Tropical Agricultural Research Vol. 13: 220-230 (2001)

Influence of Nitrogen Application and Varietal Differences on Selected Physiological Parameters of Sugarcane

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ABSTRACT. *Effect of nitrogen and variety on physiological processes associated with yield determination of sugarcane has been given little attention under Sri Lankan growing conditions. This study examined how nitrogen and variety interactive effects influenced physiological parameters of sugarcane in the low country dry zone of Sri Lanka. Three levels of nitrogen with 3 varieties were tested as 9 treatment combinations in a split plot design with 4 replicates. Leaf area index, photosynthetically active radiation, radiation use efficiency, total dry matter production, partitioning of biomass to sink, leaf nitrogen content, leaf chlorophyll content and rate of photosynthesis were studied in this field experiment. Application of nitrogen fertilizer positively influenced all parameters measured under the tested field condition. The leaf area index was lowest in SL8306 with no nitrogen treatment. Lack of nitrogen application caused 28, 18, 28, 10 and 13% reduction in leaf area index, photosynthesis rate, leaf nitrogen content, leaf chlorophyll content and partitioning of biomass to sink respectively from that of high nitrogen treatment plants at their peaks. Highest radiation use efficiency (3.91 g/MJ) was observed with the 200 kg of nitrogen per hectare and this was an increment of 42 and 25% from that of control and 100 kg of nitrogen per hectare respectively. Variety SL8306 showed higher radiation use efficiency (3.35 g/MJ) than CO775 and SL7130. Though CO775 and SL7130 had higher values of leaf area index (7 and 4% increment) and chlorophyll content (11 and 7% increment) compared to SL8306, biomass production (5 and 15% increment) and partitioning of biomass to sink (4 and 7% increment) were higher in SL8306 than that of CO775 and SL7130 at 210 and 270 sampling dates. The interactive effects of nitrogen and variety were not significant on the physiological parameters measured, but the main effects of nitrogen and variety were significant with most of the parameters measured throughout the growing period.*

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.), a C4 species, is an economically important crop widely grown throughout the subtropical and tropical regions of the world. It is estimated that the energy value of 1000 kilocalorie, which is required in average man's annual food consumption could be produced from about 0.05 ha of sugarcane. In comparison, rice requires six times and whole wheat flour five times as much land to produce the same amount of energy (Mettananda, 1990). Therefore, sugar produced by the sugarcane plant is the cheapest form of energy producing the food required by humanity (Mettananda, 1990).

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Sugarcane has been described as the most efficient of all crops in storing the sun's energy (Subasinghe, 1994). Sugarcane productivity is an integration of various factors. Among the several factors responsible for increasing sugarcane yield, suitable varieties and adequate supply of nutrients, particularly N, P and K are important. Nitrogen is regarded as the most essential element in regulating sugarcane growth, development and yield (Clements, 1980). Nitrogen fertilization increases the growth rate, leaf area, cane yield and sugar yield (Rathi and Singh, 1982; Srivastava *et al.*, 1984). This is partially attributable to increased photosynthesis of sugarcane with increasing nitrogen availability because nitrogen is a major component of ribulose 1, 5 bisphosphate carboxylase oxygenase (Rubisco), phosphoenolphyruate carboxylase (PEPC), which are two major enzymes involved in C4 photosynthesis. The nitrogen fertilizer requirement of sugarcane varies depending on genotypic and environmental differences. It has been reported that sugarcane cultivars differ in the rate of assimilation at different physiological stages of development and these differences are responsible for the different nutritional requirement and responses among cultivars (Davidson, 1953; Yadav and Sharma, 1980).

Most of the previous studies on sugarcane nutrition were mainly focused on the effect of differential supply of nutrients on cane and sugar yield. These studies have reported diverse and sometimes contrasting results. Information on specific physiological responses of sugarcane to nutrient supply is needed to provide a background for interpretation of agronomic studies in which interactions between genotypes and their aerial and edaphic environments are difficult to explain. The physiological basis for the cultivar differences in nutrient requirement of sugarcane has also not been clearly defined under the Sri Lankan conditions. The principle objective of the present study was to examine the nitrogen and variety interactive effects on the physiological parameters and to quantify the yield responses of sugarcane under Sri Lankan growing condition. In addition the coordination of individual physiological responses that leads to an overall change in growth at different nitrogen levels were characterized.

MATERIALS AND METHODS

This experiment was conducted at the Sugarcane Research Institute (SRI) at Udawalawe during 2000 and 2001. The site is situated in the low country dry zone (DL_1) of Sri Lanka (Panabokke, 1996), where the annual average rainfall is 1450 mm with a distinctly bi-modal distribution. The temperature during the experimental period was 29 to 34°C (day) and 24 to 28°C (night). The soil of the experimental site belongs to the great group Reddish Brown Earth (RBE) soils with sandy clay loam textural class and a pH of 6.7 (1:2.5 soil water). The initial total soil nitrogen level was 0.12%.

Three levels of nitrogen as N_0, N_{100} and N_{200} made by application of 0, 100 and 200 kg of N/ha and three varieties of sugarcane CO775, SL7130 and SL8306 were used as treatments in a split plot design. Nitrogen levels as the main plot and variety as sub plots with four replicates. The combinations of nitrogen and variety treatments were N_0CO775, N_0SL7130, N_0SL8306, N_{100}CO775, N_{100}SL7130, N_{100}SL8306, N_{200}CO775, N_{200}SL7130 and N_{200}SL8306. Irrigation was done once in 10 days until the 11[th] month after planting. The plot size was 10 m long with six rows and the space between rows was 1.37 m. Three meter space was maintained between plots. Eight month old 3 budded stem cuttings were used as planting materials and 210 cuttings were planted per plot. Urea was used as the nitrogen source. Other than urea, all the plots were fertilized with Triple Super Phosphate (TSP) and Murate of Potash (MOP) at the rate of 40 kg/ha and 100 kg/ha respectively, according to the recommendation of SRI. One third of nitrogen and potassium, and full amount of phosphorus were applied, as basal dressing and the balance was applied 90 days after planting. Other field practices were similar for all plots.

The following parameters were measured at 90,150, 210 and 270 days after planting. Dry matter production (TDM) (kg/ha), was measured using dead plant parts (trash), green leaves, immature top parts (cabage) and stem (stalk) after oven dying at 80°C. Using these data, partitioning of biomass to stalk (PBS) was calculated. (PBS = stalk dry matter/total dry matter × 100). Leaf area (LA) was measured in all leaves of randomly selected 4 plants by a portable leaf area meter (Li-3000, Li-Co-R, Inc.) and leaf area index (LAI) was calculated by using LA and ground area, LAI = LA/ground area. Leaf chlorophyll content (mg/g of fresh leaves) was measured by light absorbance of acetone extract of chlorophyll (Yoshida *et al.*, 1976). Photosynthesis rate ($\mu mol/m^2/s$) and Photosynthetically Active Radiation (PAR) ($\mu mol/m^2/s$) were measured by a portable photosynthesis system (Li-6400, Li-Co-R, Inc.). Photosynthesis rate and PAR were measured under full sunlight (9:00 am. to 3:00 pm.). Using TDM and time duration, Crop Growth Rate (CGR) ($g\ m^{-2}\ d^{-1}$) was calculated by, CGR = (TDM_2 - TDM_1)/Time duration. Radiation Use Efficiency (RUE) (g/MJ) was calculated using CGR and PAR, RUE = CGR/PAR. Total leaf nitrogen percentage was measured by using a macro-kjeldahl distillation apparatus (Yoshida *et al.*, 1976). Leaf chlorophyll content, total leaf nitrogen percentage and photosynthesis rate were measured in the Top Visible Dewlap (TVD) or youngest fully open leaf of four randomly selected plants of each plot. Total biomass production and leaf area index were measured by using destructive sampling of four randomly selected plants. Analysis of variance (ANOVA) procedure was carried out for each sampling date separately using the SAS statistical package.

RESULTS AND DISCUSSION

Leaf area index (LAI), total dry matter production (TDM) and radiation use efficiency (RUE)

Application of N significantly increased LAI at all sampling dates (Fig.1a). All treatments attained their maximum LAI at 210 days after planting (DAP) and thereafter it decreased. Highest value of the LAI was observed in treatment N_{200} while N_{100} and N_0 gave medium and lowest LAI respectively. LAI of the medium and zero nitrogen plants (N_{100} and N_0) reduced by 12 and 28% respectively compared to the N_{200} plants at 210 DAP. Variety CO775 had higher LAI compared to SL7130 and SL8306 at all the sampling dates and these values were significant ($P<0.05$) except at 150 DAP in these treatments (Table 1). LAI of variety CO775 increased approximately by 4 and 8% compared to SL7130 and SL8306 respectively at their peaks. After 210 days of planting LAI showed a rapid reduction. Wolf *et al.* (1988) showed that this is due to the start of maturity of sugarcane with higher demand of nitrogen by sink and higher rate of respiration.

As sugarcane is a determinate crop it produces its leaves only in the early (vegetative) stage of the crop cycle (1-9 months). Therefore to achieve maximum expansion of the initiated leaves, nitrogen is necessary during this stage. The pattern of LAI

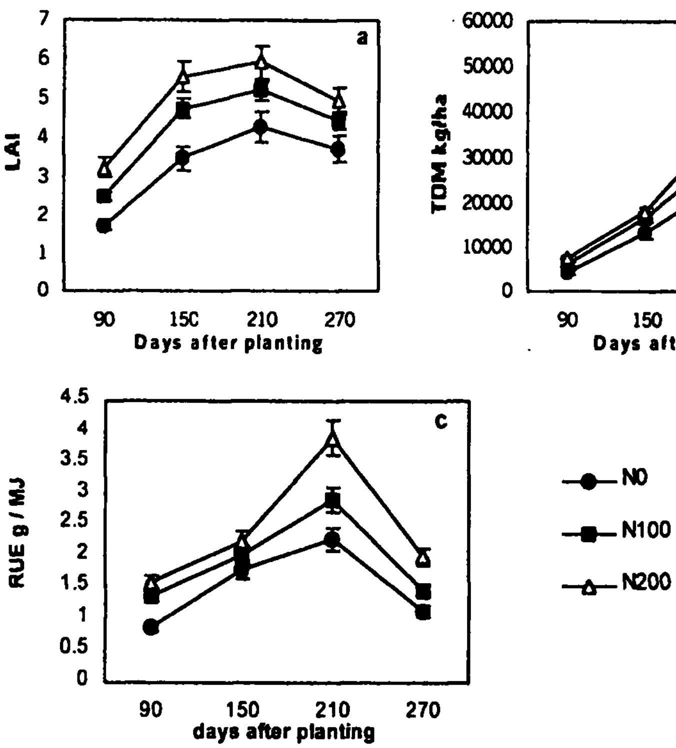

Fig. 1. Seasonal variation of leaf area index (LAI) (a) and total dry matter production (TDM) (b) and Radiation Use Efficiency (RUE) (c) of sugarcane in response to nitrogen.
[Note. These graphs were plotted using average values of the three sugarcane varieties (CO775, SL7130 and SL8306)].

in response to different treatment combinations is positively correlated with Radiation Use Efficiency (RUE) (Fig. 2). With increase of LAI, RUE increased in all three varieties. Plants in N_{200} treatment increased RUE approximately by 42 and 25% compared to N_0 and N_{100} plants at their peaks. RUE increased up to 210 days after planting and then decreased rapidly with the age (Fig. 1c). Since at the early stages of the plants biomass production was at an increasing rate, and therefore increased crop growth rate and thus the RUE. With the maturity of the plant the crop growth rate reduced through the biomass increased with decreasing rate. Highest value of the RUE (3.91 g/MJ) was given by N_{200} plants. This was due to highest LAI (5.92) and highest crop growth rate (32.1 g/m^2/s) through highest biomass production (37267 kg/ha) of N_{200} plants was at 210 DAP.

N_0 and N_{100} plants produced 30296 kg/ha and 38811 kg/ha of TDM respectively, while N_{200} plants had 45108 kg/ha of TDM at the 270 DAP. The increment of TDM in N_{200} plants was approximately 33 and 14% compared to N_0 and N_{100} respectively at 270 DAP. TDM of the three varieties were almost the same at the early stages except 270 DAP. At 270 DAP, SL8306 plants had highest TDM (40667 kg/ha) and it had a significant increment ($P<0.05$) in varieties CO775 and SL7130 by 5 and 15% respectively (Table 1).

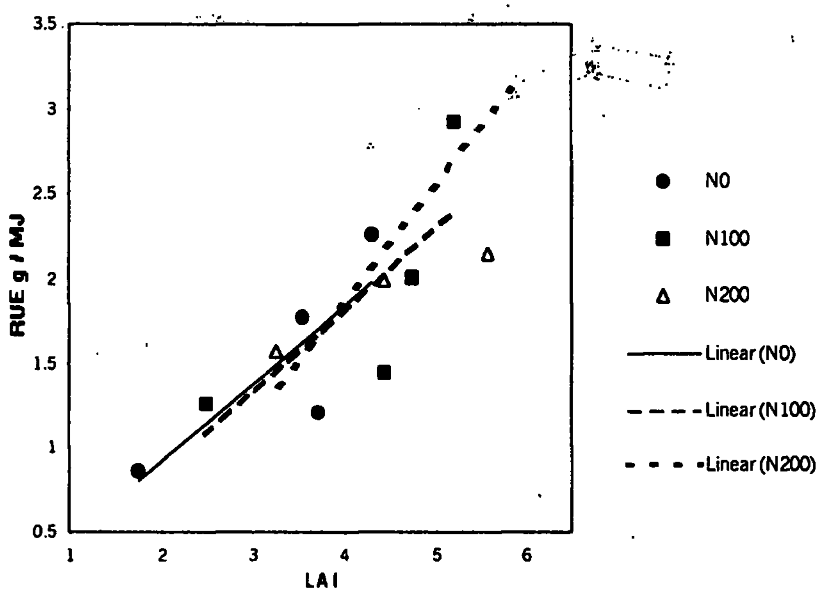

Fig. 2. Relationship between leaf area index (LAI) and radiation use efficiency (RUE).

Table 1. Varietal effect on leaf area index (LAI), total dry matter production (TDM) and radiation use efficiency (RUE).

Parameter	Variety	Sampling days			
		90	150	210	270
LAI	CO775	2.68a	4.73a	5.32a	4.60a
	SL7130	2.64a	4.60a	5.18a	4.25b
	SL8306	2.17b	4.53a	4.97b	4.22b
	CV%	9.46	7.35	11.26	8.41
TDM (kg/ha)	CO775	5850a	16755a	30802a	38820b
	SL7130	6769a	16201a	29477b	34728c
	SL8306	5432a	14681a	31267a	40667a
	CV%	11.75	13.63	10.10	14.62
RUE (G/MJ)	CO775	1.02a	1.82a	2.83b	1.62b
	SL7130	1.06a	1.90a	2.88b	1.42b
	SL8306	1.21a	1.97a	3.35a	1.90a
	CV%	7.56	9.11	12.64	8.78

These values are means of 12 observations. Means with the same letter in a column within a parameter are not significantly different at $P<0.05$.

These results confirmed previous observations (Muchow, 1988; Subasinghe, 1994) showing nitrogen had a marked influence on leaf area development and dry matter production. Effect of nitrogen on both cell number and size would be the reason for increasing leaf area (Muchow, 1988). The maintenance of green leaves for a long period even in the maturity stage would have enabled the crop to intercept radiation for a long period and increased biomass accumulation through photosynthesis at all high rates of nitrogen treatments (N_{200}CO775, N_{200}SL7130 and N_{200}SL8306). The reason for decrease in biomass production in N_0 plants could be either a reduction in the amount of radiation intercepted by the canopy or from a decrease in the efficiency with which the intercepted radiation is used for dry matter production or a combination of both these factors.

Radiation use efficiency (RUE) of C4 plants is more responsive to nitrogen supply than radiation interception, and RUE increased with higher rates of applied nitrogen (Muchow, 1988; Subasinghe, 1994). LAI in variety SL8306 plants decreased approximately by 7 and 4% compared to CO775 and SL7130 respectively. Although CO775 and SL7130 showed higher values of LAI than SL8306, total dry matter production of the SL8306 was higher than that of CO775 and SL7130 at 210 and 270 DAP. This was due to high radiation use efficiency (RUE) of SL8306 and SL8306 which increased RUE approximately by 15 and 14% than that of CO775 and SL7130 respectively (Table 1.). There was no significant interaction ($P>0.05$) effect by nitrogen and variety on LAI, TDM and RUE.

Leaf nitrogen, leaf chlorophyll and photosynthesis rate

Nitrogen fertilizer application significantly increased ($P<0.05$) leaf nitrogen, chlorophyll content and photosynthesis rate at all sampling dates (Fig. 3a, b, c). Rate of photosynthesis, leaf chlorophyll and leaf nitrogen content were lower in plants grown at zero nitrogen by approximately 18, 10 and 28% respectively than that of N_{200} plant at their peaks (at 150 DAP). These three physiological factors were not significantly different ($P<0.05$) between N_{100} and N_{200} except leaf chlorophyll and nitrogen contents at 210 and 270 DAP (Fig. 3a, b, c). Lower photosynthesis rate in N_0 plants may be associated with significant reduction in leaf nitrogen and chlorophyll in all stages of sampling. Leaf nitrogen had a positive correlation with photosynthesis rate in all three varieties (Fig. 4).

Variety SL8306 was highly responsive to nitrogen than the other two varieties, and therefore SL8306 showed lowest photosynthesis rate with lower leaf nitrogen (1.21%) and highest photosynthesis rate with higher leaf nitrogen (2.61%). Variety CO775 and SL7130 showed fairly higher photosynthetic rate with lower leaf nitrogen and photosynthesis was restricted to 2.11 and 1.98% respectively (Table 2 and Fig. 4). Therefore, SL8306 was more responsive to nitrogen fertilizer application than the other two varieties. Nitrogen is a major component of ribulose 1, 5 bisphosphate carboxylase oxygenase (Rubisco) and phosphoenolphyruate carboxylase (PEPC), which are two major enzymes involved in C4 photosynthesis. Thus the stress of nitrogen to sugarcane will affect the above two enzymes due to which photosynthesis may reduce significantly (Davidson, 1953; Yadav and Sharma, 1980; Gascho *et al.*, 1986).

High nitrogen level is accompanied by increases in both mesophyll and stomatal conductance in C4 plants (Bolton and Brown, 1980; Subasinghe, 1994). This is consistent with the strong correlation between photosynthesis rate and leaf nitrogen content observed in numerous crops and native species (Field and Mooney, 1986; Sinclair and Horie, 1989;

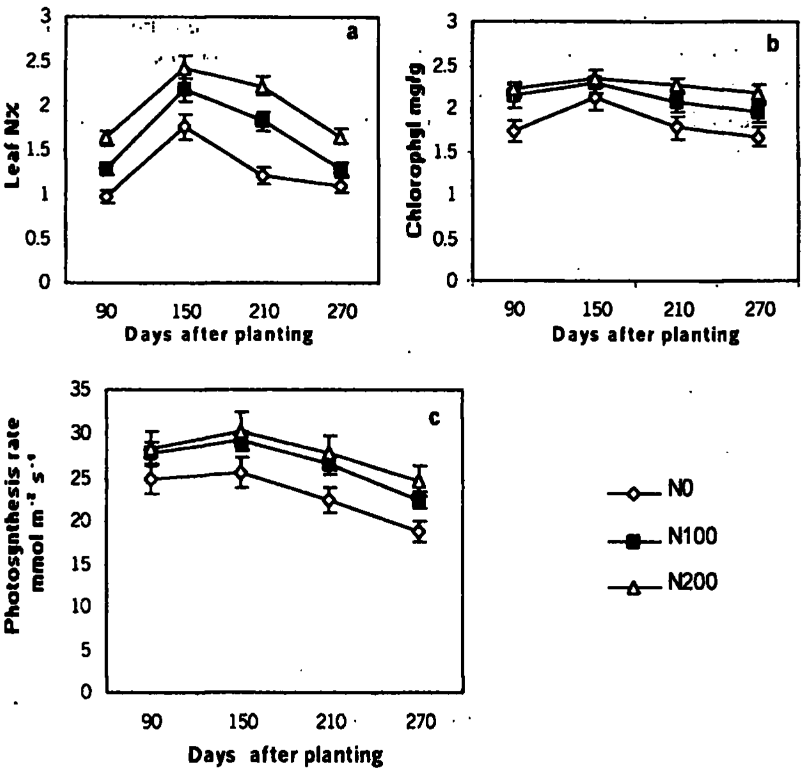

Fig. 3. **Seasonal variation of leaf nitrogen (a), leaf chlorophyll (b) and photosynthesis rate (c) in response to nitrogen fertilizer.**
[Note: These graphs were plotted using average values of the three sugarcane varieties (CO775, SL7130 and SL836)].

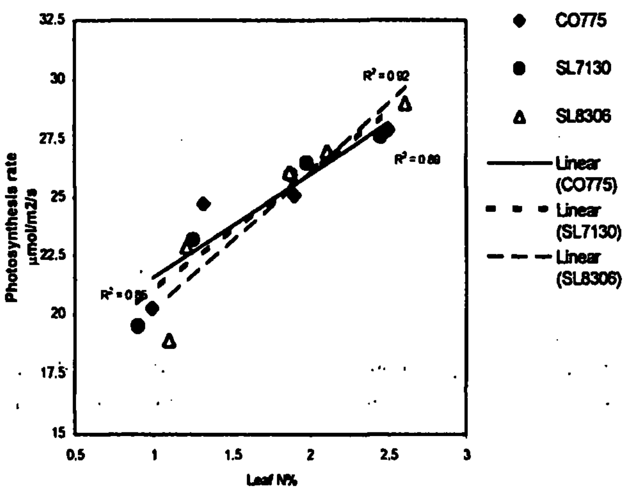

Fig. 4. **Relationship between leaf nitrogen % and photosynthesis rate in three varieties of sugarcane.**

Table 2. Varietal effect on leaf N%, chlorophyll content and photosynthesis rate.

Parameter	Variety	Sampling days 90	150	210	270
Leaf N%	CO775	1.19a	1.97a	1.97a	1.04a
	SL7130	1.04a	1.89a	1.13a	0.99a
	SL8306	0.99a	1.82a	1.49a	0.85a
	CV%	9.45	7.31	11.41	12.68
Leaf chlorophyll (mg/g)	CO775	2.15a	2.34a	2.21a	2.09a
	SL7130	2.10a	2.24a	2.18a	2.06a
	SL8306	1.85a	2.10a	1.74b	1.64b
	CV%	10.81	11.60	8.77	7.35
Photosynthesis rate mol $m^{-2} s^{-1}$	CO775	26.19a	28.81a	25.88a	21.97a
	SL7130	27.97a	29.20a	26.38a	22.50a
	SL8306	26.98a	28.40a	24.76a	21.67a
	CV%	7.08	14.03	11.50	10.55

These values are means of 12 observations. Means with the same letter along the column are not significantly different at $P<0.05$.

Evans, 1989). The reductions in photosynthesis and leaf chlorophyll content observed with nitrogen supply were partly attributed to a decrease in nitrogen content (Fig. 3 and Fig. 4). Decrease in leaf chlorophyll content with decreasing leaf nitrogen have also been observed in other species (Makino *et al.*, 1984; Seeman *et al.*, 1987; Terashima and Evans, 1988; Evans, 1989).

Varieties CO775 and SL7130 maintained high leaf chlorophyll content throughout the growing season while SL8306 had a lower value for the above parameter. It was significant ($P<0.05$) after 150 days and this significant increment of chlorophyll content was approximately by 11 and 7% respectively from that of SL8306 at their peak (Table 2). Photosynthesis rate and leaf nitrogen content were not significantly different ($P>0.05$) between the three varieties.

Partitioning of biomass to sink (PBS%)

Application of nitrogen significantly increased ($P<0.05$) partitioning of biomass to the sink up to 100 kg of N/ha and then it remained fairly constant up to 200 kg/ha at 150, 210 and 270 DAP. Zero level of nitrogen (N_0) reduced PBS approximately by 13, 11 and 8% at 150, 210 and 270 DAP respectively than that of N_{100} plants (Fig. 5a). The highest PBS (61.96%) was observed in N_{100} plants at 270 DAP. Before 150 days, no significant effect of nitrogen application on PBS could be observed. With the increase of nitrogen fertilizer application LAI, TDM, RUE, leaf chlorophyll and nitrogen contents increased significantly ($P<0.05$), but PBS became maximum with the N_{100} level of nitrogen and negative effects were observed with the N_{200} level of nitrogen. This may be due to large part of dry matter remaining in other plant parts such as trash, leaves and cabage.

In variety SL8306 PBS increased approximately by 4 and 7% than CO775 and SL7130 respectively at the 270 DAP (Fig. 5b). Partitioning of biomass to sink had a positive correlation with biomass production in all varieties (Fig. 6), because all three varieties showed increased PBS% with TDM at all sampling dates. Variety SL8306 maintained highest biomass production (40667 kg/ha) and highest PBS (61.42%), even though it had given low LAI and low leaf chlorophyll content at later stages compared to other two varieties. This may be because SL8306 had higher radiation use efficiency (RUE) than CO775 and SL7130.

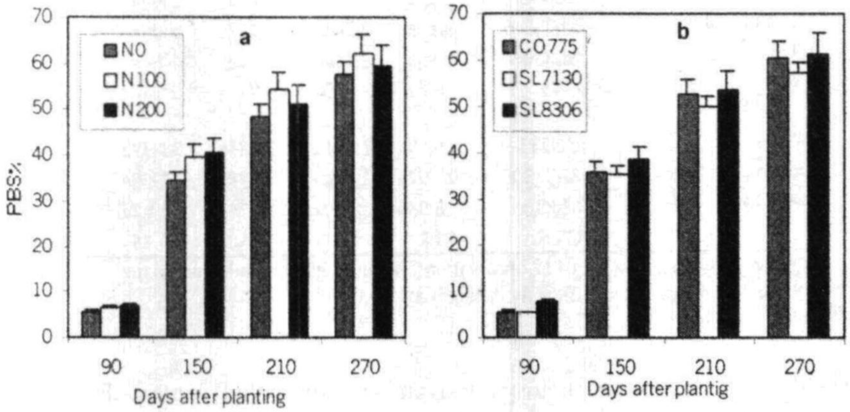

Fig. 5. Seasonal variation of biomass partitioning % to sink in response to nitrogen fertilizer (a) and variety (b).

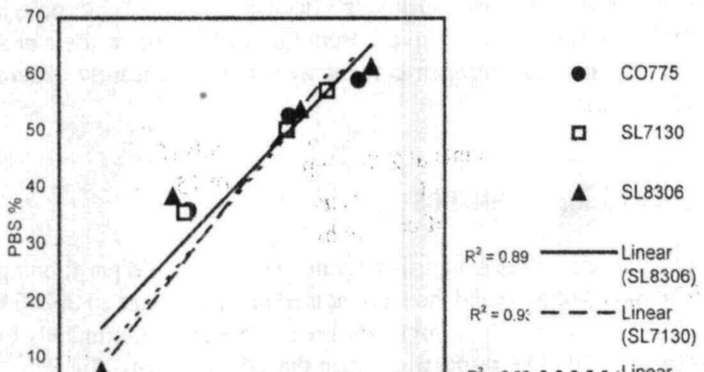

Fig. 6. Relationship between total dry matter (TDM) production and % of partitioning of biomass to sink (PBS%) of three varieties of sugarcane.

CONCLUSIONS

This study showed that increased application of nitrogen fertilizer significantly increased leaf nitrogen and leaf chlorophyll content through which photosynthesis capacity was also increased. The lack of nitrogen caused higher reduction of leaf nitrogen and leaf chlorophyll contents in all three varieties. Therefore, with the increase of nitrogen application, leaf area index, photosynthesis rate and thus total biomass production increased. The significance of nitrogen effect on biomass production was supported by physiological measurements of young leaves. Variety SL8306 showed the highest radiation use efficiency through high rate of biomass production than CO775 and SL7130. Leaf nitrogen had a positive correlation with photosynthesis rate in all three varieties at all different levels of applied nitrogen. The leaf area indcx had a positive correlation with radiation use efficiency in all three varieties. Partitioning of biomass to sink had a positive correlation with biomass production and photosynthesis rate. Though CO775 and SL7130 had higher LAI and leaf chlorophyll contents compared to SL8306, biomass production, radiation use efficiency and partitioning of biomass to sink were high in SL8306 at 210 and 270 DAP. Variety SL8306 was highly responsive to nitrogen application than the other two varieties (CO775 and SL7130). All of the above yields determining physiological parameters increased with nitrogen application except partitioning of biomass to sink. Maximum partitioning of biomass to sink was observed with 100 kg of nitrogen per hectare and further increment of applied nitrogen (200 kg N/ha) negatively affected partitioning of biomass to sink.

ACKNOWLEDGEMENTS

This research was funded by the National Science Foundation (NSF). The assistance by the staff of the Sugarcane Research Institute (SRI) and Department of Agricultural Biology are gratefully acknowledged.

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