Ethiop. J. Appl. Sci. Technol. Vol. 3 (1): 9-22(2012)

ORIGINAL ARTICLE

Correlation of Foliar Nutrient Status with Yield of Sugarcane Varieties at Different Crop Stages and Nitrogen Levels at Wonji-Shoa and Finchaa Sugarcane Plantations of Ethiopia

Ambachew Dametie[1], Abiy Fantaye[2]* and Zeleke Teshome[3]
[123]Sugar Corporation, Research and Training, P. O. Box 15, Wonji, Ethiopia
***Corresponding author:** E-mail: abiyf@yahoo.com

ABSTRACT

A study was conducted at Wonji-Shoa and Finchaa sugarcane plantations to determine critical and optimum foliar N level and identify effect of N fertilizer rates, cuttings and varieties on foliar N, P and K composition at different age of cane. Field trials were conducted from 2000 to 2006 on vertisol and fluvisol at Wonji-Shoa and vertisols and luvisols of Finchaa. Three factor randomized complete block design with three replications was used. The treatments were arranged in split split plot by assigning nitrogen rates as main plot, crop stage (PC, I and II ratoons) as sub plot and varieties as subsub plot. The result indicated that cane and sugar yield across cutting consistently decreased from plantcane to the subsequent ratoons in addition the foliar N content of the ratoons were lower than the plantcane in both sugarcane plantations. Moreover, in both sites the foliar N, P and K levels decreased consistently from the 3 months to the 6 months cane. Cane and sugar yield of Wonji-Shoa was positively and significantly ($P<0.05$) correlated with foliar N % at 4 month age, while at Finchaa cane and sugar yield was positively and significantly ($P<0.05$) correlated with foliar N % from 3 to 6 months cane age with strong correlation at 5 months of age. It was suggested that the standard foliar sampling time to be 4 month at Wonji-Shoa and 5 month at Finchaa as long as the standard fertilizer application time was maintained 4 to 6 weeks before leaf sampling. The critical foliar nitrogen levels of Wonji-Shoa and Finchaa sugar estates were 1.66 % and 1.82 %, respectively, and the optimum foliar N range were 1.68-1.74% for Wonji-Shoa and 1.83-1.85 % for Finchaa. In addition the foliar N levels vary among cutting and variety therefore; adjustment should be made before interpretation.

Keywords: Foliar Nutrient, Nitrogen, Plantcane, Ratoon, Sugarcane, Variety

INTRODUCTION

Fertilizer management is an important agronomic practice in sugarcane production. Sugarcane producers relay on field fertilizer trials, soil testing and foliar analysis to plan fertilizer programs (Elwali and Gascho, 1984). Consistent soil testing is a valuable soil management practice that allows making sound economic fertilization decisions. Soil testing remains an excellent pre-plant practice but its reliability for the successive ratoon crops has been questioned. There are two major limitations of soil testing under the existing condition of the Ethiopian Sugar Estates in which nitrogen is the major limiting nutrient. The first limitation is that soil tests are not calibrated for nitrogen. Secondly, there is problem of obtaining representative soil samples after banding of fertilizers in the furrow at planting and in later side dress applications on ratoons. Thus it was hypothesized that the use of leaf nutrient analysis in combination with visual evaluation of malnutrition symptoms can complement the fertilization program and give additional information that will improve decision.

Leaf analysis provides a picture of crop nutritional status at the time of sampling, while soil testing provides information about the continued supply of nutrients from the soil. For sugarcane leaf analysis, the top visible dewlap (TVD) leaf blade is sampled during the grand growth period (Evans 1956; Gascho and Elwali 1978; McCray *et al*., 2006). According to Holford (1968) yields of sugar cane is highly correlated with leaf nutrient status during the maximum growth period indicating that leaf analysis allows early detection of nutritional problems. Plant analysis could also be a useful tool for correcting plant nutrient deficiencies and imbalances (Baldock and Schulte, 1996), and optimize crop production (Walworth *et al*., 1986), through evaluation of fertilizer requirements. Results of foliar analyses are interpreted on the basis of the critical nutrient level (CNL), which defines a nutrient concentration below which the nutrient is considered to limit production. The CNL refers to the concentration of a particular nutrient in a particular plant part at a specific stage of growth, at which production losses reach 10 % (Richards and Bevege, 1972; McCray *et al*., 2006). The CNL approach may also include the use of "nutrient's optimum range", defined as the range of concentration of a nutrient considered optimum for production. However, the interpretation of CNL depends on age of the plant at sampling, the sugarcane variety, plant part sampled, soil condition and inorganic fertilizer application (Gascho, 2000). When using CNL approach it is particularly important to collect leaf samples at the specified growth stage because nutrient contents change during the crop growth cycle.

In Ethiopia even though sugarcane cultivation began at commercial level since 1954, no attempt has been made to guide fertilizer application programs based on foliar diagnostic techniques. The general practice is applying a fixed rate of fertilizer regardless of variety to certain soil management groups but varying the rate depending on the successive cuttings based on field fertilizer trials. The objectives of this study were to determine critical and optimum foliar N levels and identify effect of N fertilizer rate, cuttings and varieties on foliar N, P and K composition at different age of sampling.

MATERIALS AND METHODS

Wonji-Shoa Sugar Estate is located 8°31′N and 39°12′E at an altitude of 1500 m a.sl. in Awash River Basin. The major soil types are vertisols and fluvisols. The climate at Wonji-Shoa is semiarid. While Finchaa sugar estate is located 9°30′ to 10°00′N and 37°15′ to 37°30′E at altitude ranging from 1,350 – 1,600 m.a.s.l., in Abay River Basin. The major soil types of Finchaa Sugar Estate are luvisols and vertisols and the area has sub humid climate.

The study was conducted from 2000 to 2006 cropping seasons on two major soil types of each sugar estate: vertisol and fluvisol at Wonji-Shoa Sugar Estate and on vertisol and luvisol at Finchaa Sugar Estate. Three factor randomized complete block design with three replication was used in which the three factors were arranges in split split plot layout as shown in Table 1.

Table 1.Arrangement of treatment combinations

Site	Main plot (Nitrogen kg ha^{-1})	Sub plot (Cutting)	Sub sub plot (Variety)
Wonji-Shoa	0	I	B41-227
	130	II	B52-298
	260	III	CO 421
	390		N 14
			NCO310
			NCO334
Finchaa	0	I	B41-227
	130	II	B52-298
	260	III	CO449
	390		NCO334
			CO421

The nitrogen treatment was applied in the form of urea (46% N) fertilizer at Wonji-Shoa and Finchaa. Moreover, following the standard fertilizer recommendation of the estate basal dressing of phosphorus (115 kg P_2O_5 ha^{-1}) for plantcane and succeeding ratoons was made at Finchaa. The time of N fertilizer application was at 2.5 months for plantcane and just after harvest on ratoons in both sugar estates. To simulate condition of the commercial fields of the sugar estates all other cultural practices were the same as the commercial fields.

Leaf N, P, K; cane yield and sugar yield were measured. The top visible dewlap (TVD) leaf was sampled from primary stalk. The sampling was made from the central four furrows to avoid border effect. Before leaf analysis the midrib of the leaf was removed. The foliar samples were collected at crop age of 3, 4 and 5 months at Wonji-Shoa, but at Finchaa additional samples were also collected at 6 months cane age. Nitrogen was estimated by steam distillation, potassium using flame photometer and phosphorus following vanadomolybdate color development method as described by Cottenie (1980).

Twenty randomly selected millable stalks from the middle four furrows were sampled at harvest for juice quality determination (Pol percent cane, degree brix, purity % and rendement %) following the procedures outlined by Mathur (1981) to calculate sugar yield. In addition, to calculate cane yield the total plot cane weight was measured using a crane scale loaded on a grab loader. Then cane and sugar yield was adjusted to 24 and 17 months cane age harvest for plantcane and ratoons, respectively as shown in equation 1.

Adjusted yield = (Measured yield/harvest age) mean harvest age of cutting* --- Equation 1.

Analysis of variance and mean separation of cane and sugar yield was made using MSTATC statistical software. Correlation coefficients of the foliar N, P and K with cane and sugar yield at different cane age was determined using XL spreadsheet to identify time of foliar diagnosis correlated with cane and sugar yield.

In this study the optimum range was taken to be the foliar nutrient concentration between the economic optimum and the biological maximum yield level (100 %) assuming economic optimum fertilizer rate to be at 95% yield level.

RESULTS AND DISCUSSION

Main and interaction effect of nitrogen, cuttings and variety on yield

Highly significant difference ($P<0.01$) in cane and sugar yields at Wonji-Shoa were obtained among nitrogen levels and cutting (Table 2). All N treated plots showed significantly high cane yield than untreated. This is due to growth promotion effect of N. The cane yield decreases with cutting due to the progressive yield reduction over ratooning and the difference in maturity age for harvest among plantcane and ratoons. Even if the varieties did not have any significant cane yield difference, there was highly significant ($P<0.01$) difference in sugar yield among varieties. Moreover, all the interaction effects were statistically non significant. This implies that any of the varieties have no exceptional N demand either at plantcane or ratoon stage. At Finchaa nitrogen, cutting and varieties have shown highly significant ($P<0.01$) difference in cane and sugar yield (Table 3). Moreover, among the interaction effects except non-significant difference among interaction effects of nitrogen, cutting and variety, all the other interaction effects (N & cutting, N & varieties, and cutting & varieties) were statistically highly significant ($P<0.01$) (Table 4 - 5).

Among all cutting plantcane showed the highest cane yield at 206 and 309 kg ha^{-1}N and the highest sugar yield was achieved at 206 kg ha^{-1} N. This is due to low N rate retarded growth of cane while at very high N applications the sucrose accumulation is depressed. B52-298 showed the highest cane yield followed by CO421 at 390 kg ha^{-1} N rate. CO421 also showed superior sugar yield at 260 kg ha^{-1} N rate. CO421 cane variety was found to be highly responsive in terms of cane and sugar yield for N application followed by B52-298. But, CO449 was found to be low yielding and less responsive for N.

The significant cane and sugar yields difference obtained among the varieties of Finchaa and sugar yield at Wonji-Shoa was different from the result of Ambachew and Tekalign (2000) that showed non significant difference among all varieties of plantcane crop of Metahara. This implies that sugarcane varieties have much difference in yield at ratoon stage than the plantcane stage. Moreover, types of varieties present in the sugar estates and difference in environmental conditions could also contribute.

Table 2. Effect of nitrogen cutting and variety on yield and foliar NPK at Wonji-Shoa

Variable		Cane ($t\ ha^{-1}$)	Sugar ($t\ ha^{-1}$)	Foliar N (%)			Foliar P (%)			Foliar K (%)		
				Sampling age (months)			Sampling age (months)			Sampling age (months)		
				3	4	5	3	4	5	3	4	5
Nitrogen (kg ha^{-1})	0	142.68b	19.58c	1.82	1.60	1.56	0.25	0.23	0.19	1.57	1.41	1.22
	130	187.66a	24.56ab	1.83	1.66	1.53	0.24	0.21	0.18	1.79	1.54	1.36
	260	202.75a	27.78a	1.90	1.81	1.66	0.24	0.21	0.18	1.74	1.43	1.44
	390	200.52a	27.26a	1.92	1.76	1.73	0.23	0.22	0.18	1.76	1.51	1.48
	Mean	183.40	24.80	1.87	1.72	1.62	0.24	0.22	0.18	1.72	1.47	1.38
	Sig	**	**	-	-	-	-	-	-	-	-	-
	LSD	19.09	2.16	-	-	-	-	-	-	-	-	-
Cutting	I	223.89a	32.77a	2.16	2.03	1.69	0.27	0.24	0.19	1.69	1.64	1.22
	II	195.31a	25.81ab	1.58	1.48	1.50	0.20	0.20	0.16	1.50	1.47	1.27
	III	131.01b	15.81c	1.84	1.64	1.67	0.26	0.21	0.20	1.95	1.30	1.64
	Mean	183.40	24.80	1.86	1.72	1.62	0.24	0.22	0.18	1.71	1.47	1.38
	Sig	**	**	-	-	-	-	-	-	-	-	-
	LSD	39.24	3.80	-	-	-	-	-	-	-	-	-
Varieties	B41-227	179.53	24.32bc	1.88	1.69	1.64	0.25	0.24	0.19	1.75	1.61	1.43
	B52-298	178.15	24.50bc	1.87	1.70	1.58	0.22	0.21	0.19	1.72	1.55	1.44
	CO 421	177.98	23.92c	1.86	1.71	1.63	0.24	0.22	0.18	1.64	1.43	1.36
	N 14	192.37	25.89ab	1.89	1.71	1.65	0.24	0.21	0.17	1.64	1.35	1.30
	NCO310	183.04	23.98c	1.83	1.73	1.64	0.24	0.22	0.18	1.70	1.39	1.32
	NCO334	190.04	26.15a	1.83	1.76	1.59	0.25	0.22	0.18	1.83	1.51	1.42
	Mean	183.52	24.79	1.86	1.72	1.62	0.24	0.22	0.18	1.71	1.47	1.38
	Sig	NS	**	-	-	-	-	-	-	-	-	-
	LSD	-	1.58	-	-	-	-	-	-	-	-	-
Interaction	N*C	NS	NS	-	-	-	-	-	-	-	-	-
	N*V	NS	NS	-	-	-	-	-	-	-	-	-
	C*V	NS	NS	-	-	-	-	-	-	-	-	-
	N*C*V	NS	NS	-	-	-	-	-	-	-	-	-
CV (%)	-	22.35	10.50	-	-	-	-	-	-	-	-	-

Means followed by the same letter for each parameter were not significantly different at $P \leq 0.05$

NB: Foliar NPK determined was made from composite samples thus ANOVA not done; NS: non significant *: significant; **: highly significant

Table 3. Effect of nitrogen cutting and variety on yield and foliar NPK at Finchaa

Variable		Cane (t ha^{-1})	Sugar (t ha^{-1})	Foliar N (%) Sampling age (months)				Foliar P (%) Sampling age (months)				Foliar K (%) Sampling age (months)			
				3	4	5	6	3	4	5	6	3	4	5	6
Nitrogen (kg ha^{-1})	0	144.78c	16.87b	1.75c	1.59c	1.53	1.43	0.27	0.23	0.22	0.22c	1.30a	1.25	1.21	1.21
	130	203.79b	20.48a	2.14b	2.04b	1.79	1.60	0.29	0.21	0.23	0.23b	1.25ab	1.24	1.23	1.26
	260	222.55a	21.75a	2.32a	2.19ab	1.94	1.66	0.29	0.23	0.24	0.24b	1.21b	1.22	1.20	1.24
	390	232.16a	21.12a	2.40a	2.31a	1.92	1.69	0.30	0.24	0.26	0.25a	1.21b	1.20	1.14	1.23
	Mean	200.82	20.06	2.15	2.03	1.80	1.59	0.29	0.23	0.24	0.24	1.24	1.23	1.20	1.24
	Sig	**	**	**	**	ND	ns	ns	ns	ND	**	**	ns	ND	ns
	LSD	12.04	1.62	0.116	0.205	ND				ND	0.008	0.082		ND	
Cutting	I	281.39a	25.34a	2.42a	2.49a	1.86	1.63a	0.24b	0.23	0.23	0.21b	1.29	1.33a	1.19	1.34a
	II	153.78b	17.10b	1.83b	1.81b	1.73	1.72a	0.37a	0.23	0.24	0.23b	1.18	1.23b	1.20	1.29a
	III	167.29b	17.74b	2.21a	1.78b	1.66	1.39b	0.26b	0.21	0.24	0.27a	1.21	1.21ab	1.19	1.08b
	Mean	200.82	21.54	2.15	2.03	1.75	1.71	0.29	0.22	0.24	0.24	1.23	1.26	1.19	1.24
	Sig	**	**	**	**	ND	**	**	ns	ND	**	ns	*	ND	**
	LSD	17.55	1.42	0.274	0.304	ND	0.110	0.032	-	ND	0.022	-	0.184	ND	0.146
Varieties	B41-227	198.68b	19.07b	2.24a	2.04	1.95	1.70a	0.31a	0.23	0.25	0.25a	1.25ab	1.24a	1.24	1.26
	B52-298	213.87a	20.14a	2.13ab	2.05	1.76	1.58b	0.26b	0.24	0.23	0.22c	1.17c	1.18b	1.19	1.26
	CO449	187.47c	20.17a	2.10a	2.04	1.73	1.53b	0.26b	0.20	0.22	0.21d	1.26ab	1.24a	1.2	1.24
	NCO334	197.17bc	20.34a	2.15ab	1.98	1.79	1.54b	0.29ab	0.23	0.25	0.25a	1.31a	1.27a	1.18	1.23
	CO421	206.91ab	20.58a	2.14ab	2.04	1.76	1.56b	0.31a	0.22	0.24	0.23b	1.22bc	1.18b	1.16	1.20
	Mean	201.73	20.06	2.15	2.03	1.80	1.58	0.29	0.22	0.24	0.23	1.24	1.22	1.19	1.24
	Sig	**	**	*	ns	ND	**	**	ns	ND	**	*	**	ND	ns
	LSD	9.92	0.99	0.127		ND	0.01	0.041		ND	0.009	0.072	0.051	ND	-
Interaction	N*C	**	**	NS	NS	ND	NS	NS	NS	ND	NS	NS	NS	ND	NS
	N*V	**	**	NS	NS	ND	NS	NS	NS	ND	NS	NS	**	ND	NS
	C*V	**	**	NS	**	ND	NS	NS	NS	ND		NS	**	ND	NS
	N*C*V	NS	NS	NS	NS	ND	NS	NS	NS	ND	NS	NS	NS	ND	NS
CV (%)	-	7.55	7.58	6.33	6.52	-	7.04	14.18	24.58	-	8.02	7.23	5.37	-	10.01

Means followed by the same letter for each parameter were not significantly different at P≤ 0.05

ND: NS: non significant *: significant; **: highly significant

Table 4. Interaction effect of N and cutting on cane and sugar yield at Finchaa

Nitrogen (kg ha^{-1})	I Cutting	II Cutting	III Cutting	Mean	I Cutting	II Cutting	III Cutting	Mean
	Cane yield (t ha^{-1})				Sugar yield (t ha^{-1})			
0	206.32c	126.80g	101.24h	144.78	20.59c	15.59fg	14.44g	16.87
130	291.71b	146.59f	173.07de	203.79	26.13b	16.55f	18.77de	20.48
260	309.87a	163.07e	194.72c	222.55	28.07a	17.75e	19.45cd	21.76
390	317.69a	178.70d	200.12c	232.17	26.57b	18.51de	18.29de	21.12
Mean	281.40	153.79	167.29	200.83	25.34	17.10	17.74	20.06

Table 5. Interaction effect of variety and N on cane and sugar yield at Finchaa

Variety	0 kg ha^{-1} N	130 kg ha^{-1} N	260 kg ha^{-1} N	390 kg ha^{-1} N	Mean	0 kg ha^{-1} N	130 kg ha^{-1} N	260 kg ha^{-1} N	390 kg ha^{-1} N	Mean
	Cane yield (t ha^{-1})					Sugar yield (t ha^{-1})				
B41-227	160.02 i	193.50h	216.77def	224.45cda	***198.69***	16.85cd	17.58cb	21.47ab	20.36ab	***19.07***
B52-298	158.33i	211.21efg	238.87abc	247.09a	***213.88***	18.03c	20,22b	21.43ab	20.89ab	***20.14***
CO449	131.18j	196.08gh	209.70efgh	212.92ef	***187.47***	16.83cd	21.06ab	21.84ab	20.95ab	***20.17***
NCO334	137.13j	200.56fgh	217.43def	233.45abcd	***197.14***	16.12d	21.67ab	21.95ab	21.62ab	***20.34***
CO421	137.13j	217.59def	229.99bcd	242.92ab	***206.91***	16.53cd	21.90ab	22.07a	21.80ab	***20.58***
Mean	***144.76***	***203.79***	***222.55***	***232.17***	***200.82***	***16.87***	***20.49***	***21.75***	***21.12***	***20.06***

Table 6. Interaction effect of variety and cutting on cane and sugar yield at Finchaa

Variety	I Cutting	II Cutting	III Cutting	Mean	I Cutting	II Cutting	III Cutting	Mean
	Cane yield (t ha^{-1})				Sugar yield (t ha^{-1})			
B41-227	289.95a	148.48e	157.63de	*198.69*	24.17b	17.15de	15.87e	*19.06*
B52-298	287.44a	172.33c	181.86c	*213.88*	25.19ab	18.15cd	17.08de	*20.14*
CO449	266.37b	147.65e	148.39e	*187.47*	25.89a	16.50e	18.12cd	*20.17*
NCO334	272.15b	151.21e	168.17cd	*197.18*	25.66a	16.44e	18.91c	*20.34*
CO421	291.07a	149.26e	180.40c	*206.91*	25.77a	17.25de	18.70c	*20.57*
Mean	***281.40***	***153.79***	***167.29***	***200.82***	***25.34***	***17.10***	***17.74***	***20.06***

Yield response for N application

The biological maximum cane yield at Wonji-Shoa was 207 t ha^{-1} obtained at 302 kg ha^{-1} nitrogen application, while the maximum sugar yield was 28 t ha^{-1} at 319 kg ha^{-1} nitrogen (Figure 1). The level of N required to obtain the biological maximum sugar yield was not the same as that of cane yield. This implies that application of nitrogen after 302 kg ha^{-1} will not increase cane yield but it increases sucrose content until 319 kg ha^{-1}. Then after both cane and sugar yield will decline.

The economic optimum nitrogen rate for Wonji-Shoa is 184 - 230 kg ha^{-1} N for ratoons (Ambachew and Abiy 2009) which gives about 95 - 98 % of the maximum biological cane yield. At the critical foliar nutrient level (10 % cane yield loss) the N rate was 130 kg ha^{-1} N and at the optimum foliar N (> 95% cane yield) level the nitrogen rate was between 184 and 302 kg ha^{-1} nitrogen.

The biological maximum cane yield at Finchaa was 227 ton ha^{-1} obtained at 321 kg ha^{-1} nitrogen application, while the maximum sugar yield was 22 ton ha^{-1} at 290 kg ha^{-1} nitrogen (Figure 1). At the critical foliar nutrient level of Finchaa (10 % cane yield loss) the N rate was 150 kg ha^{-1} N and at the optimum foliar N (> 95% cane yield) the nitrogen rate was between 200 and 321 kg ha^{-1} nitrogen. At Finchaa the N rate in which maximum sugar yield achieved was less than the maximum cane yield, while the reverse was true at Wonji-Shoa. This implies that higher N rates have more detrimental effect in sugar yield at Finchaa than Wonji-Shoa.

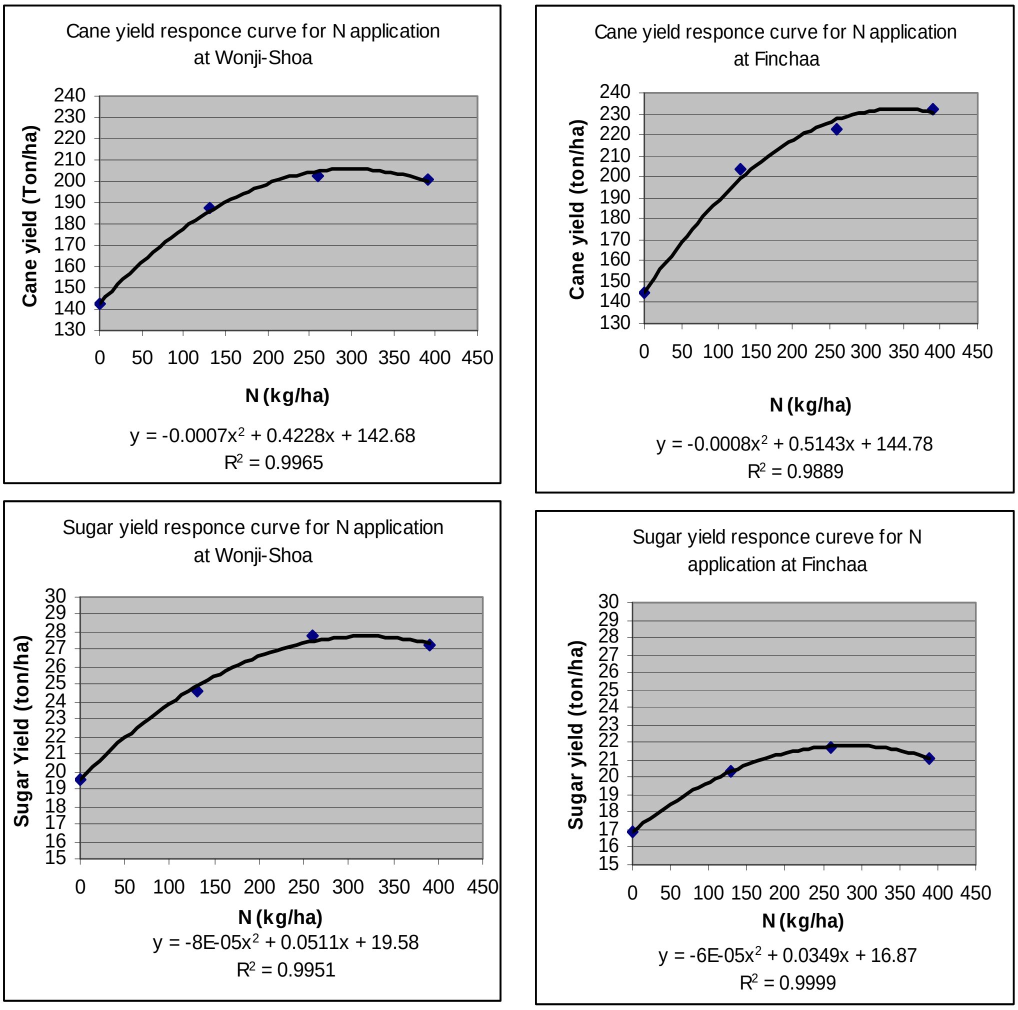

Figure 1. Cane and sugar yield response curve for N application

Foliar N, P and K at different cane age

In Wonji-Shoa and Finchaa Sugar Estates the foliar N content was the highest at 3 month and declines consistently in the subsequent months up to the 6 month (Figure 2). Since N was applied for 2.5 month cane, the foliar N content obtained at the 3 month of cane age was the highest indicating the maximum uptake of the nutrient immediately after N application. This is because of that sugarcane uptakes and store nutrient in early periods at the maximum amount and digest in the subsequent periods.

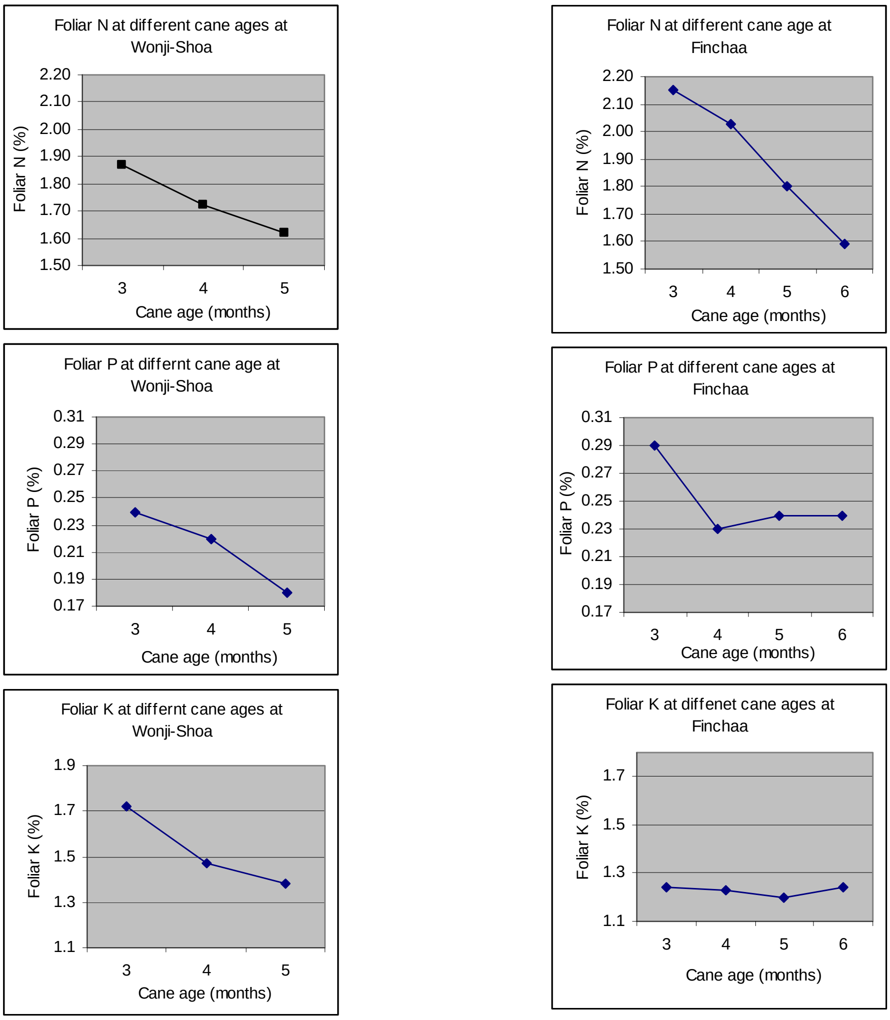

Figure 2. Foliar N, P and K levels at different cane age

At Wonji-Shoa the foliar P and K consistently decreased as the cane age increases from 3 to 5 months. However, at Finchaa even if the foliar P decreases from 3 month up to the 4th month and the foliar K up to the 5th month, it has shown slight improvement afterwards up to the 6th month.

Foliar N levels at different N levels

As the applied N rate increases the foliar N content increases consistently at both Wonji-Shoa and Finchaa (Figure 3 and 4). The foliar N levels of Wonji-Shoa are higher than that of Finchaa.

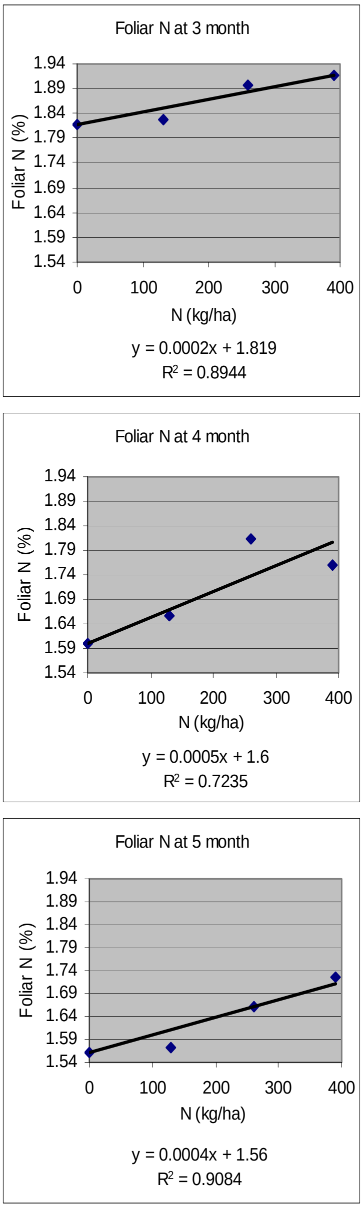

Figure 3. Foliar N curve at different age of sugarcane at Wonji-Shoa

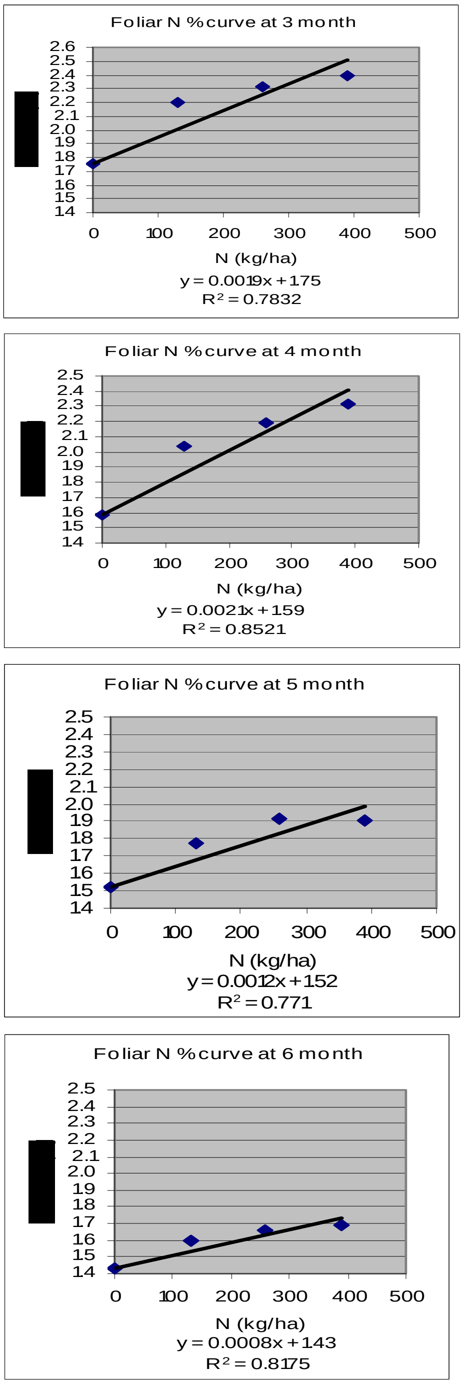

Figure 4. Foliar N content curve at different age of sugarcane at Finchaa

Effect of N application on foliar P and K

The foliar P and K content at Wonji-Shoa ranges from 0.22 to 0.30 % and 1.15 to 1.30 % respectively. The highest foliar P was obtained at the lowest N rate applied and the highest foliar K was obtained at untreated plots. Nitrogen fertilizer application had dilution effect on foliar P at Wonji-Shoa (Figure 5).

At Finchaa the foliar P and K content ranges from 0.22 to 0.30 % and 1.15 to 1.30 % respectively. Unlike to Wonji-Shoa the highest foliar P was obtained from highest N rate applied and similar to Wonji-Shoa the highest foliar K was obtained from none fertilized plots. As the cane age increases the foliar P declines but foliar K starts to increase (Figure 5). Application of N at Wonji-Shoa resulted in dilution effect on foliar P while application of N and P at Finchaa resulted in dilution effect on foliar K. This shows the foliar nutrient composition is much affected by the soil nutrient reserve and the type of nutrient considered in the fertilization program.

Effect of cutting and variety on foliar N, P and K

In both sugar estates the cane and sugar yield across cutting consistently decreases from plantcane to the subsequent ratoons. The lower foliar N content of the ratoons than the plantcane could be due to the lower nitrogen use efficiency of ratoons (Hunsigi 1993). Plantcane had the highest foliar N and K content than ratoons while the foliar P declines with increasing N application.

At Wonji-Shoa the foliar N content at 5 month cane was relatively higher for N14 and B41-227 lowest for NCo 334 and B52-298 while NCo 310 and CO241 had medium amount. Similarly at 5 month cane age variation of foliar P and K had similar pattern and it was high in B41227, B52298 and low in N 14 and NCo310 while NCo334 and CO241 were medium.

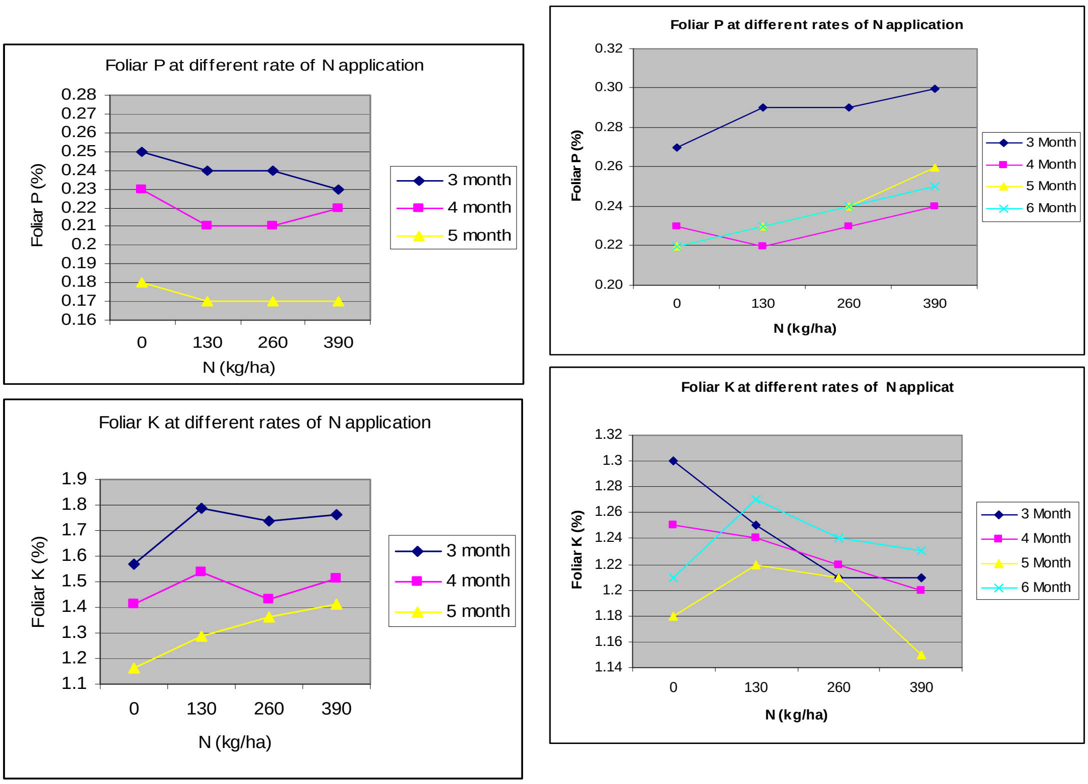

Figure 5. Foliar P and K content at different nitrogen levels

At Finchaa variety B41-227 had higher foliar N and CO449 the lowest at all cane age in both plantcane and ratoon, B52-298, CO421, and NCo 334 were intermediate. There the critical N level varies across variety and cutting accordingly the foliar N level should be adjusted using correction factor.

Among the three varieties tested in both sugar cane plantations higher cane yield was obtained at Finchaa than Wonji-Shoa, but the reverse was true for sugar yield, moreover, the foliar N at Wonji-Shoa was higher than Finchaa (Table 7). At Wonji-Shoa NCo 334 was high yielder while at Finchaa it was B52-298. The high yielder varieties in both estates have the lowest foliar N. Since foliar N indicates the nutrient up take and cane yield the efficient utilization of the nutrient the high yielder varieties in both estates are those that have high N use efficiency.

Table 7. Yield and Foliar N levels of cane varieties

Cane variety	Cane (ton ha^{-1})		Sugar (ton ha^{-1})		Foliar N at 5 month (%)	
	Wonji-Shoa	Finchaa	Wonji-Shoa	Finchaa	Wonji-Shoa	Finchaa
B41-227	179.53	198.68	24.32	19.07	1.64	1.25
B52-298	178.15	213.81	24.50	22.14	1.70	1.17
NCo 334	190.04	197.17	26.15	20.34	1.59	1.31

Correlation of cane and sugar yield with foliar N, P and K at different cane age

Cane and sugar yield was positively and significantly ($P<0.05$) correlated with foliar N % at 4 month age (Table 8). Therefore, at Wonji-Shoa foliar N level only at 4 month cane is related with cane and sugar yield and the regression equation fits with high R^2 value (R^2= 0.95). Therefore 4 month foliar sampling can be taken as standard. Significant ($P<0.05$) negative correlation of foliar P with cane yield only was obtained at 5 month cane. But for foliar K was significant ($P<0.05$) and positively correlated with cane and sugar yield at 5 month cane.

Table 8. Correlation of foliar NPK with cane and sugar yield at different cane age

Sugar estate	Age of cane (months)	Foliar N		Foliar P		Foliar K	
		Cane yield	Sugar yield	Cane yield	Sugar yield	Cane yield	Sugar yield
Wonji-Shoa	3	0.690	0.779	-0.845	-0.836	0.902	0.831
	4	0.954*	0.981*	-0.801	-0.739	0.507	0.393
	5	0.611	0.700	-0.971*	-0.927	0.967*	0.979*
Finchaa	3	1.000**	0.973*	0.970*	0.901	-0.981*	-0.967*
	4	0.998**	0.958*	0.296	0.135	-0.863	-0.754
	5	0.987*	0.989*	0.856	0.728	-0.046	0.162
	6	1.000**	0.972*	0.926	0.835	0.496	0.581

At Finchaa cane and sugar yield was positively and significantly ($P<0.05$) correlated with foliar N % at all cane age sampled (Table 8). Therefore, all the sampling time can give reasonable indication about the impact of the foliar concentration on yield. Moreover, highly significant ($P<0.01$) positive correlation was also obtained at 3 month cane indicating that absorption of nitrogen takes place closer to the time of application and it is strongly related to the yield. At Finchaa the regression equation fits more precisely (R^2= 0.999) for 5 month.

Therefore 5 month foliar sampling can be taken as standard.

Significant ($P<0.05$) and positive correlation of foliar P with cane yield was observed at 3 month cane at Finchaa. But for foliar K significant ($P<0.05$) negative correlation with cane and sugar yield was obtained at the 3 month cane only.

Critical and optimum foliar nutrient concentration

The critical foliar N level at 4 month cane at Wonji-Shoa was 1.66 %. At Finchaa the critical N level at 5 month cane was 1.82 %. In USA the critical value is 1.8 % (Evans 1956; Gascho and Elwali 1978; Anderson and Bowen 1990) which is higher than that of Wonji-Shoa. The critical foliar N level varies with age of cane; it was higher at 3 month cane and consistently decreases up to 6 month. Therefore, in interpreting foliar nutrient levels the conversion factor indicated in Table 9 should be used to convert to 5 month cane to compare with other sites like Finchaa that have 5 month standard sampling time.

Table 9. Critical and optimum foliar N levels at different cane age

Cane age (months)	Wonji-Shoa			Finchaa		
	Critical level	Optimum range	Conversion factor to 5 month	Critical level	Optimum range	Conversion factor to 5 month
3	1.84	1.85-1.88	0.87	2.22	2.25-2.27	0.82
4	1.66	1.68-1.74	0.97	2.07	2.11-2.13	0.88
5	1.61	1.62-1.68	1.00	1.82	1.83-1.85	1.00
6	-	-	-	1.62	1.63-1.64	1.12

At Wonji-Shoa the optimum range was between 1.68 and 1.74 while at Finchaa it was between 1.83 and 1.85 % foliar N. According to Gascho and Elwali (1978) the optimum foliar N for sugarcane ranges from 2.0 to 2.6 %. With this regard the optimum range is relatively lower and narrow at both Wonji-Shoa and Finchaa.

Sugarcane P and K levels at Wonji-Shoa ranges from 0.20 to 0.0.23 % and 1.41 to 1.58 % respectively, moreover, the critical P level was not meaningful because of the negative correlation of foliar P with yield. The concentration of foliar P and K at critical N level were 0.21% and 1.51 % respectively. The foliar P and K levels of Wonji-Shoa at 90 % yield level were above the critical values reported by Nelson (1980) P critical value of 0.2 % and Orlando Filho (1985) K critical value of 1.3 %.

Foliar P and K levels range from 0.22 to 0.26 % and 1.15 to 1.22 % respectively at Finchaa. The concentration of foliar P and K in Fuji ranges from 0.13 to 0.21 % and 0.9 to 1.5 % respectively (Holford, 1968) which is lower than Finchaa. The foliar P and K levels at critical N level at Finchaa were 0.23 % and 1.26 % respectively. According to the critical foliar P and K levels of 0.19 and 0.9 % reported by Anderson and Bowen (1990) foliar P and K levels of Finchaa are above the critical limits. In other report the critical values of P was also reported to be 0.2 % (Nelson 1980) and for K 1.3% (Orlando Filho 1985) again the foliar P and K values of Finchaa were also above the reported critical values. However, since the foliar P values are negatively correlated with cane yield due to application of nitrogen and the foliar P levels being closer to the critical values set elsewhere the foliar P levels should be farther investigated.

Variation of critical foliar nutrient level among cane varieties

There was variation in foliar N level among varieties at Wonji-Shoa. Correction factor of greater than one indicates varieties having lower foliar N concentration and correction factor of less than one for varieties having high foliar concentration. Accordingly both NCo334 and NCo310 have higher foliar N and B52-298 the lowest; the foliar N level of N14 is the same as the estate average.

Table 10. Critical foliar N level (CNL) and correction factor (CF) of cane varieties at different crop stage

Sugar estate	Crop stage	Parameter	B41-227	B52-298	CO421	NCo334	N 14	NCo310	CO449	Mean
Wonji-Shoa	Plantcane	CNL	1.913	1.880	1.886	1.977	2.157	1.98	-	1.966
		CF	0.868	0.883	0.880	0.840	0.770	0.838	-	0.846
	I ratoon	CNL	1.465	1.423	1.497	1.495	1.435	1.442	-	1.460
		CF	1.133	1.167	1.109	1.110	1.157	1.151	-	1.138
	II ratoon	CNL	1.605	1.549	1.606	1.612	1.545	1.674	-	1.599
		CF	1.034	1.072	1.034	1.030	1.074	0.992	-	1.039
	Mean	CNL	1.661	1.617	1.663	1.695	1.712	1.699	-	1.675
		CF	1.012	1.040	1.008	0.993	1.000	0.994	-	1.008
Finchaa	Plantcane	CNL	2.086	1.787	1.930	1.997	-	-	1.910	1.942
		CF	0.873	1.019	0.943	0.911	-	-	0.953	0.940
	I ratoon	CNL	1.885	1.601	1.712	1.738	-	-	1.533	1.694
		CF	0.966	1.137	1.063	1.047	-	-	1.187	1.080
	II ratoon	CNL	2.008	1.653	1.630	1.655	-	-	1.532	1.696
		CF	0.906	1.101	1.116	1.099	-	-	1.188	1.082
	Mean	CNL	1.993	1.680	1.757	1.797	-	-	1.658	1.777
		CF	0.915	1.086	1.041	1.019	-	-	1.109	1.034

Therefore, accordingly the foliar N level should be adjusted using correction factor indicated in Table 10 to convert to the recommended standard sampling of 4 month cane of the estate. At Finchaa variety B41-227 has high foliar N content and it decreases in varieties NCo334, CO421, B52-298 and CO449 respectively. Accordingly the foliar N level should be adjusted using correction factor indicated in Table 10. Cane varieties of Finchaa have shown great variation in the critical foliar N level than Wonji-Shoa indicating the need to consider the proper correction factor.

CONCLUSION

The cane and sugar yields across cutting consistently decreased from plantcane to the subsequent ratoons in addition the foliar N content of the ratoons were lower than the plantcane at Wonji-Shoa and Finchaa. In both sites the foliar N, P and K levels decreased consistently from the 3 months to the 6 months cane. Moreover, application of N has contributed to the improvement of foliar N but the effect on foliar P and K seems to depend on the nutrient reserve of the soil and the type of nutrient applied in the fertilization program. The optimum foliar sampling time was found to be 4 month at Wonji-Shoa and 5 month at Finchaa as long as the standard fertilizer application time was maintained within 4 to 6 weeks before leaf sampling. The critical foliar nitrogen levels of Wonji-Shoa and Finchaa sugar estates were 1.66 % and 1.82 %, respectively, and the optimum foliar N range were 1.68-1.74% for Wonji-Shoa and 1.83-1.85 % for Finchaa. In addition the foliar N levels vary among cutting and variety therefore; adjustment should be made for the different cuttings and varieties.

ACKNOWLEDGEMENTS

The help and support provided by Wonji-Shoa and Finchaa Sugar Estates and facilitation of Research and Training Stations at Wonji-Shoa and Finchaa are gratefully acknowledged and considerably contributed to the achievements of this research work.

REFERENCES

Anderson, DL and Bowen, JE. 1990. Sugarcane nutrition. Potash and Phosphate Institute, Norcross, GA.

Baldock, JO and Schulte, EE. 1996. Plant analysis with standardized scores combines DRIS and sufficiency range approaches for corn. Agron. J. 88: 448-456.

Dara ,ST, Fixen, PE and Gelderman, RH. 1992. Sufficiency level and diagnosis and recommendation integrated system approaches for evaluating the nitrogen status of the corn. Agron. J. 84:1006-1010.

Evans, H. 1965. Tissue diagnostic analysis and their interpretation on sugarcane. Proc. Int. Soc. Sugar Cane Technol. 12:156-180.

Gascho, GJ and Elwali, AMO. 1978. Tissue testing of Florida sugarcane. Gainesville (FL): University of Florida Institute of Food and Agricultural Sciences (IFAS). Belle Glade Agricultural Research and Education Center Research Report EV-1978-3.

Gascho, GJ. 2000. Sugarcane. In: C. R Campbell (ed.) Reference sufficiency ranges for plant analysis in the southern region of the United States. Southern Cooperative Series Bulletin No.394. North Carolina.

Hunsigi, G. 1993. Production of sugarcane - theory and practice. Advanced Series in Agricultural Sciences, Volume 21, London.

Holford, ICR. 1968. Nutrient status of sugar cane in relation to leaf nutrient concentration. Aust. J. Exp. Agric. Anim. Husb. 8(34) 606 – 614.

Jones Junior, JB. 1993. Modern interpretation systems for soil and plant analysis in the USA. Aust. J. Exp. Agric. 33:1039-1043.

McCray, JM, Rice,RW, Ezenwa, IV, Lang,TA and Baucum, L. 2006. Sugarcane plant nutrient diagnosis Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. edis.ifas.ufl.edu/pdffiles/SC/SC07500.pdf

Muchovej, RM. and Newman, PR. 2004. Nitrogen fertilization of sugarcane on a sandy soil: i. yield and leaf nutrient composition. JASSCT. 24:210-224.

Nelson, LE. 1980. Phosphorous nutrition of cotton, peanuts, rice, sugarcane and tobacco. In Khasawneh, FE, Sample, EC and Kamprath, EJ. (eds.). The role of phosphorous in agriculture. American Society of Agronomy. Madison, WI.

Orlando Filho, J. 1985. Potassium nutrition of sugarcane. In Munson, RD. (ed) Potassium in agriculture. American Society of Agronomy. Madison, WI.

Payne, GG, Rechcigl JE and Stephenson, RL. 1990. Development of diagnosis and recommendation integrated system norms for bahiagrass. Agron. J. 82: 930-934.

Richards, BN and Bevege, DI. 1972. Principles and practice of foliar analysis as a basis for crop-logging in pine plantations I. Basic considerations, Plant Soil 36: 109-119.

Walworth, JL, Sumner, ME, Isaac RA and Plank, CO. 1986. Preliminary DRIS norms for alfalfa in the Southeastern United States and a comparison with the Midwest norms. Agron. J. 78:1046-1052.