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Impacts of Rate and Split Application of N Fertilizer on Sugarcane Quality

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Abstract: Effect of nitrogen (N) rate and its split application (AP) on qualitative and quantitative characteristics of sugarcane (*Saccharum officinarum* L.) cultivar CP48-103 was investigated on a loamy soil texture from 2006 to 2008 in the Sugarcane Research Center of the Khuzestan Province, Iran. The experiment was arranged in split plot randomized complete block design with three replications consisted of three different rates of N (N_1 = 92, N_2 = 138, N_3 = 184 kg N ha^{-1}) as main plots and three different AP (AP_1 = 20-40-40%, AP_2 = 30-35-35%, AP_3 = 30-30-40%) as subplots. Twenty canes were randomly harvested from each plot and their quantitative and qualitative characteristics were determined. The results showed that both rate and split application of N fertilizer had no significant effect on sugarcane characteristics. The interactive effects of N application rate and AP on juice purity depicted applying 92 kg N ha^{-1} and AP of 30-30-40% gave the purest juice with 90%. The Nitrogen Use Efficiency (NUE) was significantly greater for N_1 with values of 1.39 and 0.13 t kg^{-1} N in Cane Yield (CY) and Sugar Yield (SY), respectively. The results showed that the highest cane and sugar yield was obtained with 92 kg N ha^{-1} and AP of 30-35-35%.

Key words: Nitrogen use efficiency, sugarcane yield, Khuzestan

INTRODUCTION

Nitrogen is vital for most plant metabolic processes and plays an important role in tillering and stalk elongation. In addition, N deficiency results in reduction of leaf area and thus, causes photosynthesis reduction which in turn leads to suppress in yield and quality (Sreewarome *et al*., 2007).

Fertilizers application is more common in intensive sugarcane cultivation which requires a high amount of nitrogen due to production of a great deal of biomass (Thorburn *et al*., 2005). However, N application may lead to soil acidification, ground or surface water contamination and emission of greenhouse gases such as nitrous oxide (Keating *et al*., 1997). The high water and N requirements of sugarcane, has the maximum potential for polluting ground or surface water (Peralta and Stockle, 2001). N uptake depends on the quantity and quality of the N fertilizer, time and frequency of application, the crop grown and its duration, crop N-utilization efficiency, rooting depth, rainfall, soil hydraulic characteristics and management practices (Rasiah and Armour, 2001).

In Australia, fertilizer N rates between 97 and 160 kg ha^{-1} generated returns above 95% of the optimum (Keating *et al*., 1997). Thorburn *et al*. (2001) depicted that cane yield increases from 102 to 117 t ha^{-1} after raising N rate from 100 to 150 kg ha^{-1}. However, it was reported that cane yield was not affected with increasing N. The NUE of sugarcane is related to dry matter yield. Dilz (1988) reported that typical ranges of N recovery for some crops under good conditions in Western Europe are 50-60% for wheat; 77% for sugar beet; 50-60% for potato and 50-70% for grassland. Also, the results of Isa *et al*. (2006) showed high recoveries (>90%) in the sugarcane plant growing on a non-saline soil.

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Proper land management programs should include the establishment of fertilization regimes that optimize growth with minimum nutrient leaching (Van Miegroet *et al*., 1994). These involve adjusting fertilizer application rates and frequencies to maximize N utilization while minimizing N leaching from the rooting zone (Lee and Jose, 2005). Sugarcane has been cultivated in the Khuzestan province (SW of Iran) since 1956. The area under sugarcane is estimated to be 100000 ha. Fertilizer application for plant crop was 400 kg ha^{-1} urea and the same amount diammonium phosphate annually (Barzegar and Koochekzadeh, 2001). But, this amount has declined to 300 kg ha^{-1} in recent years. Urea is applied for crop in 2 or 3 split applications through May to July. However, it is necessary to find out the appropriate doses and application methods.

The objectives of this study were to assess the effects of rates and split applications of nitrogen on (1) qualitative and quantitative characteristics of plant cane and (2) nitrogen use efficiency in sugarcane cultivation.

MATERIALS AND METHODS

The study was conducted in South West of Iran at Sugarcane Research Center, (31°02'N, 48°14'E). The study area has a semiarid climate (average annual temperature of 24.9°C and average annual rainfall of 170 mm). Soil is fine loamy carbonatic hyperthermic, typic torrifluvents. Before planting on August 2006, 300 kg ha^{-1} diammonium phosphate was added to the soil and then, sugarcane cultivar CP48-103 was planted through placing stalks in the furrows.

On May 2007, mixed samples were taken from soil at depth of 0-30, 30-60 and 60-100 cm before adding N to soil. Soils were air dried and sieved 2 mm in diameter. Electrical conductivity of saturated extract (Rhoades, 1996) and pH of saturated paste (Thomas, 1996) of soil samples were determined. Organic carbon content was measured by the oxidation procedure (Nelson and Sommers, 1996). Particle size distribution was measured by the pipette method (Gee and Bauder, 1986). Soil samples were analyzed for total nitrogen after digestion with concentrated sulfuric acid (Bremner, 1996). Available P was measured by ascorbic acid method (Kuo, 1996). Available K was determined by the ammonium acetate method (Helmke and Sparks, 1996) and nitrate and ammonium by the KCl method (Mulvaney, 1996).

The experiment was arranged in a split plot design including three N application rates 92, 138 and 184 kg N ha^{-1} (hereafter refereed as N_1, N_2 and N_3, respectively) as main plots and three split applications of N (AP_1: 20-40-40%, AP_2: 30-35-35%, AP_3: 30-30-40%) as subplots with three replications. The applied fertilizer was dissolved in water and then added to the soil at grand growth period on 5 May, 5 June and 6 July (263, 294, 325 days after planting, respectively). Each plot was 6 rows 10 m length with 1.83 m apart. A 2 m distance between adjacent plots and 3.66 m between blocks was established to prevent N leach of any plot to each others.

Sugarcane was harvested on 28 February 2008 (562 days after planting). The middle two rows of each plot were harvested, then all leaves and sheaths of all canes were removed. Fresh weight of canes and leaves plus sheaths were measured separately. These values were attributed as cane yield and trash, respectively. A random 20-canes sample from each plot crushed using a Hydraulic Roller Mill and juice were analyzed for total dissolved solids (brix) and sucrose concentration (pol) using refractometer and Saccharimeter, respectively. Cane sucrose content was calculated using the Winter-Carp formula (Chen and Chou, 1993). Electrical conductivity, sodium and potassium contents and residual N of juice were also determined. Ten canes were taken separately from each subplot and fiber content was measured by wet disintegrator method (ICOUMSA, 1994). Also, nitrogen use efficiency was calculated as the ratio of yield over applied N (Lakshmikantham, 1983).

Data were statistically analyzed using the SAS 9.1 package and mean comparisons were made using Duncan's multiple range test.

RESULTS AND DISCUSSION

Soil Characteristics

Soil texture of different soil layers varied from loam to silty clay loam with highest clay content at 60-100 cm depth. The organic carbon of soil is 4 g kg^{-1}. Total N and NO_3^- concentration of soils are relatively low (Table 1).

Cane and Juice Characteristics

Variance analysis of data (Table 2) revealed that except N effect on NUE for cane and sugar and interactions between N and AP on juice purity, there is no other significant effect.

Interaction between N rates and split applications in different treatments is shown in Table 4. Present results indicated that cane yield was varied from 114.5 t ha^{-1} in N_3AP_1 to 133.5 t ha^{-1} in N_1AP_2 (Table 4). Cane yield reached the value of 128.2 t ha^{-1} averagely with application of 92 kg N ha^{-1}. This value is slightly greater with respect to cane yield values obtained in other N treatments, 138 and 184 kg N ha^{-1}, but the difference is not significant (Table 3). The high level of N concentration resulted in unbalance uptakes of other crop nutrients such as P and microelements, which in turn may reduced cane yield from 128.2 to 120.4 t ha^{-1}. Gawander *et al*. (2004) found that cane yield and sucrose content are significantly interrelated with applied fertilizers. Wiedenfeld (2000)

Table 1: Mean soil characteristics before N application

Depth (cm)	EC[a] (dS m^{-1})	pH	Texture	Sand	Silt	Clay	OC[b]	N total (%)	Ava[f].P	Ava[f].K	NH_4^+	NO_3^-
				--------------(g kg^{-1})------------					------------------(mg kg^{-1})----------------			
0-30	1.5	7.9	L[c]	394	354	252	3.6	0.043	0.94	121.8	0.88	0.65
30-60	1.5	7.9	CL[d]	234	474	292	2.4	0.052	0.60	95.7	1.0	0.22
60-100	3.5	7.7	SiCL[e]	194	494	312	2.1	0.035	0.53	87.0	0.81	1.70

[a]EC: Electrical Conductivity, [b]OC: Organic Carbon, [c]L: Loam, [d]CL: Clay Loam, [e]SiCL, Silty Clay Loam, [f]Ava: Available

Table 2: Analysis of variance of sugarcane quality parameters (mean squared)

		Fresh cane			Juice cane									NUE[f]	
SOV	df	CY[a]	Trash	Fiber	Brix	Pol	Purity	RS[b]	SY[c]	EC[d]	Na	K	Res.N[e]	Cane	Sugar
Rep.	2	18.78	0.003	9.76*	0.14	0.25	2.39	0.17	0.86	1.15	5.97**	172502.24	0.00003	0.006	0.00008
N	2	141.22	0.11	4.62	0.88	1.09	2.43	0.56	4.25	0.06	11.60	1535.08	0.00008	1.27**	0.013**
Rep.×N	4	567.02	0.08	1.21	0.29	0.48	2.39	0.28	6.17	0.27	4.92	89499.58	0.00005	0.05	0.0006
AP	2	56.37	0.01	0.39	0.01	0.01	0.23	0.008	0.42	0.28	1.44	42760.94	0.00002	0.009	0.00008
AP×N	4	201.62	0.05	0.16	0.49	0.78	4.80*	0.47	0.46	0.52	1.56	16907.32	0.000009	0.01	0.00004
Error	12	246.34	0.19	1.51	0.34	0.45	1.02	0.24	2.28	0.42	0.63	58397.39	0.00004	0.01	0.00009
CV (%)		12.60	12.00	10.5	3.40	4.40	1.10	5.10	12.7	6.70	2.30	5.80	20.4	10.1	10.0

Without any superscription indicate not significant, * and ** are significant at 0.05 and 0.01, respectively. [a]CY: Cane Yield, [b]RS: Recovery Sugar, [c]SY: Sugar Yield, [d]EC: Electrical Conductivity, [e]Res.N, Residual Nitrogen, [f]NUE: Nitrogen Use Efficiency

Table 3: Mean comparison by Duncan's method

	Fresh cane		Juice cane										NUE[f]	
	CY[a]	Trash	Fiber	Brix	Pol	Purity	RS[b]	SY[c]	EC[d]	Na	K	Res.N[e]	Cane	Sugar
Treatment	(10^3 kg ha^{-1})		-----------------(%)-----------------					(10^3 kg ha^{-1})	(dS m^{-1})	(mg kg^{-1})		(%)	(10^3 kg kg^{-1} N)	
N_1	128.2	3.6	12.5	17.5	15.6	88.8	9.7	12.5	9.5	33.7	4144.8	0.028	1.39[a]	0.13[a]
N_2	125.6	3.7	11.7	17.2	15.4	89.1	9.6	12.0	9.6	33.7	4170.8	0.029	0.91[b]	0.09[b]
N_3	120.4	3.5	11.1	16.9	14.9	88.1	9.2	11.1	9.7	35.7	4160.0	0.033	0.65[b]	0.06[b]
AP_1	125.2	3.6	11.6	17.2	15.3	88.8	9.5	11.9	9.8	34.4	4197.7	0.031	1.00	0.09
AP_2	127.0	3.6	12.0	17.2	15.3	88.5	9.5	12.1	9.7	34.0	4199.0	0.028	1.00	0.09
AP_3	122.0	3.6	11.7	17.3	15.3	88.7	9.5	11.6	9.4	34.8	4079.0	0.031	0.95	0.09

Without and with letter(s) in superscription within the column indicate non-significant and significant difference ($p<0.05$), respectively. [a]CY: Cane Yield, [b]RS: Recovery Sugar, [c]SY: Sugar Yield; [d]EC: Electrical Conductivity, [e]Res.N: Residual Nitrogen, [f]NUE: Nitrogen Use Efficiency

Table 4: Interaction between N rates and split applications on quantitative and qualitative characteristics of plant cane

	Fresh cane		Juice cane										NUE[f]	
	CY[a]	Trash	Fiber	Brix	Pol	Purity	RS[b]	SY[c]	EC[d]	Na	K	Res.N[e]	Cane	Sugar
Treatment	(10^3 kg ha^{-1})		(%)					(10^3 kg ha^{-1})	(dS m^{-1})	(mg kg^{-1})		(%)	(10^3 kg kg^{-1} N)	
N_1AP_1	133.3	3.6	12.4	17.0	15.1	88.5^{abc}	9.4	12.5	10.0	33.3	4221.1	0.031	1.45	0.13
N_1AP_2	133.5	3.5	13.0	17.7	15.6	87.9^{bc}	9.6	12.9	9.7	33.3	4226.3	0.025	1.45	0.14
N_1AP_3	117.9	3.7	12.3	18.0	16.2	90.0^{a}	10.2	12.0	8.8	34.5	3987.1	0.027	1.28	0.13
N_2AP_1	127.8	3.8	11.6	17.4	15.4	88.4^{abc}	9.6	12.3	9.7	33.3	4232.8	0.029	0.93	0.09
N_2AP_2	128.9	3.7	11.7	17.1	15.3	89.4^{ab}	9.6	12.3	9.5	33.3	4200.3	0.028	0.93	0.09
N_2AP_3	120.0	3.6	11.8	17.2	15.4	89.3^{ab}	9.6	11.5	9.6	34.6	4079.4	0.029	0.87	0.08
N_3AP_1	114.5	3.5	10.8	17.2	15.4	89.4^{ab}	9.6	11.0	9.5	36.5	4139.2	0.033	0.62	0.06
N_3AP_2	118.5	3.6	11.3	17.0	14.9	88.1^{bc}	9.3	11.0	9.7	35.3	4170.4	0.031	0.64	0.06
N_3AP_3	128.2	3.4	11.2	16.6	14.4	86.7^{c}	8.9	11.4	9.8	35.2	4170.4	0.036	0.70	0.06

Without and with letter(s) in superscription within the column indicate non-significant and significant difference ($p<0.05$), respectively. [a]CY: Cane Yield, [b]RS: Recovery Sugar, [c]SY: Sugar Yield, [d]EC: Electrical Conductivity, [e]Res.N: Residual Nitrogen, [f]NUE: Nitrogen Use Efficiency

reported that N application is not required for plant cane in a sandy clay loam soil, in Texas. However, Van Antwerpen *et al*. (2001) revealed that sugar cane production in the absence of N inputs reduces amounts of soil organic matter and hence soil health. Gana (2008) found that application of more than 120 kg N ha^{-1}, there was no significant difference between tillers number, stalk length and cane yield. Keating *et al*. (1997) showed that low application rates of N could be applicable in fertile soils and plant crops. Present study also indicated that a substantial amount of cane yield can be achieved with applying 92 kg N ha^{-1}.

The values of brix, pol, purity and recovery sugar varied from 16.6, 14.4, 86.7 and 8.9% to 18.0, 16.2, 90 and 10.2%, respectively against different treatments. However, comparison of their means in different treatments and split applications was not significant. Since sugar yield is gained by product of recovery sugar and cane yield, this parameter is highest in N_1AP_2 and reached 12.9 t ha^{-1} and is the lowest for N_3AP_1 and N_3AP_2, equivalent to 11.0 t ha^{-1} (Table 4). Rattey and Hogarth (2001) and Muchow *et al*. (1995) reported that sugar yields reduced with increasing levels of N. This study also shows that with application of 92 kg N ha^{-1}, the average sugar yield reached its highest value of 12.5 t ha^{-1} (Table 3).

Electrical conductivity, Na, K and residual N contents of juice are varied from 8.8 to 10.0 dS m^{-1}, 33.3 to 36.5 mg kg^{-1}, 3987.1 to 4232.8 mg kg^{-1} and 0.025 to 0.036%, respectively (Table 4).

Potassium and sodium in juice lead to increasing of ash in juice which prevents sugar to be extracted in factory. Malavolta (1994) reported that lack of K decreased the translocation of the assimilates from leaves into stalks. Table 1 shows that the K content of soil ranged from 121.8 to 87.0 mg kg^{-1}. Thus, the high concentration of K may result in higher K accumulation in juice. The current study also showed that potassium content was more than sodium in juice. Whitbread *et al*. (2005) observed that potassium ion in juice is one of the main components of ash. Present results illustrated that the values of K in N_1 treatment was less than other treatments. Na content in both N_1 and N_2 are identical and the highest in N_3 treatment (Table 3). Electrical conductivity was not significantly influenced by different treatments. Residual N in juice which prevents sugar to be extracted in factory was negligible in different treatments.

The fiber value was varied from 10.8% in N_3AP_1 to 13.0% for N_1AP_2 (Table 4). Fiber value was decreasing from 12.5% for N_1 treatment to 11.1% for N_3 treatment (Table 3). Malavolta (1994) indicated that with increasing N application, the fiber value decreases. Also the amount of trash ranged from 3.4 to 3.8 t ha^{-1} with mean values of 3.5 t ha^{-1} in N_3 and 3.7 t ha^{-1} in N_2 (Table 3). The comparison among means of data in Duncan's method revealed that different rates of fertilizer and its split application had no significant effect on different measured parameters (Table 3).

Nitrogen Use Efficiency

The highest NUE in sugar was obtained for N_1AP_2 treatment with the value of 0.14 t kg^{-1}N and the least value in sugar is belonged to N_3 treatment which is equivalent to 0.06 t kg^{-1} N. In addition, these extreme values for NUE in cane are 1.45 for N_1AP_1 and N_1AP_2 and 0.62 t kg^{-1} N for N_3AP_1. Comparison of means indicated that NUE value in sugar and cane for N_1 treatment (92 kg N ha^{-1}) are the highest and are 0.13 and 1.39 t kg^{-1} N, respectively which are significantly different to other treatments. These results depicted that split application of N had no effect on NUE (Table 3). According to Table 2, different rates of nitrogen can cause significant changes in NUE due to higher N uptake, thus less amounts of this nutrient is absorbed by the plant. Results of variance analysis and mean comparison of NUE data in cane and sugar yield are shown in Tables 2 and 3, respectively. The reason of NUE being significant after application of N_1 treatment may be explained in such a way that high rates of fertilizer may make the vegetation growth period longer and shorten the period of sugar accumulation and as consequence, sugar yield did not increase while a better balance was made after applying 92 kg N ha^{-1}. The highest NUE is achieved when the least rate of N is applied. Present results indicated that the NUE values in sugar and in cane are highest and reached the values of 0.13 and 1.39 t kg^{-1} N, respectively when applying the least rate for N application (92 kg N ha^{-1}) which are significantly different in comparison with other treatments (Table 3).

The interactive effects of N and AP on juice purity depicted that application of 92 kg N ha^{-1} and AP of 30-30-40% gave the purest juice with percentage of 90 and increasing N rate with this AP treatment results in declining the juice purity noticeably (Fig. 1). Although, AP treatment of 20-40-40% resulted in more pure juice with increasing N rate, the juice purity in the best condition can reach 89.4% which is still a bit lower than the situation when 92 kg N ha^{-1} was applied in AP treatment of 30-30-40%. Therefore, it is not economically and environmentally justified to apply N_3 (184 kg ha^{-1}) due to high cost of fertilizers and adverse environment impacts. Excessive use of N fertilizers has resulted in increasing leaching of NO_3^- and caused groundwater pollution (Ersahin, 2001). Lee and Jose (2005) revealed that increasing N application raises nitrogen leaching without making any difference in woody plants growth.

Although, none of the influences related to N rates and split applications and their interactive effects was significantly effective on sugar yield, studying the effect of application method showed that the highest sugar yield can be obtained by application of the lowest N rate (92 kg ha^{-1}) and AP treatment of 30-35-35% and it reached to 12.9 t ha^{-1} (Fig. 2a). Neither increasing N application nor the kind of split application can compensate the adverse effect of N application on sugar yield. Rattey and Hogarth (2001) reported that sugar yields reduced with increasing N.

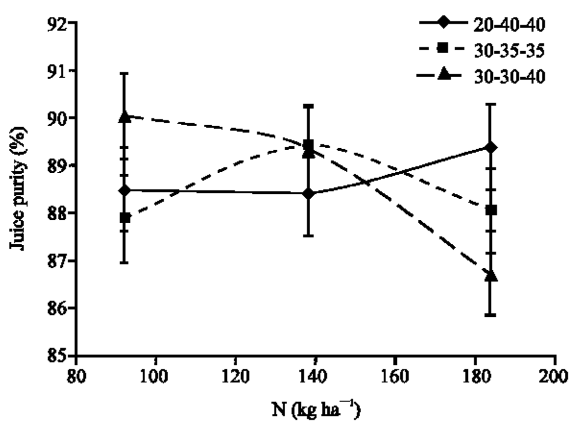

Fig. 1: Effect of N rate on juice purity for different split applications (The bars on the plot are SD)

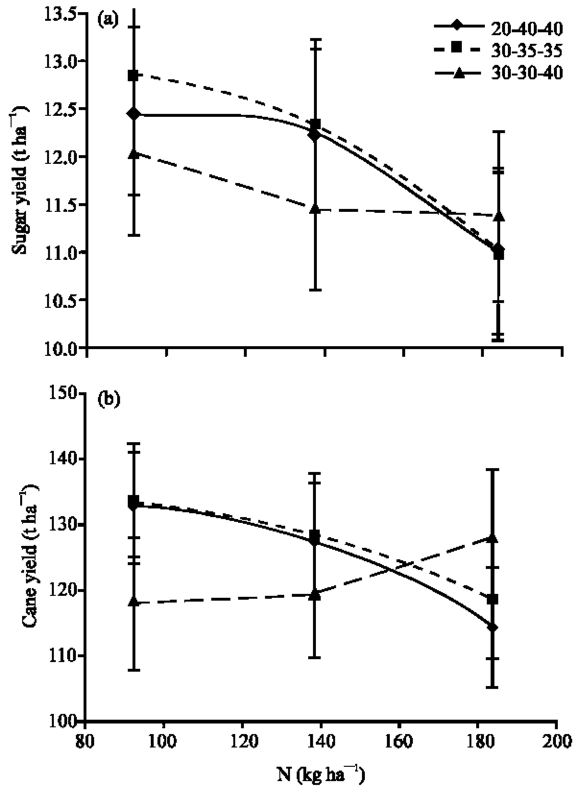

Fig. 2: Effect of N rate and split application on (a) sugar yield and (b) cane yield (The bars on the plot are SD)

The similar trend is obtained for cane yield (Fig. 2b). In the other words, the highest cane yield obtained after the lowest N application rate and it reached the maximum value of 133.5 t ha^{-1}. Even, increasing N rate led to decreasing of cane yield. But Thorburn *et al*. (2001) reported that cane yield was not affected with increasing N. Wiedenfeld (2000) depicted that rate of N application did not affect cane and sugar yields in the plant crop.

CONCLUSION

Among all applied nitrogen rates (92, 138 and 184 kg N ha^{-1}) and different split applications (20-40-40, 30-35-35 and 30-30-40%), the treatment of 92 kg N ha^{-1} and AP of 30-30-40% gave the purest juice. But, the greatest amount of sugar yield achieved using treatment of 92 kg N ha^{-1} and AP of 30-35-35% because cane yield was the highest in this treatment. Also, the highest NUE value gained after applying the least amount of N. The amount of potassium content in juice was higher than sodium content. In general, the least amounts of potassium and sodium of juice of sugarcane obtained when applying 92 kg N ha^{-1}. The N application rate had no influence on enhancing the fiber and trash amounts of sugarcane.

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REFERENCES

Barzegar, A.R. and A. Koochekzadeh, 2001. Cadmium status of soils under sugarcane in Khuzestan Province. J. Sci. Tech. Agric. Nat. Resour., 5: 55-64.

Bremner, J.M., 1996. Nitrogen-Total. In: Methods of Soils Analysis: Chemical Methods. Part 3, Sparks, D.L. (Ed.). SSSA, Book Series, No. 5, Soil Science Society of America,, Madison, WI. USA., pp: 1085-1121.

Chen, J., C.P. and C.C. Chou, 1993. Chen-Chou Cane Sugar Handbook: A Manual for Cane Sugar Manufactures and their Chemists, 12th Edn., John Wiley and Sons, Inc., New York, pp: 1120.

Dilz, K., 1988. Efficiency of Uptake and Utilization of Nitrogen by Plants. In: Nitrogen Efficiency in Agricultural Soils, Jenkinson, D.S. and K.A. Smith (Eds.). Elsevier Applied Science, London, pp: 1-26.

Ersahin, S., 2001. Assessment of spatial variability in nitrate leaching to reduce nitrogen fertilizers impact on water quality. Agric. Water Manage., 48: 179-189.

Gana, A.K., 2008. Determination of optimal rate of nitrogen for chewing sugarcane production in the Southern Guinea Savanna of Nigeria. Sugar Tech., 10: 278-279.

Gawander, J.S., P. Gangaiya and R.J. Morrison, 2004. Potassium responses and budgets in the growth of sugarcane in Fiji. Sugar Cane Int., 22: 3-8.

Gee, G.W. and J.W. Bauder, 1986. Particle-Size Analysis. In: Methods of Soil Analysis Part 1: Physical and Mineralogical Methods, Klute, A. (Eds.). SSSA, Book Series, No. 9, 2nd Edn., Soil Science Society of America, Madison, WI, USA., ISBN: 0-89118-088-5, pp: 383-411.

Helmke, P.A. and D.L. Sparks, 1996. Lithium, Sodium, Potassium, Rubidium and Cesium. In: Methods of Soil Analysis Part 3: Chemical Methods, Sparks, D.L. (Eds.). SSSA, Book Series, No. 5, Soil Science Society of America, Madison, WI, USA., ISBN: 0891188258, pp: 551-574.

ICOUMSA, 1994. International commission for uniform methods of sugar analysis. Method GS5/7-1, Methods Book, with 1st Supplement 1998, UK., p: 1-8.

Isa, D.W., G. Hofman and O. van Cleemput, 2006. Uptake and balance of fertilizer nitrogen applied to sugarcane. Field Crops Res., 95: 348-354.

Keating, B.A., K. Verburg, N.I. Huth and M.J. Robertson, 1997. Nitrogen Management in Intensive Agriculture: Sugarcane in Australia. In: Intensive Sugarcane Production: Meeting the Challenges Beyond 2000. Keating, B.A. and J.R. Wilson (Eds.). CAB International, Wallingford, UK., pp: 221-242.

Kuo, S., 1996. Phosphorus. In: Method of Soil Analysis. Part 3-Chemical Methods, Sparks, D.L., A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M.E. Sumner (Eds.). Soil Science Society American Inc. American Society Agronomy, Inc., Wisconsin, pp: 869-919. ISBN: 0-89118-825-8.

Lakshmikantham, M., 1983. Technology in Sugarcane Growing. 2nd Edn., Oxford and IBH Publishing Co., New Delhi.

Lee, K.H. and S. Jose, 2005. Nitrate leaching cottonwood and loblolly pine biomass plantations along a nitrogen fertilization gradient. J. Agric. Ecosys. Environ., 105: 615-623.

Malavolta, E., 1994. Nutrient and Fertilizer Management in Sugar Cane. International Potash Institue, Basel, Switzerland, pp: 104.

Muchow, R.C., M.J. Robertson, A.W. Wood and B.A. Keating, 1995. Effect of nitrogen on the time-course of sucrose accumulation in sugarcane. Field Crop Res., 47: 143-153.

Mulvaney, R.L., 1996. Nitrogen-Inorganic Forms. In: Method of Soil Analysis. Part 3-Chemical Methods, Sparks, D.L., A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M.E. Sumner (Eds.). Soil Science Society America, Inc. American Society Agronomy, Inc., Wisconsin, pp: 1123-1184. ISBN: 0-89118-825-8.

Nelson, D.W. and L.E. Sommers, 1996. Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 3. Chemical Methods, Sparks, D.L. (Eds.). American Society of Agronomy/Soil Science Society of America, Madison, WI., pp: 961-1010.

Peralta, J.M. and C.O. Stockle, 2001. Dynamics of nitrate leaching under irrigated potato rotation in Washington State: A long-term simulation study. J. Agric. Ecosyst. Environ., 88: 23-34.

Rasiah, V. and J.D. Armour, 2001. Nitrate accumulation under cropping in the ferrosols of Far North Queensland wet tropics. Aust. J. Soil Res., 39: 329-341.

Rattey, A.R. and D.M. Hogarth, 2001. The effect of different nitrogen rates on CCS accumulation over time. Proc. Int. Soc. Sugar Cane Technol., 24: 168-170.

Rhoades, J.D., 1996. Salinity: Electrical Conductivity and Total Dissolved Solids. In: Methods of Soil Analysis, Part 3. Chemical Methods, Sparks, D.L. (Ed.). Soil Science Society of America, Inc., American Society of Agronomy, Inc., Madison, WI, USA., pp: 417-435.

Sreewarome, A., S. Saensupo, P. Prammannee and P. Weerathworn, 2007. Effect of rate and split application of nitrogen on agronomic characteristics, cane yield and juice quality. Prog. Int. Soc. Sugar Cane Technol., 26: 465-469.

Thomas, G.W., 1996. Soil pH and Soil Acidity. In: Methods of Soil Analysis, Part 3. Chemical Methods, Sparks, D.L. (Ed.). Soil Science Society of America Inc, American Society of Agronomy, Inc, Madison, WI, pp: 475-490.

Thorburn, P.J., J.S. Biggs, B.A. Keating, K.L. Weier and F.A. Robertson, 2001. Nitrate in groundwaters in the Australian sugar industry. Proc. Int. Soc. Sugar Cane Technol., 24: 131-134.

Thorburn, P.J., E.A. Meiera and M.E. Probert, 2005. Modelling nitrogen dynamics in sugarcane systems: Recent advantages and applications. Field Crop Res., 92: 317-351.

Van Antwerpen, R., J.H. Meyer and P.E.T. Turner, 2001. The effects of cane trash on yield and nutrition from 61 year old BT1 trial at mount Edgecombe. Proc. South Afr. Sugar Technol. Assoc., 75: 235-241.

Van Miegroet, H., R.J. Norby and T.J. Tschaplinski, 1994. Nitrogen fertilization strategies in a short-rotation sycamore plantation. For. Echol. Manage., 64: 13-24.

Whitbread, M., G.R.E. Lionnet, J.H. Meyer and R.A. Wood, 2005. Ash and sugar in cane juice at Nchalo Sugar Estate, Malowi: Relationship with inorganic constituents in soil. Sugar Cane Int. J. Cane Agric., 23: 35-35.

Wiedenfeld, R.P., 2000. Water stress during different sugarcane growth periods on yield and response to N fertilization. J. Agric. Water Manage., 43: 173-182.