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Determination of Optimum Harvesting Age for the Existing Sugarcane Varieties at Amibara/Middle Awash Agricultural Development Enterprise, Ethiopia

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Abstract
A field experiment was conducted at Amibara/Middle Awash Agricultural Development Enterprise farm in factorial combination of two sugarcane varieties and five harvesting ages in RCBD with five replication to determine the optimum harvesting age for the existing sugarcane varieties on heavy and light soils. The combined analysis over soil types proved significant differences for all parameters considered. Significant variation was observed by main and interaction effect of harvesting age and sugarcane varieties on cane yield, sugar yield, brix percent juice , pol percent and recoverable sugar on both light and heavy soils. The maximum sugar yield ton ha^{-1} $month^{-1}$ (1.49) and (1.60) were obtained from the variety B52298 at the harvesting age of 14 months on both light and heavy soils, respectively. since no significant variation is observed among the 14 and 15 months of harvesting ages and attractive benefit cost ration was observed on light soils there is a possibility of harvesting both B52298 and Nco334 varieties at the age of 14 and 15 months while on heavy soils, there is a tendency to harvest at the range of 14 to 16 months for the variety B52298 and at 15 and 16 months for the variety Nco334 at Amibara situation.
Keywords: harvesting age, sugarcane varieties and soil types

1. INTRODUCTION

Age of harvest is one of the most important factors affecting sugarcane productivity (Sundara, 2000). sugarcane grows under different weather conditions directly affecting crop maturation and improper harvest age is persistent problems of pre-harvest cultural practices, which severely affect quality and yield of cane. Harvesting of sugarcane at a proper time, i.e., peak maturity, is necessary to realize maximum weight of the mill able canes produced with the least possible field losses under the given growing environment (Muchow et al., 1998). On the other hand, harvesting either under-aged or over-aged cane with improper time of harvest leads to loss in cane yield, sugar recovery, poor juice quality and problems in milling (Khandagave and patil, 2007).

The peak sucrose content of sugarcane at harvest time is affected by different growing environment and plant physiological conditions during the maturation period (Cox et al., 1998; O'Leary, 2000). Furthermore, the variation among soil on cane fields causes considerable differences in soil moisture holding capacity, degree of drying, and, consequently, the rate at which cane fields ripen (Muchow et al., 1993; Scarpari and Beauclair, 2004).

In the existing Sugar Estates of Ethiopia, 18 to 24 months harvesting age is used for plant cane for all varieties. But due to climatic variations among the area the growing conditions of sugarcane also varies. Principal climatic components that control cane growth, yield and quality are temperature, light and moisture availability. Many of the biologically significant processes that contribute to final yield and sucrose content respond to temperature differently (Inman-Bamber 1994; Robertson et al. 1998). Among these climatic factors at Amibara condition as compared to Metahara sugarcane farm long year metrological data indicated that there is 1.5oc and 200masl temperature and altitude difference respectively, this implies that there is a growth variation among the respective age of the area. Visual observation also indicated that a clear growth difference also seen at the same age of the respective areas. Through the huge expansion of sugar projects in Ethiopia there are a number of newly emerging sugar factories which demand agricultural technology packages for their specific agro-climatic conditions. Among these projects, Kessem Sugar Factory is now under the way to crush cane. Since, Amibara out grower sugarcane farm is one of the main supplier of Kessem factory and it is new for sugar cane production, relevant information with regard to harvesting age for the major sugarcane varieties with high sucrose content and sugar yield is highly imperative. Therefore, this study was initiated to determine economically optimum harvesting age for the existing sugar cane varieties at Amibara condition .

2. MATERIALS AND METHODS

2.1 Description of the study area

The experiment was conducted at Amibara/Middle Awash Agricultural Development Enterprise farm in Afar Regional State during 2014/15 cropping season. The experimental site is located in the rift valley of Ethiopia with an altitude of 750 mater above sea level and its latitude from $9^0 16'$N and a longitude from $40^0 9'$ E in the rift valley of warm climate. The mean annual rain fall of the area is 560 mm and the average monthly maximum and minimum temperatures are 19.6^{o}C and 34.4^{o}C, respectively. Major soil types are Vertisoils (heavy soils) and Fluvisols (light soils) (Anonymous, 2012).

2.2 Experimental design and data collection

Factorial combination of two sugarcane varieties (B52298 and Nco334) and five harvesting ages (12, 13, 14, 15 and 16 month) were investigated in RCBD with five replications both in light and heavy soils. Each experimental plot was composed of six rows of 10 m length with an area of 87 m2 (10 m x 1.45 m x 6 m). The net plot size for data collection was 58m^2.

All the necessary parameters were collected at an appropriate time throughout the experimental season. Stalk Characteristics like Stalk weight, Stalk length and Stalk thickness were recorded from randomly selected 20 stalks from each harvestable plot at different ages. Juice quality Parameters: like Brix, Pol, recoverable sugar (field yield) were taken, Brix reading also taken from randomly selected five stalks using Handrefractometer. Millable stalk count in each plot were counted before harvesting from the net plot area (58 m2) at harvesting and then converted to the hectare base. Girth measurement was taken from 20 sample stalks taken randomly from the middle four rows, measurement was made using a caliper on three points of the stalks (upper, middle and bottom part of the stalk) after removal of the sheath. Weight per stalk was determined by taking 20 samples randomly from the middle four rows and by measuring the weight of each sample using a measuring balance. Then the average weight per stalk was taken. Cane yield (t ha-1/ month) was calculated based on cane stalk weight harvested from the central four rows. Percent recoverable sucrose was calculated using Winter Carp indirect method of cane juice analysis (James and Chung, 1993) and the commercial sugar (t/ha) yield was calculated as the product of cane yield per middle rows and recoverable sucrose percent per plot. Then Commercial sugar yield per hectare was calculated as follows; CSY (t/ha) CYH(t/ha) x RS (%) Where; CSY = commercial sugar yield
RS = Recoverable cane sucrose.

2.3 Methods of data analysis

Data were analyzed using Gen Stat 15th edition. The collected data for a character under certain treatment were calculated and statistically analyzed following Factorial Completely Randomized Block Design (RCBD). The analysis of variance was performed and means were compared by Tukey's Studentized Range (HSD) Test at 5% level of probability for interpretation of results.

3. Result and Discussion

The combined analysis over soil types proved significant differences for all parameters considered. Therefore, the results of the study was analyzed separately for each soil types.

3.1 Effect of harvest age and sugar cane varieties on cane and sugar yield

3.1.1 Cane yield

As indicated in Table 1 and 2, cane yield ton ha^{-1} month^{-1} was significantly ($P<0.001$) affected by the main effect of sugar cane varieties and harvesting age on light soil. But the main effect of sugar cane varieties was not affected significantly on heavy soils. Hagos *et al*., 2014 reported that there is a Significant increase in cane yield with an increase in harvest age from 10 to 14 months. In the present study the mean value of cane yield ton ha^{-1} month^{-1} , 12.1 and 10.9 were recorded for B52298 and Nco334, on light soils respectively. In the same way, the maximum numerical value of cane yield ton ha^{-1} month^{-1} was recorded at the harvesting age of 14 months for both varieties on light soils. Likewise, on heavy soils, the maximum numerical value of cane yield ton ha^{-1} month^{-1} was recorded at the harvesting age of 14 months.

Similarly, significant variation ($P<0.001$) was observed due to interaction effect of sugar cane varieties and harvesting age on both light and heavy soils (Table 1 and 2). From the interaction effect of sugar cane varieties and harvesting age the maximum cane yield ton ha-1 month-1 (13.44) was observed from the variety Nco334 at the harvesting age of 14 months. But, statistically significant variation were not observed at the harvesting age of 15 and 16 months of the variety Nco334 and B52298 at the age of 14 months on light sols. The maximum numerical value of cane yield ton ha^{-1} month^{-1} (14.89) was observed from the variety B52298 at the harvesting age of 14 months on heavy soils. This is due to the fact that soil types play a great role in determining productivity of sugar cane varieties.

Table 1. Main and interaction effect of sugarcane varieties & harvest age on cane yield at Amibara light soils

	Cane yield ton ha^{-1} month $^{-1}$					
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	10.92^{bc}	10.34^{bc}	12.69^{ab}	10.61^{bc}	10.02^{c}	10.9^{b}
Nco334	9.66^{c}	13.77^{a}	13.44^{a}	12.68^{ab}	11.50^{abc}	12.1^{a}
Mean	10.29^{c}	11.85^{ab}	13.06^{a}	11.65^{abc}	10.76^{bc}	
SE±						1.1
CV%						9.6

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

Table 2. Main and interaction effect of sugarcane varieties & harvest age on cane yield at Amibara heavy soils

	Cane yield ton ha^{-} Month $^{-1}$					
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	12.61^{bc}	11.46^{c}	14.89^{a}	12.75^{abc}	12.06^{c}	12.8
Nco334	8.53^{d}	12.88^{abc}	13.22^{abc}	14.34^{ab}	12.6^{abc}	12.3
Mean	10.57^{d}	12.17^{c}	14.06^{a}	13.54^{ab}	12.38^{bc}	
SE±						1.04
CV%						8.3

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

3.1.2 Sugar yield

significant variation (P<0.01) and (P<0.001) was observed due to interaction effect of sugar cane varieties and harvesting age on light and heavy soils, respectively (Table 3 and 4). From the interaction effect of sugar cane varieties and harvesting age the maximum sugar yield ton ha^{-1} month-1 (1.49) was observed from the variety B52298 at the harvesting age of 14 months on light soils. But, statistically significant variation were not observed at the harvesting age of 15 months of the variety B52298 and Nco334 at the age of 14 and 15 months. On heavy soils, from the interaction effect of sugar cane varieties and harvesting age the maximum sugar yield ton ha^{-1} month^{-1} (1.60) was observed from the variety B52298 at the harvesting age of 14 months. However, statistically no significant variation were observed at the harvesting age of 15 and 16 months for B52298 variety and 14 and 15month harvesting age of Nco334 variety . This might be due to the contribution of maximum cane yield at the age of 14 months and the increasing effect of quality parameters with increasing age. Similarly, sugar yield is a function of both cane yield and sucrose accumulation. Hagos *et al*,.2014 also confirmed that the highest cane yield and sugar yield is obtain due to the increasing effect of longer harvest ages on yield components and quality parameters. Beyond 14 months age sugar yield starts to decline in both soil types at Amibara condition. This may be attributed to decrease in cane yield due to lodging effect which have a direct effect on sugar yield even if the quality parameters still have a tendency to increase with increasing age. Generally, on light soils, there is a possibility of harvesting both B52298 and Nco334 varieties at the age of 14 and 15 months while on heavy soils, there is a tendency to harvest at the range of 14 to 16 months for the variety B52298 and at 15 and 16 months for the variety Nco334.

Table 3. Main and interaction effect of sugarcane varieties & harvest age on sugar yield at Amibara light soils

	Sugar yield ton ha^{-1} Month $^{-1}$					
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	1.215^{bc}	1.161^{bc}	1.494^{a}	1.407^{ab}	1.23^{bc}	1.3^{a}
Nco334	0.755^{d}	1.056^{c}	1.416^{ab}	1.281^{abc}	1.189^{bc}	1.14^{b}
Mean	0.985^{d}	1.109^{cd}	1.455^{a}	1.344^{ab}	1.21^{bc}	
SE±						0.122
CV%						10

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

3.2 Effect of varieties and harvest age on quality parameters

3.2.1 Brix percent juice

The interaction of harvest age and sugarcane varieties showed highly significant (p<0.001) and (p<0.01) influence on brix % juice on light and heavy soils respectively (Table 5 and 6). Similarly, the main effect of

sugar cane varieties and harvesting age showed significant ($p<0.01$) effect on brix % juice on both light and heavy soils.

Table 4. Main and interaction effect of sugarcane varieties & harvest age on sugar yield at Amibara heavy soils

Sugar yield ton ha^{-} month $^{-1}$						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	1.326^{bc}	1.131^{c}	1.601^{a}	1.468^{ab}	1.467^{ab}	1.40^{a}
Nco334	0.739^{d}	1.272^{bc}	1.288^{bc}	1.517^{ab}	1.400^{ab}	1.24^{b}
Mean	1.032^{c}	1.202^{b}	1.444^{a}	1.483^{a}	1.434^{a}	
SE±						0.122
CV%						9.3

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different.

From the interaction effect the highest brix percentage (21.69) was achieved by the variety B52298 at the age of 15 months followed by the same variety at the age of 13,14 and 16 months on light soils. Variety Nco334 recorded inferior brix % value in all consecutive ages this may be due to genetic potential difference of the variety. From the interaction effect of sugar cane varieties and harvesting age on heavy soils the highest brix percentage (18.79) was achieved by the variety B52298 at the age of 16 months followed by the variety Nco334 at the age of 16 months.

Table 5. Main and interaction effect of sugarcane varieties & harvest age on quality parameters at Amibara light soils

Brix % Juice						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	18.11^{c}	19.24^{b}	19.3^{b}	21.69^{a}	19.38^{b}	19.54^{a}
Nco334	14.56^{e}	14.86^{e}	17.63^{cd}	16.96^{d}	16.76^{d}	16.15^{b}
Mean	16.34^{d}	17.05^{c}	18.47^{b}	19.33^{a}	18.07^{b}	
SE±						0.45
CV%						2.5

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

Table 6. Main and interaction effect of sugarcane varieties & harvest age on quality parameters on heavy soils

Brix % Juice						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	17.53^{abc}	17.39^{bc}	17.54^{abc}	17.24^{bc}	18.79^{a}	17.697^{a}
Nco334	15.13^{d}	16.20^{cd}	16.63^{c}	16.96^{bc}	18.05^{ab}	16.594^{b}
Mean	16.33^{b}	16.79^{b}	17.00^{b}	17.10^{b}	18.42^{a}	
SE±						0.6334
CV%						3.7

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

3.2.4 Estimated recoverable sucrose (ERS)

Significant variation ($p<0.001$) and ($p<0.05$) have been observed from the interaction effect of sugar cane varieties and harvesting age on ERS both on light and heavy soils, respectively (Table 7 and 8). Similarly, the main effect of sugar cane varieties and harvesting age showed significant variation ($p<0.01$) on estimated recoverable sugar both on light and heavy soils.

From the interaction of sugar cane varieties and harvesting age the maximum ERS percentage (13.24) was obtained from the variety B52298 at 15 months of harvesting age followed by the same variety at the age of 16 months on light soils. This indicates that, those sugarcane varieties have the probability of high sucrose accumulation if properly harvested in the proper age. Hagos, et al 2014. also confirmed that maximum sucrose accumulation is observed at appropriate harvesting age.

Table 7. Main and interaction effect of sugarcane varieties & harvest age on estimated recoverable sugar at Amibara light soils.

ERS %						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	11.16^{edc}	11.23^{bcd}	11.77^{bc}	13.24^{a}	12.28^{ab}	11.94^{a}
Nco334	7.82^{f}	7.9^{f}	10.54^{de}	10.10^{e}	10.34^{dc}	9.34^{b}
Mean	9.49^{b}	9.57^{b}	11.16^{a}	11.67^{a}	11.31^{a}	
SE±						0.498
CV%						4.7

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

On heavy soils, from the interaction effect of sugar cane varieties and harvesting age the maximum ERS percentage (12.17) was obtained from the variety B52298 at the age of 16 months but statistically no significant variation was observed from the variety B52298 at the age of 15 months and NCo334 at the age of 16 months. Sucrose accumulation was rapidly active until it reaches peak then declined. This could probably be attributed to normal growth habit of sugarcane as it is known that the initial stages of sugarcane growth are associated with starch accumulation in chloroplasts, and in later growth stages, the starch converts to sucrose that increases as the growth continues [Blackburn, 1984].

Table 8. Main and interaction effect of sugarcane varieties & harvest age on estimated recoverable sugar at Amibara heavy soils

ERS %						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	10.58^{bcd}	9.96^{cd}	10.74^{bcd}	11.52^{ab}	12.17^{a}	10.99^{a}
Nco334	8.66^{e}	9.85^{cde}	9.74^{de}	10.58^{bcd}	11.03^{abc}	9.97^{b}
Mean	9.62^{b}	9.91^{b}	10.24^{b}	11.05^{a}	11.6^{a}	
SE±						0.6037
CV%						5.8

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

Generally, the increase of the percentage of quality parameters like brix pol purity and ERS until the age of 16 months of variety B52/298 on heavy soils might be due to the dilution effect of sugarcane enzymes changing the reducing sugars and non-sucrose materials (fiber) to sucrose. The other factor may be the impact of harvest age on the yield components (plant height and cane yield) which allow accumulation of additional soluble solid or sucrose by delaying harvest age. Similarly, Rostron (1972) confirmed that Percent of soluble solids, percent pol, purity and percent of estimated recoverable sucrose significantly increased as age of sugarcane increased. The present study also in agreement with Rostron (1972) on heavy soils. However, from the present study, beyond 15 months harvest age of variety B52298 on light soils quality parameters like brix pol and ERS showed a declining trend which indicates the reduction of sucrose content this might be due to heavy lodging and remobilization to supply the unproductive bull shoots (newly growing shoots) [Qudsieh et al 2001]. Gilani, et al 2008. also confirmed that improper time of harvest leads to loss in cane yield, sugar recovery, poor juice quality and problems in milling.

3.3. Effect of harvest age and varieties on hand refractometer brix test (brix ratio)

Significant ($P<0.05$) interaction effects were observed between sugar cane varieties and harvesting age on brix ratio on light soils but not on heavy soils (Table 9 and 10).

Table 9. Main effect of harvesting age and interaction effect of sugarcane varieties & harvest age on hand refractometer brix test on light soils.

Brix ratio						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	0.82^{cde}	0.756^{e}	0.928^{ab}	0.984^{a}	0.986^{a}	0.89
Nco334	0.794^{de}	0.864^{bcd}	0.912^{abc}	0.982^{a}	0.978^{a}	0.91
Mean	0.807^{b}	0.810^{b}	0.920^{a}	0.983^{a}	0.982^{a}	
SE±						0.049
CV%						5.5

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

From the interaction effect the maximum brix ratio(0.986) was recorded by the variety B52298 at the harvesting age of 16 months. But no statistically significant variation was observed by the variety B52298 at the age of 14 and 15 months, similarly by the variety Nco334 at the age of 14,15 and 16 months on light soils.

On heavy soils, the main effect of harvesting age showed significant variation ($P<0.001$) on brix ratio. The maximum hand refractometer brix test of sugarcane parts (brix ratio) (0.979) was observed at 16 months age followed by 15 and 14 months and the lowest hand refractometer brix in all stalk parts was obtained at 12 months age (0.81) followed by 13 months age on heavy soils (Table 10).

All the stalk parts accumulated peak soluble solids indicating the sign of maturity to harvest. The bottom part stored highest amount of brix followed by the middle and top part of the stalk. In agreement with this result, studies reported that brix percent of all the bottom, middle and top parts of the stalk increase with cane age [Qudsieh et al 2001.]. In milling operations, the preferred varieties are those with high and nearly equal percentage of hand refractometer brix on its all stalk parts at maturity.

Table 10. Main effect of harvesting age on hand refractometer brix test on heavy soils

Brix ratio						
Varieties	Harvesting age					
	12	13	14	15	16	Mean
B52298	0.826	0.80	0.95	0.978	0.974	0.91
Nco334	0.794	0.824	0.944	0.962	0.984	0.90
Mean	0.81[b]	0.812[b]	0.974[a]	0.97[a]	0.979[a]	
SE±						0.0548
CV%						6.1

SE= standard error, CV= coefficient of variation. Means within a column followed by the same letter (s) are not significantly different

5. Conclusions

From the present study it can be observed that there is a remarkable significant interaction effect of sugar cane varieties and harvesting age were observed in all the parameters considered both in light and heavy soils except purity percent juice and brix ratio for heavy soils. From the interaction effect of sugar cane varieties and harvesting age the maximum sugar yield ton ha^{-1} $month^{-1}$ (1.49) and (1.60) were observed from the variety B52298 at the harvesting age of 14 months on both light and heavy soils, respectively. But, statistically significant variation were not observed at the harvesting age of 15 months for variety B52/298 and Nco334 at the age of 14 and 15 months on light soils. The harvesting age of 15 and 16 months for variety B52/298 and the harvesting age of 14 and 15 month variety for Nco334 on heavy soil not show statistical significance. Beyond 14 months age sugar yield starts to decline in both soil types at Amibara condition due to lodging effect which have a direct effect on sugar yield even if the quality parameters still have a tendency to increase with increasing age. Furthermore, In view of convenient, since no significant variation is observed among the 14 and 15 months of harvesting ages and attractive benefit to cost ration (>1) was observed on light soils there is a possibility of harvesting both B52/298 and Nco334 varieties. While on heavy soils, no significant variation is observed among 14 to 16 months of harvesting ages and attractive benefit to cost ration (>1) was observed there is a tendency to harvest at the range of 14 to 16 months for the variety B52/298 and at 15 and 16 months for the variety Nco334 at Amibara situation. Moreover, these finding have to be confirmed through further research across years with extending harvest age beyond 16 months to ascertain the consistency of the recommendation.

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6. Reference

Blackburn, F.H.B. (1984). Sugarcane. Longman Inc.; New York.p. 30-42.

Gilani S, Wahid A, Ashraf M, Arshad M (2008). Changes in growth and leaf water status of sugarcane (Saccharum officinarum L.) during heat stress and recovery. Department of botany, university of agriculture, Pakistan. International Journal of Agricultural Biology 10: 191-195.

Gilbert R, Shine J, Miller J, Rice R, Rain bolt C (2004). Maturity curves and harvest schedule recommendations for canal point sugarcane varieties at Florida. University of Florida,1-12.

Hagos H, Mengistu L, Mequanint Y (2014). Determining Optimum Harvest Age of Sugarcane Varieties on the Newly Establishing Sugar Project in the Tropical Areas of Tendaho, Ethiopia. Adv Crop Sci Tech 2: 156

Inman-Bamber NG (1994). Temperature and seasonal effects on canopy development and light interception of sugarcane. Field Crops Research 36, 41–51. doi: 10.1016/0378-4290(94)90051-5

Khandagave, R. and Patil B (2007). Manipulation of cutting age, varieties and planting time to improve sugar and cane yield. Int. Sugar Cane Technl., 26:212-220.

Muchow, R. C., A. J. Higgins, A. V. Rudd and Ford, A.W (1998). Optimizing harvest date in sugar production: A Case Study for the Mossman Mill Region in Australia-I. Sensitivity to Crop Age and Crop Class Distribution. Field Crops Research, 57:243–251.

Qudsieh HY, Yosuf S, Osman A, Rahman RA (2001). Physico-chemical changes in sugarcane and the extracted juice at different portions of the stem during development and maturation. Faculty of Food Science, Malaysia. Journal of Food Chemistry 75: 131-137.

Robertson MJ, Bonnett GD, Hughes RM, Muchow RC, Campbell JA (1998). Temperature and leaf area expansion of sugarcane: integration of controlled-environment, field and model studies. Australian Journal of Plant Physiology 25, 819–828.

Rostron H (1972). Effects of age and time of harvest on productivity of irrigated sugarcane. South African Sugar Association Experiment Station, South Africa: 142-150.

SAS 1989. SAS Institute Inc. Cary, NC, USA. SAS software release 9.1

Sundara B (2000). Sugarcane cultivation. Vikas Publishing House Pvt ltd, New Delhi,India.

Tadesse N and Abiy G (2009). Effect of Pre-harvest Drying-off Period on Cane Quality at Metahara Sugar Factory.Proc. Ethiop.Sugar.Ind.Bienn.Conf., 2010 2:1-12.

Yohannes M and Netsanet A (2015). Effect of Harvesting Age on Yield of Exotic Sugarcane varieties at Metahara Sugar Estate. Sugar corporation research and training division annual research result report,2015.