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Response of Sugarcane to Varying Nitrogen Rate and Application Timings Under Semi-Arid Climate

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Abstract

To enhance crop yields, nitrogen is one of essential basic nutritional elements that enable any plant to withstand in stressful conditions. An experiment was carried out to investigate the impact of N rates and its application timings on growth, development and sugarcane yield at farm area of Sugarcane Research Institute, Faisalabad, Pakistan for two consecutive crop seasons (spring 2014 and 2015). Four Nitrogen (N) rates *viz.*170, 227, 284 and 341 kg ha^{-1}were applied at four different application schedules i.e. T_1= 45-75-90 days after planting (DAP); T_2= 45-75-90-120 DAP;T_3= 45-75-90-120-150 DAP and T_4= 45-75-90-120-150-180 DAP, in RCBD having three replications. The results revealed that the treatments significantly affected quantitative traits like tillers plant^{-1}, cane girth, millable count, cane and sugar yield and growth parameters like leaf area index (LAI), leaf area duration (LAD), seasonal total dry matter accumulation (TDM) and seasonal crop growth rate (CGR). Interactive effect of treatments was also significant for cane girth, number of millable canes and LAD. Treatments did not affect cane length significantly during the course of study. Growth traits *viz.* LAI, LAD and CGR showed improvement by higher N application and the highest values were observed when N was applied late in the season in six splits. A close positive linear relationship was noticed between cane yield and dose & time of N application. It may be concluded from the present study that splitting of nitrogen till 180 days after planting at higher rates (upto 341 kg ha^{-1}) can improve cane and sugar yield of spring planted sugarcane crop under semi-arid climatic conditions

Keywords: Sugarcane, Cane yield, Growth, Nitrogen rate, Time of N application

Introduction

Sugarcane (*Saccharum officinarum* L.) is the world's largest food-producing C_4 crop providing nearly 3/4th of total global sugar consumption (Souza *et al.*, 2008). It is second to cotton used as cash crop in Pakistan. The country is ranked at 5thposition in cane area and total production and 49thwith respect to average yield (61 tons ha^{-1}). The share of sugarcane to national GDP and value added agriculture is 0.6 and 2.9%, respectively, (Govt. of Pakistan, 2020). The prime responsible factors for having lower sugarcane yields in Pakistan may include scarce irrigation water resources, less plants per unit area and imbalances in amount and time of fertilizers. Sugarcane stays in field for long period of time and being exhaustive crop, requires higher quantities of nutrients, yet, it is highly responsive to higher nitrogen application rates (Saleem *et al*., 2012). Hence, application of these nutrients into the soil in an appropriate amount is pre-requisite for obtaining higher cane yield. Jagtap *et al*., (2006) reported that cane crop of 100 t ha^{-1} may take up of about 207 kg N, 30 kg P & 233 kg K per hectare, respectively, from the soil. Sugarcane yield is varied in different soils and higher yields are observed in organically enriched soils (peat and muck soils) than in sandy and light soils (Zhao *et al*., 2014). Nitrogen is considered most influential factor for sugarcane growth and productivity (Wiedenfeld and Enciso, 2008). Nitrogen, being the essential element for regulating the biochemical and physiological processes underlying the crop plant, has no alternative in the universe (Sinclair and Vades, 2002). All the plant proteins including purines, pyrimidines and other coenzymes are constituted by nitrogen and hence, any disruption in its availability may hamper synthesis of protein resulting in poor growth (Ahmad *et al.*, 2000). It also improves the overall protein contents and plant look shining due to higher chlorophyll accumulation (Iqbal and Chauhan, 2003). Soils with less nitrogen contents lowers water use efficiency resulting in less crop yield (Rifat *et al.*, 2010). On contrary, nitrogen application at higher doses may contaminate the ground aquifer due to leaching in deeper soil layers (Jen-Hshuan, 2006). Many scientists have worked on nitrogen use in sugarcane crop globally. Nitrogen application @150 kg ha^{-1}was found effective for obtaining better crop related attributes (Seema *et al.*, 2014). In other studies, Chohan *et al.* (2012) found higher cane and sugar production by applying fertilizer levels of 200-80-80 kg ha^{-1}, NPK, respectively for sugarcane genotype Hoth-300. Cane yield was gradually enhanced with incremental use of N up to 240 kg per hectare (El Sogheir & Ferweez, 2009).With increasing nitrogen application, tall cane stalks with better quality seed were also observed (Azzay and Elham, 2009). Positive effect of nitrogen rates on millable canes has also been advocated by Ahmad *et al*. (2009). Efficient use of nitrogen in many crops especially cereals has been well understood as grain N value is a major harvest indicator. Whereas, nitrogen utilization in sugarcane has not been well studied due to its least fraction in its end product, the sugar. However, growing environmental apprehensions regarding air and water contamination from over fertilization of nitrogen needs to understand its utilization and logical application in sugarcane (Whan *et al*., 2007) ensuring less ill effects on environment. On contrary, the lengthy growth period of sugarcane intensifies the challenge of nitrogen use efficiency. Saleem *et al*. (2012) found that N available in crop root zone is mostly depleted, necessitating the application of total required N in splits throughout the crop grand growth period. Achieng *et al.* (2013) also carried out experiments with variable nitrogen application amounts from 0 to 180 kg $ha^{-1}$with difference of 60 kg between each rate and its splitting from 100 to 50-50 and 30-30-40 %, respectively, affecting sugarcane cultivars (CO 421 and D 8484). These results indicated that maximum cane yield was achieved with splitting of N as 30-30-40%. Widenfeld (1997) reported that application of nitrogen late in the season enhanced sugarcane cane growth and yield yet it reduced sugar production per unit area by lowering the quality of juice. Bikila *et al*., (2014) also reported improved sugarcane yield and quality when N was applied in lower dose at lateral stages of the crop growth. The present sugarcane varieties like CPF 246, HSF 240, SPF 234 and SPF 213 have out yielded older low cane producing cultivars i.e. Triton, BF-62, CP 43-33, CP 72-2086 and CoJ 84 due to the fact that these have higher nutrient requirements than the recommended under intensive and exhaustive crop rotations (Saleem *et al*, 2012), and new varieties also have higher resource utilization efficiency resulting in higher yields than earlier varieties. Hence, the present experiment was designed to estimate the influence of higher N application in spring planted sugarcane along with improving the nutritional efficiency for sugarcane based production system through adjustment in the time of N application under semi-arid environment.

Materials and methods

The research trials were conducted for two consecutive crop seasons from 2014-15 to 2015-16) at research farm of Sugarcane Research Institute (SRI), AARI, Faisalabad (31.26ºN, 73.06ºE and 184 masl). The soil samples were collected from site for physico-chemical analysis at the time of sowing (Table 1) during both years

Table 1: Physico-chemical properties of soil (average of two years)

Physical properties of soil	
Soil type/Soil Series	Sandy Clay Loam/ fine loam, shallow/Lyallpur series brown on color along with the %age of sand (66%), silt (16%) and clay (24%).
Chemical properties of soil	
Organic matter	1.28%
TSS (Total soluble salt)	12.28%
pH	7.56
Nitrogen (N)	0.64%
Phosphorus (P_2O_5)	6.94 ppm
Potassium (K)	19.5 ppm

The experiments, during both years, were laid out in randomized complete block design (RCBD) with factorial arrangements having three repeats. The trials were planted during 1st week of March in each year. The net plot size for each experimental unit was maintained as 4 m × 9.6 m with 8 rows having 1.2 m distance between two rows. The N Fertilizer doses (170, 227, 284 and 341 kg ha^{-1}) and time of its application *i.e.* T_1= 45-75-90 DAP; T_2= 45-75-90-120 DAP; T_3= 45-75-90-120-150 DAP and T_4= 45-75-90-120-150-180 DAP, were placed as per lay out plan. The field was fallow for last six months and at the start of land preparation, disk harrow was used to break the clods and eradicate the previous crop residues followed by deep ploughing using chisel plough to break the hard pan in field. Fine seed bed was prepared by repeated cultivating and planking, after which, sugarcane *ridger* was used to make 8" deep trenches at 1.2m apart. All the Phosphorus and potassium fertilizers in the form of SSP(18% P_2O_5) and SOP (50% K_2O) were applied in these trenches before the sowing of the crop at the time of planting. Good quality seed (3 budded setts ~ billets) from healthy crop was used to plant experiment during both experimental years at the same experimental site. Before planting, the setts were dipped in fungicide solution of thiophenate methyl @ 0.25 % for 10-15minutes. Pre emergence weedicides were sprayed in furrows at field capacity to keep the weed flora under control up to 30 days after planting. Interculture with high tine cultivator was also carried as and when required to keep the field weed free. Proper pest management strategies were implied to keep the pest incidence under threshold. Irrigation was applied as and when required by the crop depending upon the climatic variations. At total, sixteen (16) irrigations were applied (about 64 inches delta of water) during whole crop growth period.

Crop allometry: Meteorological data of the site during both seasons is given in Fig. 1. Germination data were recorded at 45 days after planting during both years. Data regarding tillers plant^{-1} were observed at 100 days after planting.

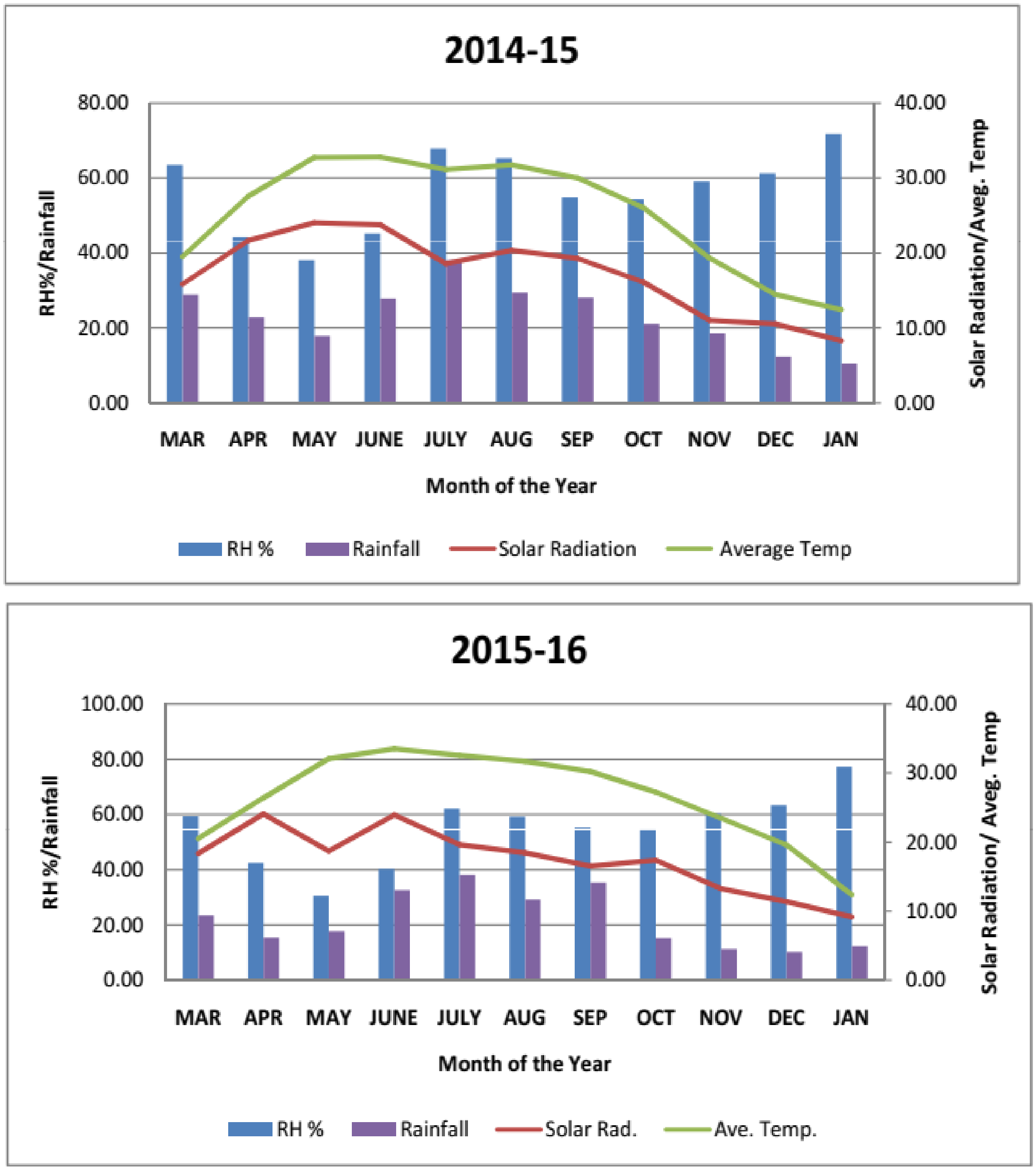

Fig. 1: Meteorological data during both the years of study (2014-15 & 2015-16)

Growth parameters: *Leaf area index*: Leaf area of the crop plots was estimated with software (ImageJ) by taking an appropriate sub sample of green leaf lamina (20g) from each plot. Leaf area index (LAI) was then estimated according to Watson, (195
).

$$LAI = \frac{\text{Leaf Area}}{\text{Land Area}}$$

Leaf area duration (days): Leaf area duration (LAD) was assessedusing the formula given by Hunt (1978) at each sampling date.

$$LAD = \frac{(LAI1 + LAI2)}{2} \times (T2 - T1)$$

LAI_1 = LAI at 1st sampling date
LAI_2= LAI at 2nd sampling date
T_2 -T_1 = Time between two samplings

Crop growth rate (g m^{-2} d^{-1}): Crop growth rate during each sampling duration was measured according to Hunt (1978).

$$CGR = \frac{W2 - W1}{T2 - T1}$$

W_1= Dry weight at 1st sampling
W_2= Dry weight at 2nd sampling
T_2-T_1= Duration between two samples

During the crop growth period, six samplings were carried out with 30 days' interval to assess the crop growth indices. The harvesting was done at physiological maturity on 20th and 21st January in 2015 and 2016, respectively at the crop age of about 10 months. Data regarding cane count per unit area and yield were recorded by harvesting whole plot of each experimental unit and collected data values were converted into standard units. For obtaining data for cane length, cane girth and sugar yield, ten canes were randomly taken from each experimental treatment. For obtaining sugar yield, ten canes were selected from each treatment and were analyzed at the Sugarcane Technology Laboratory-SRI, Faisalabad to estimate commercial cane sugar in percentage by following Meade and Chen, (1977).

$$CCS\ (\%) = \frac{3P}{2}\{1 - (F + 5)/100\} - \frac{B}{2}\{1 - \frac{(F + 3)}{100}\}$$

Where P stands for pol (%) and B is brix (%) of first expressed juice and F is fiber % of cane.
The final sugar yield was estimated by using the following formula:
Sugar yield = CCS% / 100 × Stripped cane yield

Statistical Analysis: The collected data were analyzed statistically by using analysis of variance (ANOVA) technique using computer based software Statistics 8.1 and treatment means were compared through employing least significant difference test (LSD) at 5% probability level (Steel *et al*., 1997) for both years, separately. Regression analysis was also carried out for mathematical relationship of cane yield with the treatments under study using MS Excel program.

Results

Quantitative parameters: Tiller production per plant is a genetically controlled character and the final cane yield totally depends upon it. The data (Table 2) clearly depicted the pronounced effect of treatments under study on tillers $plant^{-1}$ during both years of studies. The maximum tillers $plant^{-1}$ was documented at N_4 (341 kg N ha^{-1}) while the minimum were found at N_1 (170 kg N ha^{-1}). It is also shown that split application enhanced tillers $plant^{-1}$ and the maximum tillers were produced in T_4, where nitrogen was applied in 6 equal splits against the lowest in T_1. The data (Fig. 2) indicated the significant effect of treatments, individually as well as interactively, on the count of millable canes per unit area. The results also unveiled the closeness of values during 1st year while during 2nd year, there was prominent variation among the treatment effects on millable canes. The maximum millable canes were observed at N_4 when it was applied in 6 equal splits till 180 DAP (T_4). Cane girth, an important morphological trait, tells about the soundness of the cane. It is also evident that cane girth was affected meaningfully by the treatments along with their interaction during both years of experiment. It was also shown that with increasing N rate and by delaying application time, cane girth, was linearly increased and the maximum was observed at N_4 and T_4, respectively (Fig.2). Cane length is also very critical parameter affecting overall sugarcane productivity in any environmental condition. Yet, it was not affected promptly by the dose of N and its application time during the study, however, cane length increased accordingly with each N increment and increasing number of its splits. Cane yield is the final outcome of the crop at farmer level and it is mostly dependent upon the amount and time of nutrient application. The present study showed prominent effect of N treatments on final cane yield during the both years. Final stripped cane yield was augmented by increasing N rate and the highest cane yield was achieved at N_4 whereas, the lowest cane yield was noted at N_1. The results (Fig. 2) represented that cane yield was linearly incremented by increasing number of splits at each N rate and it was found maximum in N_4T_4 while minimum cane yield was observed in N_1T_1. The same trend was observed during 2nd year of experiment. Very close and positive linear relationship of cane yield was found with the dose (R^2= 0.98 & 0.99) and no. of splits (R^2= 0.99 and 0.99) of N application during both years, respectively (Fig.3). Higher sugar yield is the prime objective of all sugarcane research and development activities. The results comprehended that sugar yield was also considerably impacted by N treatments during both years of experiment. N application at higher rates resulted in the maximum sugar yield and vice versa. It was also found that higher sugar production was observed where N was applied till the end of grand growth period (T_4) in comparison to the treatment where complete N applied at early in the growth period (T_1). The results were similar in 2nd year of experiment (Table 2).

Growth parameters: LAI is considered as an important physiological measurement for getting higher crop yield. It is measure of assimilatory surface of a plant for its basic process of photosynthesis. Its pattern of expansion was significantly diverse during both years (2014-15 & 2015-16) (Fig. 4&5). Noticeable variations in LAI pattern were observed in all treatment plots. LAI increased up to 180 DAP but there was sharp decline in 1st year (2014-15) in contrast with 2nd year (2015-16). At the early growth stage, differences in LAI of treatments were not prominent in nature but as the plants move towards later part of growing phase, up to 180 DAP, the dissimilarities became more perceptible. Thereafter, LAI declined towards maturity of the crop. It was also shown that the pattern in LAI change during crop growth period was quite clear during 2014-15 in comparison to 2015-16 crop season with either changing N rate or no. of splits of each N dose. LAD is a measure of leaf stay green and its active contribution towards plant life sustaining processes like photosynthesis and respiration. It is depicted from periodic data for LAD that it was affected meaningfully by various N rates and its time of application during both years (Fig. 4 &5). The visible differences were observed at the start of the season which were found more prominent with crop advancement towards physiological maturity. Very close following of LAD was noted at varied nitrogen application times during 2nd year (2015-16), however, final LAD was linearly increased towards crop harvesting. The final LAD was also significantly affected by the both treatments and the maximum LAD was achieved in N_4 and T_4 where N was applied in 6 splits up to 180 DAP (Table 2). Final LAD was increased by 27.94 to 35.39 % from lowest N rate (170 kg ha^{-1}) to the highest N rate of 341 kg ha^{-1} during the course of study while the increase in final LAD from 3 splits of each dose to 6 splits was estimated between 6.72 to 22.96 % during both years of experiment. TDM accumulation is very primitive parameter for the estimation of mean rate of increase in crop biomass during whole crop season. The data (Table 2) showed that final TDM was affected significantly by different N rates during both years (18.74 & 9.42 %), respectively and the maximum TDM was achieved in N_4 (341 kg ha^{-1}). In the meanwhile, TDM was also enhanced by splitting N fertilizer (18.98 & 12.82 %, respectively) and the maximum dry matter was accumulated in T_4 (N applied in 6 equal splits till 180 DAP). CGR is the mean improvement in plant biomass from a defined land unit per unit of time. Crop species differ in their potential to utilize available nutrients in a set of environmental variables. The present results indicated higher CGR was noted up to 180 days after planting after which, it was declined sharply (Fig. 4 &5). Seasonal CGR pattern showed that the dose and time of nitrogen application had substantial effect on CGR and the maximum CGR was observed when higher rates of N were applied (F_4) and also when, it was applied equally during the whole crop growth period (T_4).

Discussion

Plants take nitrogen both in organic and inorganic forms, and in which, $NO3^-$ is once again reduced to $NH4^+$ for assimilation into plant organic N form (Jalloh *et al*., 2009). Fertilizer supplementation is very common in intensive sugarcane cultivation system where higher leaf surface is required for getting higher cane yields (Thorburn *et al*., 2005; Van Heerden *et al*., 2010). This phenomenon has also been verified during present experiment. The present study also exhibited that due to application of higher N rates in sandy loam soil, quantitative traits of sugarcane variety CPF 252 like tillers $plant^{-1}$ improved due to uninterrupted availability of N during maximum time of plant growth (Soomro *et al.,* 2014; Seema *et al.,* 2014) and for maintaining integrity of plant parts and prime physiological processes i.e. photosynthesis (Waraich *et al*, 2011).This study showed non-significant effect of the treatments on cane length yet it was revealed that taller canes were observed where nitrogen was applied at higher rates confirming its vitality for plant metabolic processes resulting in better stalk tallness (Koochekzadeh *et al.,* 2012). Researchers have also reported maximum millable canes at N rates between 100-250 kg ha^{-1} in subtropical environments (Akhtar *et al*., 2000; Ali *et al*., 2000). Whereas, present study also endorsed Miller & Gilbert (2006) finding, who reported higher sucrose contents when N was applied well before the harvesting time (42-56 days). The growth parameters like LAI, LAD, TDM and CGR were improved not only with nitrogen rate but also by splitting of N till the end of growth period. This was probably due to the sustainable photosynthetic process (Waraich *et al*., 2011) resulting in the best performance of test variety under variable environmental conditions of two years of study. In Faisalabad conditions, crop experienced higher photosynthetic efficiency due to favorable thermal ranges between 8°C & 34°C during its growth as the leaf growth is restricted below the temperature range of 14-19°C. This shows that hot days and warm nights favored sugarcane growth rate and also carbon balance in the plant (Gawander, 2007). It was also confirmed that cane yield was significantly affected by the rate and time of N application during both years of experimentation but, there was higher cane yield during 1st year (2014-15) than 2nd year confirming the positive effect of better environmental conditions (rainfall, humidity and mean temperature) for sugarcane growth and development. It also improves cane yield when nitrogen is applied in higher rates during grand growth period (Chattha *et al*., 2010) than far late N application that lowers juice quality (Lofton *et al*., 2012; Wiedenfeld (1997).

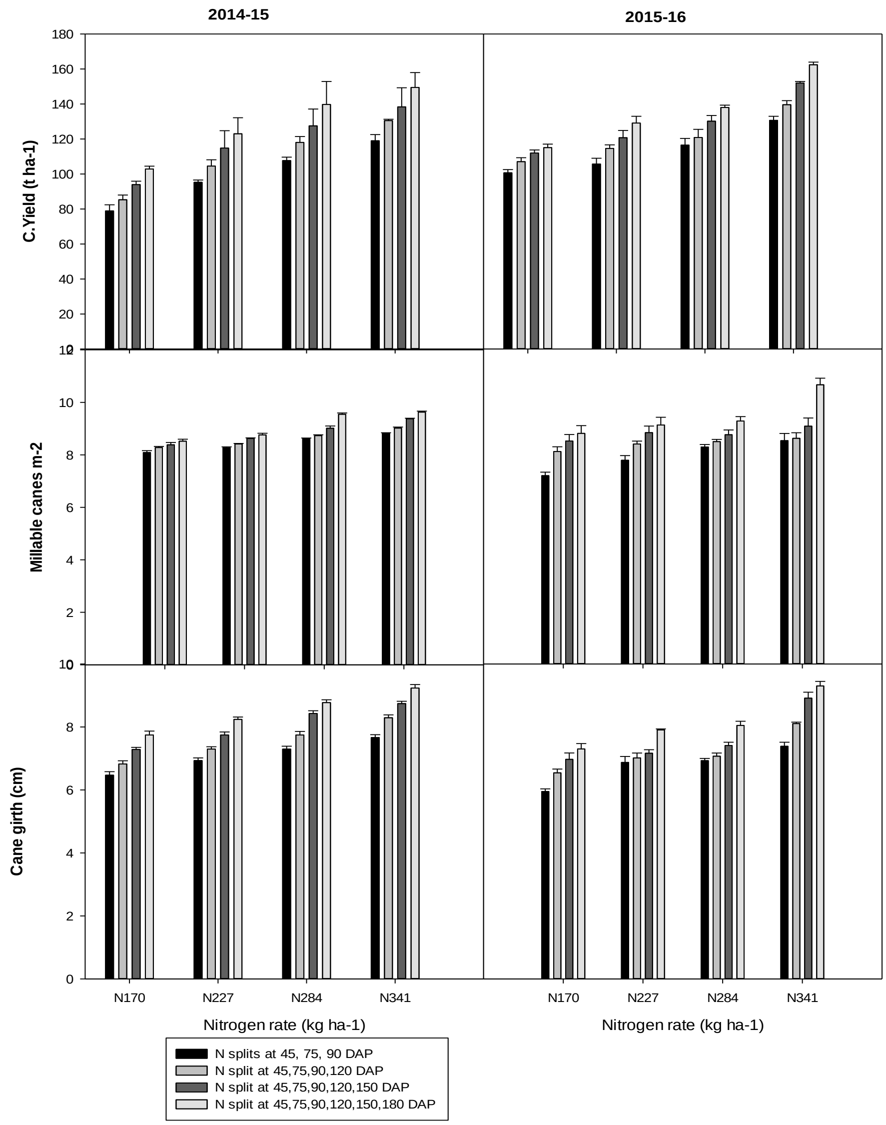

Fig. 2: Interactive effect of rate and time of N application on cane yield (t ha^{-1}), millable canes m^{-2} and cane girth (cm)

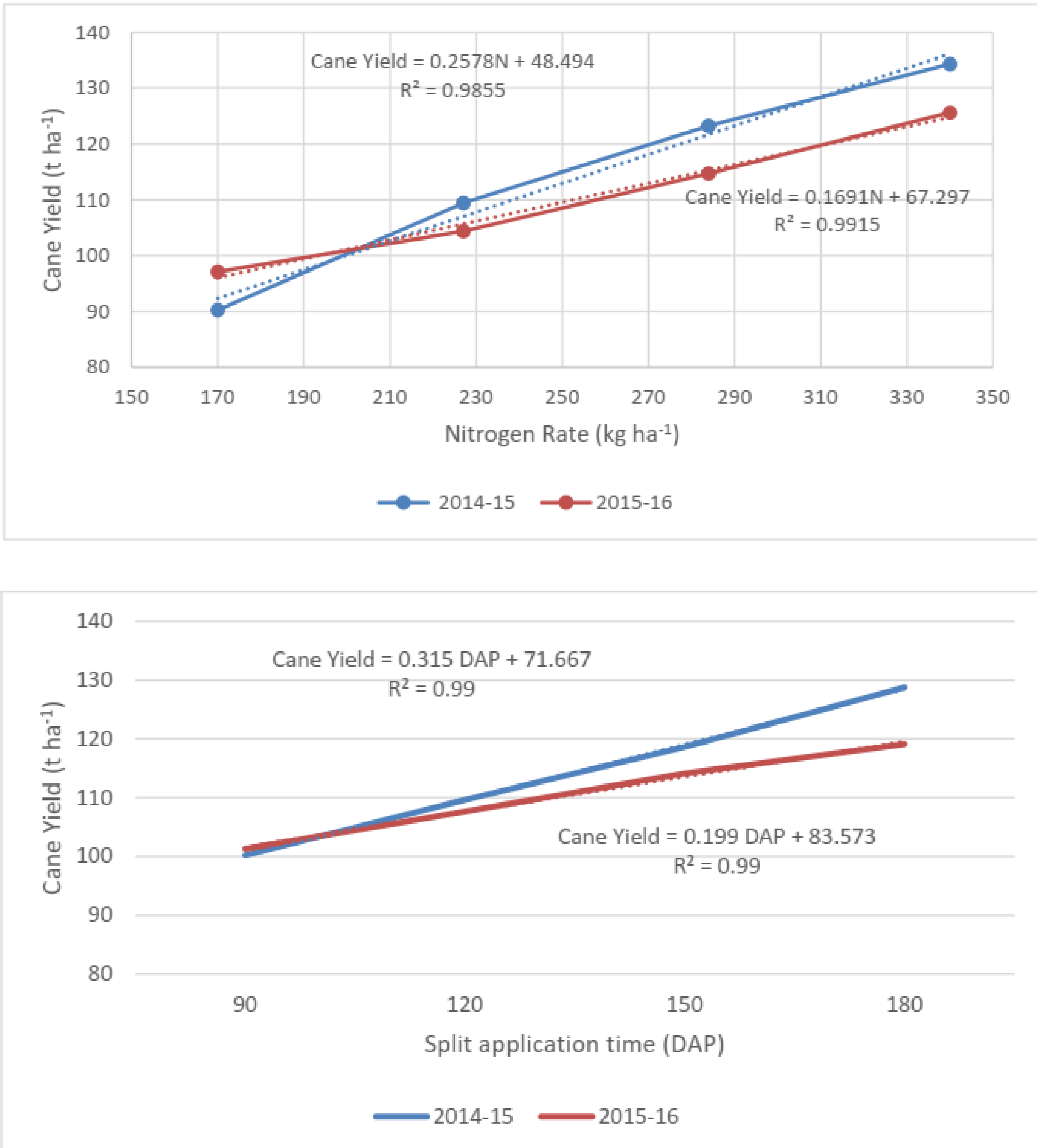

Fig.3: Effect of rates and application timings on cane yield of sugarcane during 2014-15 & 2015-16

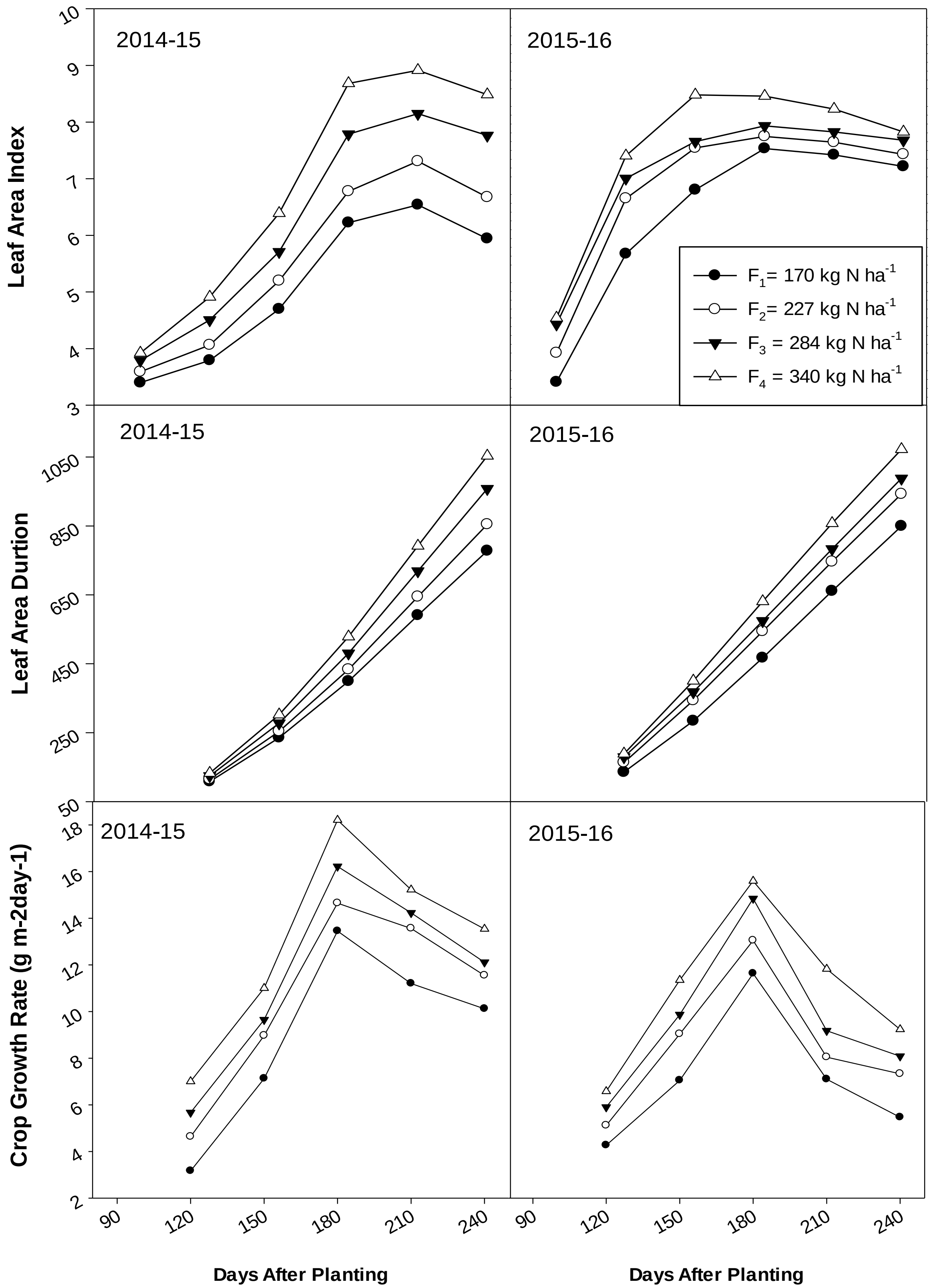

Fig. 4: Effect of N rates on LAI, LAD and CGR during both years (2014-15 & 2015-16)

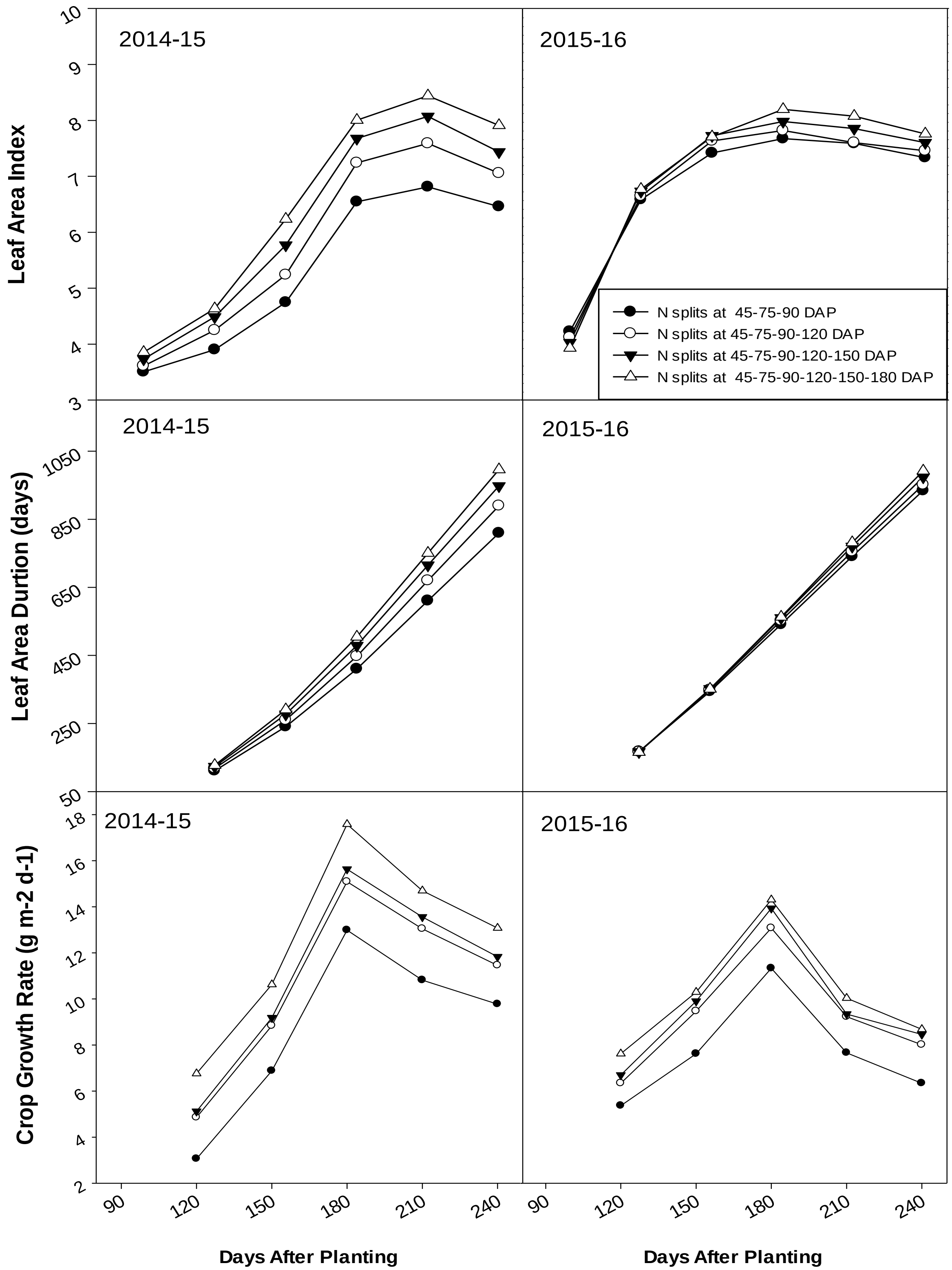

Fig. 5: Effect of time of N application on LAI, LAD and CGR during both years (2014-15 & 2015-16)

Table-2: Effect of nitrogen rates and its time of application on quantitative traits of sugarcane during both years (2014 and 2015) of experimentation

Treatments	Tillers plant^{-1}		Cane length (cm)		Sugar yield (t ha^{-1})		Maximum LAI		Final LAD (days)		Final TDM (t ha^{-1})	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
A) N rates (kg ha^{-1})												
N_1= 170	0.76 c	1.00 b	217	200	11.93 c	12.46 c	6.54 d	6.83 c	777 d	834 d	2801 c	2748 b
N_2= 227	1.05 b	1.14 a	218	206	13.90 b	13.59 b	7.31 c	7.10 bc	854 c	933 c	2954 bc	2816 ab
N_3= 284	1.06 b	1.18 a	223	210	16.24 a	14.06 b	8.14 b	7.34 b	958 b	979 b	3102 b	2892 ab
N_4= 341	1.25 a	1.25 a	231	214	17.01 a	16.48 a	8.91 a	8.02 a	1052 a	1067 a	3326 a	3007 a
LSD at 5%	0.159	0.128	n.s	n.s	0.979	0.554	0.227	0.301	5.21	4.23	210.97	219.58
B) Time of N application (Days after planting)												
T_1= 45-75-90	0.88 c	0.97 c	217	200	13.04 c	12.94 c	6.81 d	7.01 c	810 d	923 d	2781 b	2690 c
T_2= 45-75-90-120	0.95 bc	1.11 b	224	207	14.19 b	13.88 b	7.58 c	7.19 bc	890 c	941 c	2917 b	2802 bc
T_3= 45-75-90-120-150	1.09 ab	1.18 ab	227	210	15.47 a	14.38 b	8.07 b	7.40 ab	946 b	965 b	3176 a	2936 ab
T_4= 45-75-90-120-150-180	1.21 a	1.30 a	220	212	16.38 a	15.38 a	8.44 a	7.68 a	996 a	985 a	3309 a	3035 a
LSD at 5%	0.159	0.128	n.s	n.s	0.979	0.554	0.227	0.301	5.21	4.23	210.97	219.58
Interaction												
	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

Means sharing different letters in a column, statistically differ from each other

Conclusion

This study led to the conclusion that higher nitrogen rates would enhance sugarcane productivity when applied in more number of splits till the end of grand growth phase due to maintenance of higher LAI and crop growth rates. Moreover, nitrogen application till 180 DAP improves overall sugar production per unit area owing to its availability on peak demand

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