in Figure 2.

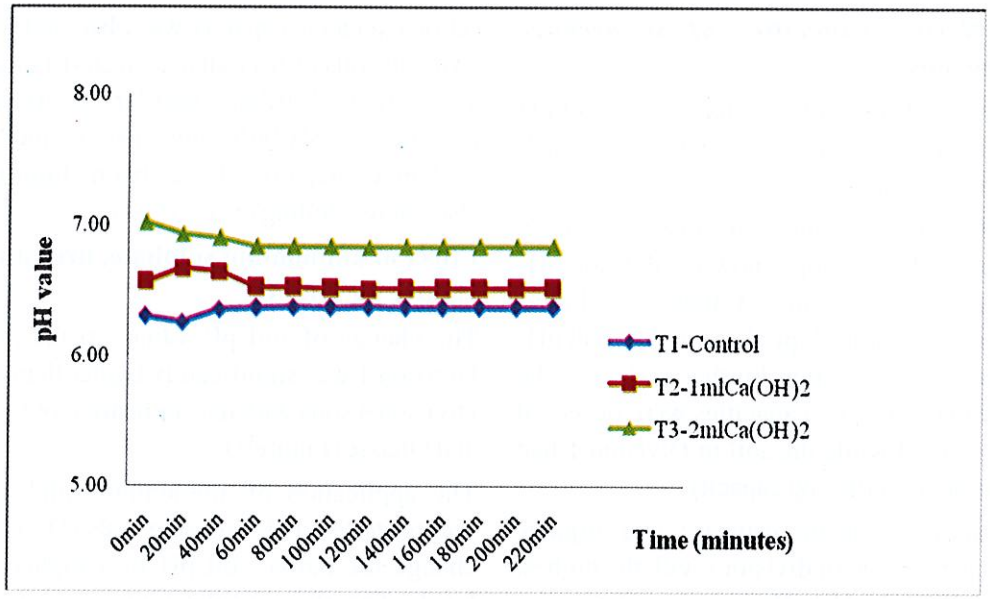

Figure 1 The mean changes of pH with time in soil suspensions containing 0 ml, 1 ml and 2 ml of 0.022 M $Ca(OH)_2$ in the soil from Divisions, 1 to 6.

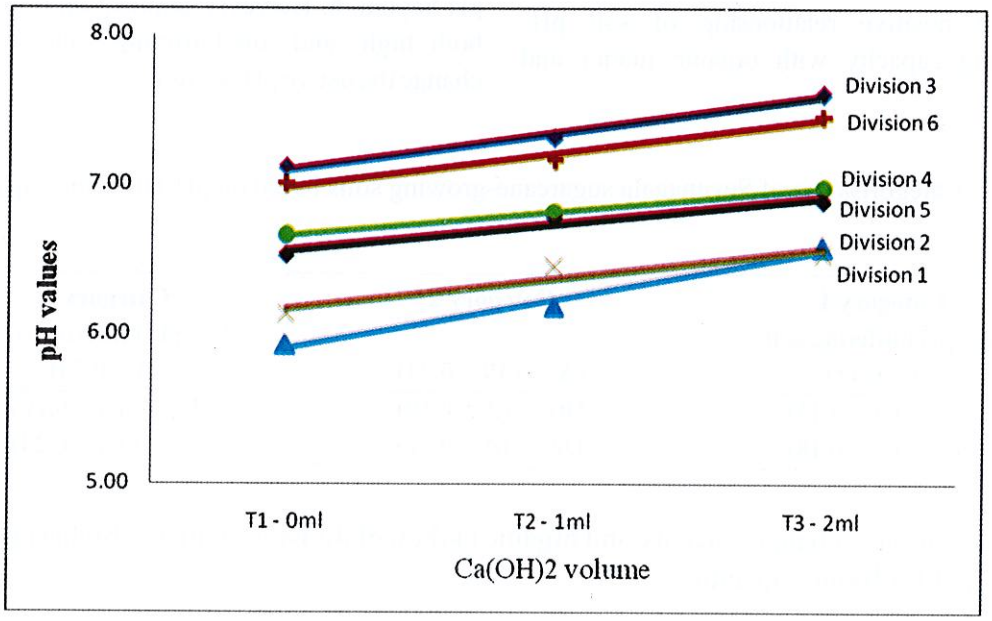

Figure 2 pH buffer curves of the soil from Divisions, 1 to 6

pH-buffering capacities of sugarcane-growing soils

The slopes of the above buffer curves provide the soil pH-buffering capacities (Δ) at each division at Sevanagala and are given in Table 2.

According to the results, category 1 soil has a comparatively low slope showing high soil pH-buffering characteristics. Category 3 has a comparatively high slope showing low soil pH-buffering characteristics. Further, soils with the highest pH-buffering capacities were observed in Division 4 while the soil in Division 1 had the lowest pH-buffering capacity.

The cation exchange capacity and organic carbon percentage of divisions with the highest and the lowest pH-buffering capacities were compared (Table 3).

According to above results, the soils with comparatively high organic carbon and cation exchange capacity showed greater pH-buffering capacities and vice versa.

Such a positive relationship of soil pH-buffering capacity with organic matter and cation exchange capacity was observed for tea-growing soils of Sri Lanka as well (Liyanage *et al.*, 2011). Further, similar relationships between soil pH-buffering capacity and cation exchange reaction have been highlighted elsewhere (Helling *et. al.*, 1964).

Effect of ammonium sulphate, urea and vinasse on soil pH

The change of soil pH values in the soils of Division 1 was significantly higher than that of Division 4 soils with the application of fertiliser and vinasse (Figure 3).

The application of ammonium sulphate and vinasse to low pH-buffering soils (Division 1), change the native soil pH to a highly acidic level. Therefore application of ammonium sulphate and vinasse to low-buffering soils would adversely affect on the native pH of the soil. On the other hand, the application of ammonium sulphate and vinasse to high pH-buffering soils does not change the native soil pH beyond 6. However, application of urea to both high- and low-buffering soils did not change the native pH below 6.5.

Table 2 Categorisation of Sevanagala sugarcane-growing soils based on pH-buffering capacities (Δ).

Category 1 high pH buffering soil ($\Delta \leq 0.18$)	**Category 2** ($\Delta = 0.19 - 0.23$)	**Category 3** low pH buffering soils ($\Delta \geq 0.24$)
Div. 4 ($\Delta = 0.15$)	Div. 2 ($\Delta = 0.19$)	Div. 1 ($\Delta = 0.26$)
Div. 5 ($\Delta = 0.18$)	Div. 6 ($\Delta = 0.22$)	Div. 3 ($\Delta = 0.24$)

Table 3 Cation exchange capacity and organic carbon of divisions with the highest and the lowest pH-buffering capacities

Division	Soil pH-buffering capacity	Cation Exchange Capacity (cmol(+)/kg)	Organic Carbon (%)
1	Lowest	10.34	0.83
4	Highest	17.13	1.43

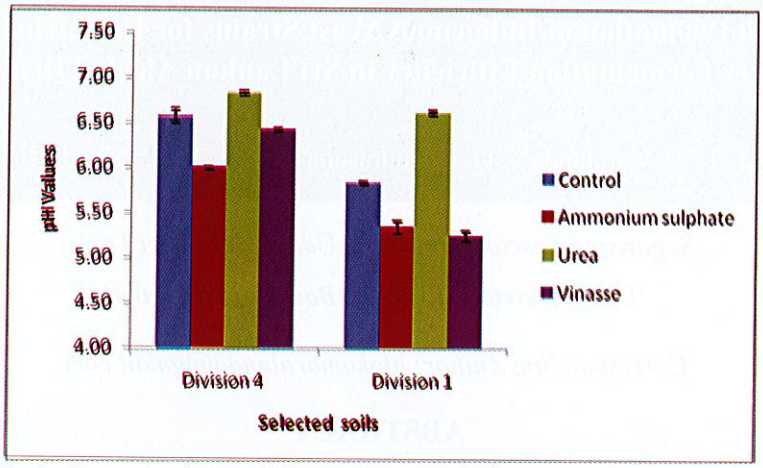

Figure 3 The effect of ammonium sulphate, urea and vinasse on soil pH of Divisions, 1 and 4 at Sevanagala

Conclusions

The findings of this study confirm that the soils in Division 4 and 5 can be grouped as comparatively high pH-buffering soils and those in Divisions 1 and 3 as low pH-buffering soils. These soils behave differently to the application of ammonium sulphate, urea and vinasse. Precautions should be taken when applying ammonium sulphate and vinasse to low pH-buffering soils in Sevanagala to avoid the soil becoming unfavourable (highly acidic) for sugarcane cultivation.

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Isolation and Evaluation of Indigenous Yeast Strains for Improving Sugarcane Molasses Fermentation Efficiency in Sri Lankan Alcohol Distilleries

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ABSTRACT

A study was conducted to isolate yeast strains from the natural environment and to screen them for efficient ethanol production from sugarcane molasses aiming to introduce a more efficient yeast strain for commercial level fermentation of sugarcane molasses into ethanol. Fourty nine indigenous yeast strains were isolated from sugar-containing materials collected from diverse sources. They were named from Y1 to Y49, characterised morphologically, and their performance in ethanol production under laboratory conditions were evaluated. The majority of the isolated yeast strains produced alcohol in molasses medium during a 72-hour laboratory fermentation. Out of the 49 strains evaluated, seven strains, Y5, Y8, Y10, Y11, Y21, Y22 and Y39 were found to be superior to bakers' yeast in terms of molasses fermentation. The isolate Y39 produced the highest ethanol concentration (7.5% v/v) compared to bakers' yeast (6.5% v/v).

Keywords: Alcohol distillery, Bakers' yeast, Fermentation, Molasses, Sri Lanka, Sugarcane

INTRODUCTION

Yeasts are easily grown unicellular eukaryotic fungi, which naturally live as either saprophytes or parasites. They are found in many diverse environments; in plants, flowers, fruits, tree exudates, tanning liquors, necrotic tissues of plants, mushrooms, animals (occasionally as pathogens), and in soil and aquatic environments. They are also found in insects (e.g., in bark beetles, *Ambrosia* beetles and other wood-boring insects and in *Drosophila*), crustaceans and other aquatic animals (Phaff and Starmer,1987; Chandrasena *et al.*, 2006).

Yeasts are of great economic importance as they are used in agricultural and industrial purposes. Many saprophytic yeasts along with bacteria decompose dead organic matter, and thereby, they help in returning the nutrients (derived from the organic matters) to the soil in a form available to green plants. Many types of yeasts are used to produce various foods. They include; bakers' yeast in bread production, brewers' yeast in beer fermentation, yeast in wine fermentation and for xylitol production (Chatterjee *et al.*, 2011). Most of the yeasts produce enzymes, alkaloids and various other organic compounds of great economic importance (Wickerham and Burton, 1952; Yamada,1999; Kurtzman and Fell, 1999). The important metabolic products produced by yeasts are the antibiotics and organic acids such as citric acid. Some yeast strains are used in industrial single-cell protein production from lignocelluloses materials, methanol, n-alkanes, starch, oils and other cheap carbon sources. The pigmented yeasts are used as feed and food colourants, and some of them as single-cell oil (Chatterjee *et al.*, 2011).

Ethanol production is one of the major economic important uses of yeasts. In view of the rising fossil fuel prices and its adverse environmental impacts, worldwide interest in the utilisation of bio-ethanol as a renewable energy source has stimulated studies on the cost and efficiency of industrial processes for ethanol production (Sheela *et al.,* 2008; Chatterjee *et al.*, 2011). Yeast cells carryout alcoholic fermentation using a range of enzymes by converting sugar into carbon dioxide gas (CO_2) and ethyl alcohol. Ethyl alcohol is manufactured by the fermentation of potatoes, cereals, molasses, etc., but in most countries, sugarcane molasses is used as the carbohydrate substrate for the production of ethanol.

Ethyl alcohol production is a major sugarcane-based industry in Sri Lanka. The distillery integrated to each sugar factory produces ethyl alcohol, a green energy source, from the co-product, molasses of sugar production. This directly influences the economic viability and environmental sustainability of the Sri Lankan sugar industry. However, the overall efficiency of the existing processes is low, compared to similar industries elsewhere in the world resulting in high production costs and loss of potential revenue. The overall processing efficiency is generally below 80%, and the alcohol yield is about 290 l/t of molasses due to the use of contaminated water for dilution of molasses, use of inferior yeast (bakers' yeast) for fermentation at Sevanagala distillery, poor control of temperature and pH, inadequate yeast nutrition and unskilled handling of the fermentation process. Therefore, rectification of these shortcomings is essential to increase the fermentation efficiencies of Sri Lankan distilleries (Chandrasena *et al.*, 2006).

The 'ideal' ethanol-producing yeast strains should possess fermentation and growth properties such as fast fermentation rates, high ethanol yields, high tolerance to high ethanol concentrations and low pH levels and high temperature tolerance during fermentation. The use of efficient yeast strains with higher ethanol tolerance to improve ethanol yields in the fermented wash would reduce distillation costs, and hence, increase the profitability of the overall process (Chen and Chen,1985; Patrascu *et al.*,2009).

This research aims at isolation of yeast strains with economically important properties for more efficient fermentation of molasses to increase ethyl alcohol yield in Sri Lankan distilleries compare to bakers' yeast.

MATERIALS AND METHODS

Collection of samples

Samples of waste molasses, waste sugarcane juice, baggasse, filter-mud, distillery effluent and other sugar-containing plant materials from various locations in Sri Lanka were collected in to sterilised containers and transported to the laboratory of the Sugarcane Research Institute, Uda Walawe where experiments were carried out.

Isolation of yeasts

Yeasts were isolated using suitably-diluted samples by streak plating onto MYPG agar (yeast extract 0.3%, malt extract 0.5%, peptone 0.3%, glucose 1% and agar 1.5%) with pH adjusted to 4.8. All isolates were named as Y1, Y2, and so on.

Purification of yeasts

A loopfull of colonies from the agar plates were streaked on MYPG agar medium (0.3% malt extract, 0.3% yeast extract, 0.5% peptone, 1% glucose, 1.5% agar at 4.8 pH) and incubated at 30°C for 3 days. The isolation and streaking were repeated on MYPG agar medium at pH 4.8 until pure cultures were obtained. Colony characters of the pure yeast isolates were examined.

Morphological characterisation

The yeast colonies grown on MYGP agar for 24 hours at 30°C were characterised

morphologically in terms of size, shape, colour and margin.

Fermentation of sugarcane molasses by yeast isolates under laboratory conditions

The samples of sugarcane molasses obtained from the Sevanagala sugar factory were transported to the Sugarcane Research Institute, Uda Walawe for laboratory studies.

The seed culture medium was prepared by diluting molasses to obtain 10% total sugars and adding 0.6% ammonium sulphate and 0.15% potassium dihydrogen phosphate. The medium pH was adjusted to 4.5 and was pasteurised at 80° C for 15 minutes. The yeast isolates sub-cultured on MYPG agar plates were used as seed cultures for molasses fermentation.

The fermentation medium was prepared by diluting molasses to 16% fermentable sugar and adding 0.6% ammonium sulphate and 0.15% potassium dihydrogen orthophosphate.

The initial pH was adjusted to 4.5 with sulphuric acid and pasteurised at 80°C for 15 minutes. The seed culture was added in shaking flasks which contained fermentation medium. The flasks were incubated in a rotary water bath at 30°C with mild shaking (at 100 rpm) (Chandrasena *et al.*, 2006).

The samples were taken from the water bath incubator at 6-hour intervals to determine the alcohol concentration. Ebiliometer was used to measure the alcohol concentration.

Data analysis

All experiments were carried out in triplicate to analyse the significance of the differences in alcohol production ability of the locally-isolated yeast by one-way analysis of variance (ANOVA). The mean differences of ethanol concentration among the isolates were tested using Tukey's test at the 5% level of probability. MINITAB 16 was used for the statistical analysis.

RESULTS AND DISCUSSION

Morphological features

Fourty nine yeast strains were isolated from various sugar-rich sources in natural environments. The yeast isolates were identified based on their colony morphology (Table 1). Most of the isolated colonies exhibited smooth surfaces with circular margins. The colour of the colonies showed a wide variation of creamy white and white. The cells were found with various shapes such as round oval and ellipsoidal.

Molasses fermentation and ethanol production capability

The yeast strains isolated from various sources were tested for their alcohol- producing capabilities in molasses medium. Table 2 indicates that most of the isolates produced high levels of alcohol from molasses fermentation compared to the bakers' yeast after 72 hours.

The results of ANOVA indicated that there was a significant variation in alcohol yields obtained from fermentation of molasses by 49 yeast strains for 72 hours ($p = 0.000$). Seven strains, namely, Y 5, Y 8, Y 10, Y11, Y21, Y 22 and Y 39 showed the best performance in molasses medium than bakers' yeast. The highest alcohol yield (7.5%v/v) was produced by the yeast isolate Y 39. It was isolated from the molasses collected from the Pelwatte distillery premises. According to the results, the maximum ethanol concentration was achieved around 48 hours after fermentation and amounted to 7.5% by Y39 yeast strain.

The yeast isolates which performed well in the fermentation of molasses than bakers' yeast were further evaluated to test their alcohol production capabilities in molasses medium. The results of the evaluation of seven selected superior yeast isolates and bakers' yeast are presented in Figure 1.

Table 1 Morphological features of the yeast isolates

Strain	Surface	Colour	Cell Shape	Margin
Y 1	Smooth	Off White	Oval	Irregular
Y 2	Smooth	Off White	Oval	Irregular
Y 3	Smooth	White	Oval	Circular
Y 4	Smooth	White	Oval	Circular
Y 5	Rough	Off White	Oval	Irregular
Y 6	Rough	White	Rounded	Circular
Y 7	Smooth	White	Oval	Circular
Y 8	Smooth	White	Oval	Circular
Y 9	Smooth	White	Oval	Circular
Y 10	Smooth	Red	Oval	Irregular
Y 11	Smooth	White	Oval	Circular
Y 12	Smooth	White	Rounded	Circular
Y 13	Smooth	Off White	Oval	Irregular
Y 14	Rough	White	Oval	Irregular
Y 15	Rough	Off White	Rounded/ Oval	Circular
Y 16	Smooth	White	Rounded/ Oval	Circular
Y 17	Smooth	White	Rounded/ Oval	Circular
Y 18	Smooth	White	Rounded	Circular
Y 19	Smooth	White	Rounded	Irregular
Y 20	Smooth	White	Ellipsoidal	Circular
Y 21	Smooth	White	Oval	Circular
Y 22	Smooth	White	Oval	Circular
Y 23	Smooth	Off White	Rounded	Circular
Y 24	Smooth	White	Oval	Circular

Y 25	Smooth	Off White	Oval	Irregular
Y 26	Smooth	Off White	Oval	Irregular
Y 27	Smooth	Off White	Oval	Irregular
Y 28	Smooth	Off White	Cylindrical	Irregular
Y 29	Smooth	White	Rounded	Irregular
Y 30	Smooth	Off White	Oval	Irregular
Y 31	Rough	White	Oval	Irregular
Y 32	Smooth	Off White	Oval	Irregular
Y 33	Smooth	White	Oval	Circular
Y 34	Smooth	Off white	Rounded	Circular
Y 35	Smooth	White	Oval	Circular
Y 36	Smooth	Off White	Oval	Irregular
Y 37	Smooth	Off White	Oval	circular
Y 38	Smooth	Off White	Oval/rounded	Circular
Y 39	Rough	White	Oval	Irregular
Y 40	Smooth	Off White	Oval	Circular
Y 41	Smooth	Off White	Oval	Irregular
Y 42	Rough	White	Oval	Irregular
Y 43	Smooth	Off White	Oval	Irregular
Y 44	Smooth	Off White	Oval	Irregular
Y 45	Smooth	Off White	Oval	Irregular
Y 46	Smooth	White	Oval	Circular
Y 47	Smooth	Off White	Oval/rounded	Irregular
Y 48	Smooth	Off White	Oval	Irregular
Y 49	Smooth	White	Oval	Circular
Bakers' yeast	Smooth	White	Oval/ Rounded	Circular

Table 2 Alcohol yields of the yeast isolates

Isolate	Source	Alcohol %
Y 1	1st mill juice	6.1IJ
Y 2	2nd mill juice	2.4W
Y 3	Bagasse	6.2IJ
Y 4	Sugar cane residues from Sevanagala	5.8L
Y 5	Rotten Cashew	6.6DE
Y 6	Rotten banana	6.4FGH
Y 7	Bagasse after 1stmilling	3.9R
Y 8	Bagasse after 2ndmilling	6.7CD
Y 9	Spent wash	6.1JK
Y 10	Spent wash (Pelwatte)	6.7CD
Y 11	Old molasses	6.9B
Y 12	Waste trickle	6.2IJ
Y 13	Jaggary juice	2.4VW
Y 14	Sugarcane base	3.1S
Y 15	Rotten tomato	2.6UV
Y 16	Rotten potato	2.6U
Y 17	Rotten orange	2.6U
Y 18	*Kithul* toddy (Kuruwita)	6.2IJ
Y 19	Rotten carrot	5.5M
Y 20	Filter mud	2.6U
Y 21	Factory waste water	6.8BC
Y 22	Spent wash	6.8BC
Y 23	Waste molasses	2.8T
Y 24	Waste molasses	6.2HIJ
Y 25	Waste molasses	2.1X
Y 26	Killinochchi coconut toddy	6.3 GHI
Y 27	Poonagarpalmyra toddy	5.8L

Y 28	Mix fruit jam	1.5^{Y}
Y 29	Sevanagala distillery effluent	4.5^{P}
Y 30	Filter mud	1.4^{Y}
Y 31	Molasses	1.1^{Z}
Y 32	Sevanagala molasses	0.5^{AB}
Y 33	Filter mud	0.8^{AA}
Y 34	Lunuwila coconut toddy	5.9^{KL}
Y 35	Molasses from Sevanagala factory site	6.4^{EFG}
Y 36	Filtermud from compost pit	2.3^{W}
Y 37	Filtermud from drain	2.1^{W}
Y 38	Spentwash	4.2^{Q}
Y 39	Molasses from Pelwatte	7.5^{A}
Y 40	Cane tops	5.1^{N}
Y 41	Bagasse	4.5^{P}
Y 42	Papaya	4.2^{Q}
Y 43	Filtermud	4.8^{O}
Y 44	Bagasse from Sevanagala sugarcane Field	4.8^{O}
Y 45	Jaggery	0^{AC}
Y 46	Akkarayankulum coconut toddy	5.1^{N}
Y 47	Cashew	5.3^{N}
Y 48	Molasses	2.3^{W}
Y 49	Filter mud	2.8^{T}
Bakers' Yeast(BY)		6.5^{DEF}

Note: Data values are means of three replicates. Means with the same letters are not significantly different according to turkey test

All superior yeast isolates produced maximum levels of ethanol after 48 hours of fermentation under laboratory conditions. The results indicated that the alcohol yields produced by the seven selected yeast strains were significantly higher than that of the bakers' yeast (Table 3).

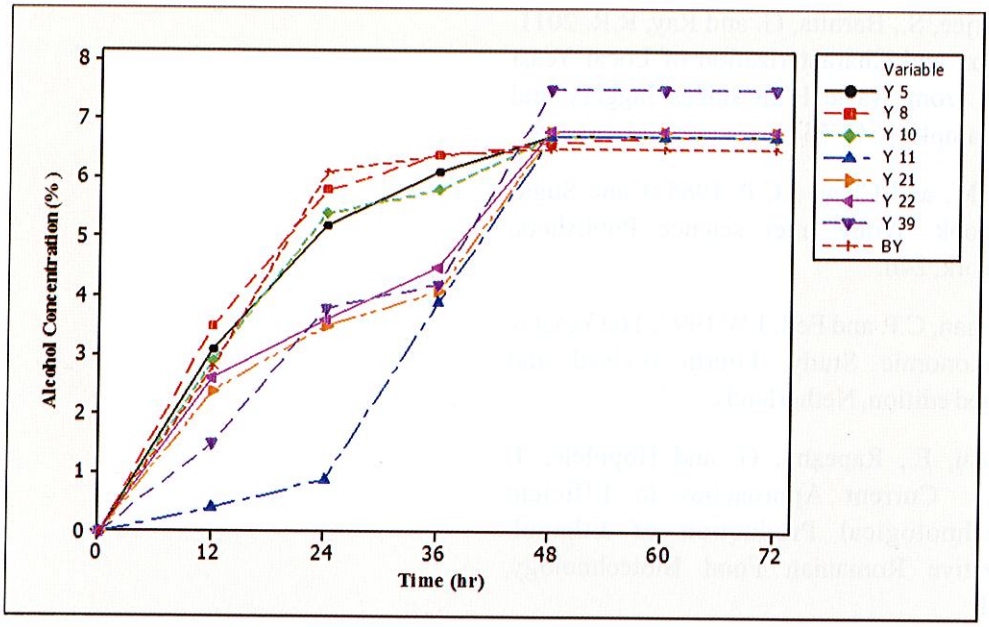

Figure 1 Kinetics of alcohol production from superior yeast isolate

Table 3 Percent alcohol produced by the seven selected yeast strains

Yeast Strain	Mean
Y39	7.4667^{A}
Y10	6.8667^{B}
Y22	6.8000^{BC}
Y21	6.7667^{BCD}
Y8	6.7000^{CD}
Y10	6.6667^{CD}
Y5	6.6333^{D}
Bakers' yeast	6.4667^{E}

Note: Data values are means of three replicates. Means with the same letters are not significantly different according to turkey test.

Conclusion

Yeast strains with superior molasses fermentation features were isolated from sugar-containing materials in Sri Lanka. Out of the fourty nine yeast strains evaluated, seven strains were found to be superior to bakers' yeast in terms of sucrose fermentation in molasses medium. The results revealed that the yeast strains isolated from the molasses have the potential to produce high alcohol yields than other strains isolated from sugary materials and the currently-used bakers' yeast. Further evaluations of these strains under scaled-up conditions are planned to find out their suitability for commercial use in alcohol distilleries

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Energy Requirements for Base Cutting of Selected Sugarcane Varieties in Sri Lanka

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ABSTRACT

Knowledge of energy requirement for sugarcane harvesting is an important requirement for designing mechanical harvesters suitable to local conditions. The objective of this study was to quantify and compare the mechanical energy requirements for base cutting of three selected sugarcane varieties under local conditions. Shear strength, specific shearing energy and energy requirement to cut sugarcane from the base for three commercial sugarcane varieties, namely, SL96 128, SL 96 328 and Co 775 were estimated. The results indicated that the shear strength of the varieties, SL 96 128, SL 96 328 and Co 775 was 1.69MPa, 2.42MPa, and 1.74MPa respectively. The variety SL 96 328 required significantly higher shear strength than the other two varieties. The specific shearing energy of the three varieties, SL 96 128, SL 96 328 and Co 775 was 27.77 mJ/mm^2, 39.30 mJ/mm^2, and 35.24 mJ/mm^2 respectively. The variety SL 96 128 showed a significantly lower energy requirement than the other two. The total energy requirement to cut 1 ha of sugarcane from the base was lower in SL 96 128, and it was 1510.4 kJ. This value was 1931.9 kJ and 1968.9 kJ for SL 96 328 and Co 775 respectively.

Keywords: Energy, Harvesting, Shear strength, Sri Lanka, Sugarcane

INTRODUCTION

Because of the practice of manual harvesting, the shortage of labour during sugarcane harvesting has been one of major constraints for sugarcane production in Sri Lanka. This has led to increase the cost of both sugarcane and sugar production. Sugarcane harvesting is the highest cost component in sugarcane production. The cost of production of sugar has increased due to failures of sugar mills to run at their maximum capacities due to insufficient cane supplies. As a result most often the mills are running at under capacity sometimes even below 50%. Therefore, introduction of appropriate mechanised harvesting devises to local sugarcane field has become an urgent requirement in sugarcane and sugar production at a lower cost. Most of the mechanical harvesters developed in other countries are not suitable for local conditions. Therefore, it is essential to study local harvesting conditions before introduction of harvesters. In Sri Lanka, most of the sugarcane lands are less than 1ha in size. The use of imported harvesters is not recommended due to their high capacity and waste of energy and increased the emission air pollutants when operating on small lands. It will increase not only the cost of sugarcane harvesting, but also, pollution of the environment. The amount of energy required for harvesting a unit area is better indicator for selecting of appropriate harvesters for local conditions. Samaila (2012) has found that energy requirement for cutting top and base of the sugarcane was 15.71J and 23.83 J respectively. Taghijarah (2010) has reported that the shear strength and specific shearing energy of the sugarcane cultivated in Iran were 3.64MPa and 51.41 mJ/mm^2 respectively. The effect of cane stalk orientation for cutting energy was studied by Taghinezhad (2012). According to that sample orientation perpendicular to the cane

stalk has been reported as to be using maximum energy to cut the cane. However, no any investigations have been carried out to study the energy requirement to harvest sugarcane under local conditions. The main objective of this study was quantification and comparison of mechanical energy requirement of cutting some selected sugarcane varieties from their base under local conditions.

MATERIALS AND METHODS

This laboratory experiment was conducted at the Division of Mechanisation Technology, Sugarcane Research Institute (SRI), Uda Walawe. Samples were taken from three commercially-cultivated sugarcane varieties, namely, SL 96 128, SL 96 328 and Co 775 separately (each variety for each treatment). Ten sugarcane stalks from each farmer plot were collected as 3 replicates. Ten-centimetre long stalks from the base of the cane were separated from all collected stalks and average diameter of each separated stalk was recorded with 15 mm away from the lower node. The moisture contents of the test samples were measured on wet basis (w.b).

The shear force of each sample was measured subjecting to shearing action by using specific shearing instrument (Figure 1) developed by SRI. This instrument was operated according to the shearing principle given by Ramalingam (2009). The shearing action on the test materials was applied by the 10mm thick two sliding plates moving from each other (Figure 2). Those plates were consisted of different sized holes to accommodate different-sized test samples. The shearing force applied on the test samples was measured from load cell, and it was indicated by digital indicator. A constant loading rate of 10 mm/min was maintained throughout the testing because loading rate significantly affects the shear strength (Taghijarah *et al.*, 2011). During shear force testing, the force applied was recorded with displacement of the sliding plates until specimen failure. The orientation of the force applied to the test sample was kept as perpendicular to the cane stalk since, the force applied to the stalk was maximum with sample in perpendicular to the cane stalk (Taghinezhad *et al.*, 2012). The average values of the shear force of ten stalks taken from each plot were calculated for each variety in each replicate. The calculated average values of shear force of each replicate were graphed against the displacement of shearing force (Figure 3). The shear strength of the test material was calculated according to the following equation (Lina, 2009):

$$\tau = \frac{P}{A}$$

where: τ is Shear strength (MPa), P is the maximum shear force (N) and A is the area (mm^2) in which shear occurs.

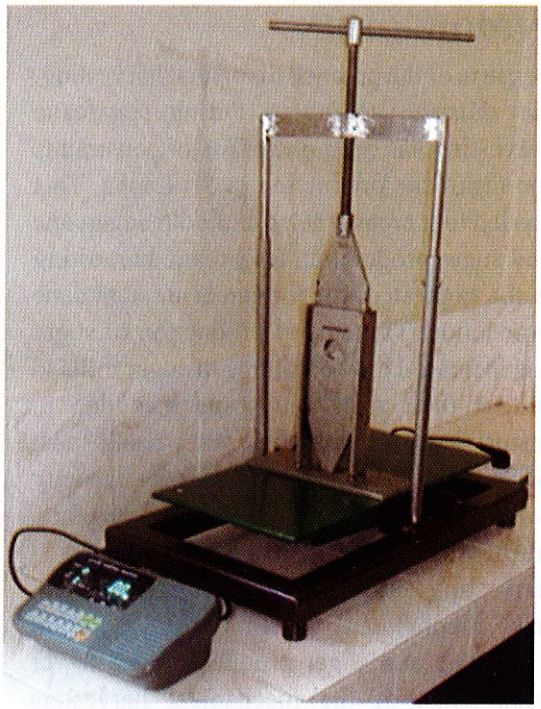

Figure 1 Shear force testing instrument

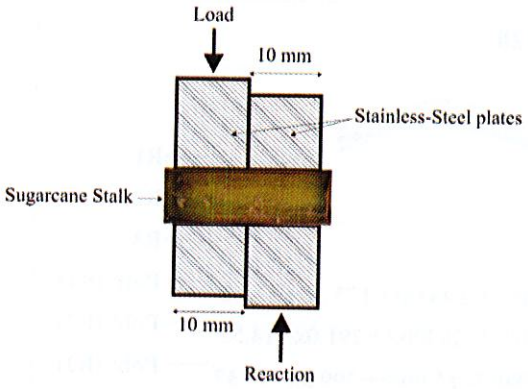

Figure 2 Application of shearing action on test sample

The best-fitted trend line with its equation for each replicate in each treatment was estimated using MS Excel 2013. Then shearing energy was calculated by integrating area under the curve (Curve equation) of the shear force displacement diagram. Taghijarah (2011) has calculated the specific shearing energy using the following equation:

$$E_{sc} = \frac{E_s}{A}$$

where: E_s is shearing energy (mJ) and E_{sc} is specific shearing energy.

Then average energy requirement for cutting of base for 1 ha was calculated using the following equation:

$$E_{ba} = \frac{E_{sc} N_c \pi \left(\frac{D}{2}\right)^2}{1000000}$$

where: E_{ba} is average energy requirement (kJ) for cutting of base for 1 ha, N_c is average number of cane stalks (Numbers) per ha according to the common planting practice adopted in Sri Lanka, and D is average diameter (mm) of cane base of the selected variety.

The means of the energy requirements of the three varieties were compared at 5% significance level using analysis of variance (ANOVA) using SAS statistical package.

RESULTS AND DISCUSSION

The results showed that the moisture contents of the test samples were in the range of 75-78% w.b. The shear strength of the variety SL 96 328 (2.42MPa) was significantly higher than that of the other two varieties at 5% significance level. The shear strength of the variety SL 96 128 and Co 775 were 1.69MPa and 1.74MPa respectively. The mean value of the shear strength of the predominant variety in Iran (IRC99-01) was 3.64MPa (Taghijarah *et al.*, 2011) at the average moisture content on 75.25% w.b. Therefore, local varieties required lesser force to cut from their base than the variety IRC99-01 in Iran.

The specific shearing energy of the variety SL 96 328 (39.30mJ/mm^2) was not significantly different from that of the variety Co 775 (35.24 mJ/mm^2). The variety SL 96 128 showed the lowest specific shearing energy value of 27.77 mJ/mm^2. But according to Taghijarah (2010),

Table 1 Mean values of shear strength and specific shearing energy and energy requirements for base cutting of different sugarcane varieties

Verity	Shear Strength (MPa)	Specific Shearing Energy (mJ/mm2)	D (mm)	Nc(No.)	E_{ba}(kJ/ha)
SL 96 128	1.69^b	27.77^b	24.0	120000	1510.4
SL 96 328	2.42^a	39.30^a	22.8	120000	1931.9
Co 775	1.74^b	35.24^a	26.7	100000	1968.9

Note: The mean values with the same letters in each columns are not significantly different at 5% probability.

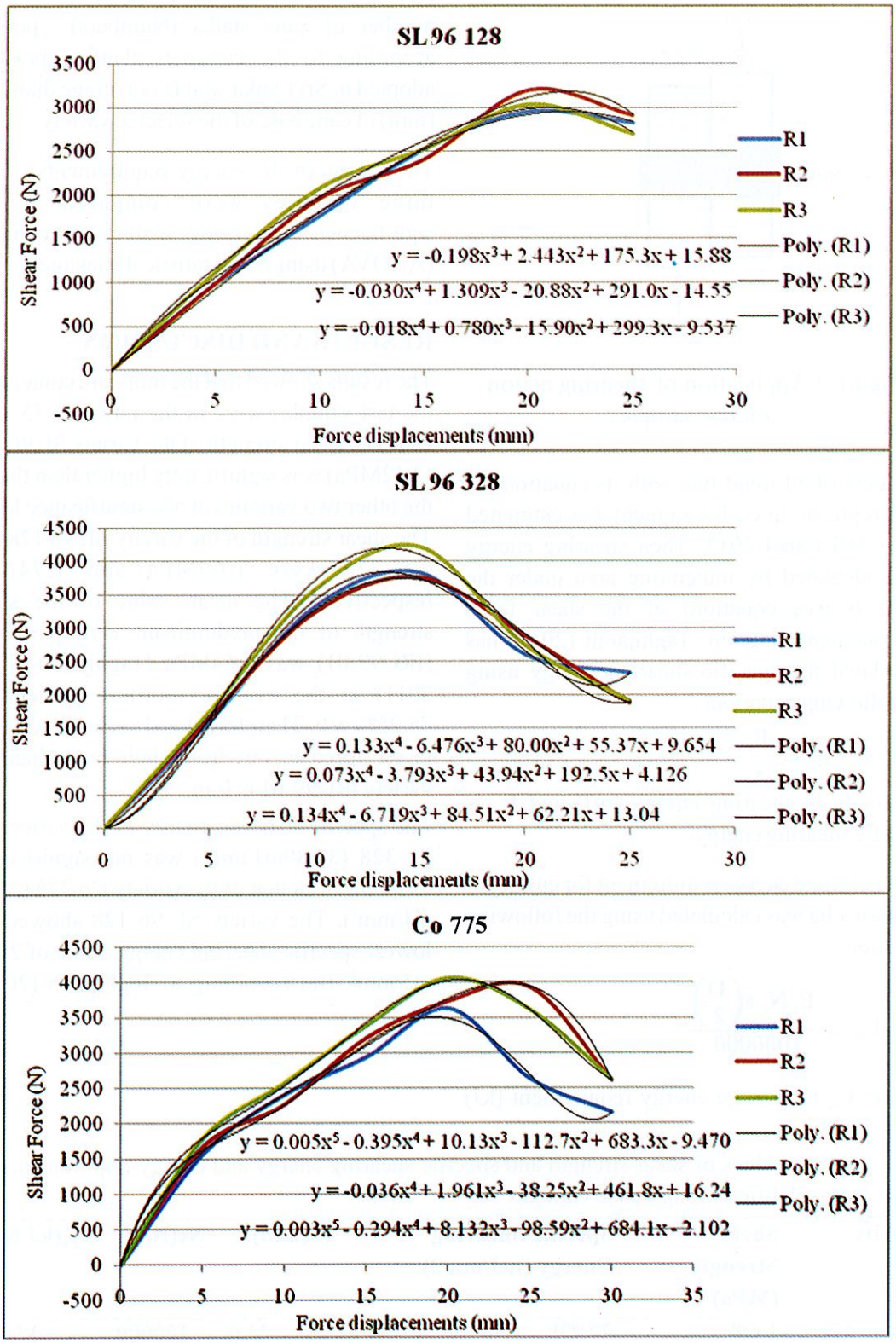

Figure 3 Average shear force versus shear force displacement in different varieties

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