Sugarcane Root Distribution in the Soil Profile at the White Nile Sugar Estate Plantation

*Abstract*— The plant root system depth is crucial as it determines the potential depth of soil available for water and nutrient uptake by the crop. When roots are shallow the plants can only take water from a small depth of soil, later as the roots grow, roots can take water from an increasing depth of soil. Consequently, the interval of irrigation water should be applied frequently at the young stage and in long intervals at the end of the season. Accordingly, the roots system distribution of the sugarcane crop was studied for the plant cane and ratoon crop to the three developmental stages at the White Nile Sugar Company fields. The study revealed that, the rooting depths of plant cane in the first season (2011/2012) for the development (DEV), middle (MID) and maturity (MAT) stages were 40, 50 and 50 cm, respectively, and in the ratoon crop in the second season (2012/2013) the rooting depths for the consecutive stages were 40, 40 and 50 cm.

***Keywords*— Ratoon Crop, Root Grid System, Root System, Plant Cane.**

1. Introduction

T

he White Nile Sugar Estate (WNSE) is one of the important economical projects in the White Nile State, Sudan. In general, its land is part of the central clay plain covered by superficial deposits, which are mainly clay underlain by basement complex. The irrigation water is diverted from the main canal into the primary canals from which the irrigation water is directly conveyed to the furrows

through hydro-flumes.

For many years in the past, roots were considered the “hidden half” of plants due to the scarcity of the research in this field [1]. Studies on roots are very important for the understanding of the relationship of water and nutrient uptake by the crops. The importance of the plant-water-soil relationship is related to the density, depth and distribution of the plant root system, and the development within the growing season. Root development in the soil is highly dependent on the physical, chemical properties and the biological conditions, which can have significant spatial variability [2]. Water uptake in plants is driven primarily by transpiration. Water moves through the soil to the root via mass flow, and it’s taken up by the roots and pulled through the xylem of the plant due to differences in water potential between the soil, root and atmosphere [3]. Rates of water

uptake are affected by root diameter, distance from stem base, age or stage of development, soil water and temperature conditions [4]. The plant roots would grow until a physically or chemically impenetrable horizon was reached. The rooting pattern varies with the physical condition of soils particularly machine-compacted soil layers, moisture distribution, aeration and the genetic profile characteristic [5]. Roots are able to force their way into the soil because of the turgor pressure of roots, when the soil strength exceeds the strength of the turgor pressure, root extension is stopped [6]. A greater rooting depth increases available water storage capacity, but the storage at lower depths is less extractable because rooting density decreases with depth [7]. Root development and distribution are affected by spatial and temporal soil water distribution [8]. At the beginning of a season, the roots are shallow and so plants can only take water from a small depth of soil. Later, as the roots grow, roots can take water from an increasing depth of soil, consequently, irrigation water may need to be applied relatively and frequently at the beginning of the season, and in long intervals at the end of the season. The effective rooting depth of the plant governs the volume of soil that can function as a water reservoir for the plant. Plants with deep root systems have access to a larger volume of soil, and therefore larger volume of soil water, than shallow rooted plants. The rooting pattern of sugarcane is classified as a “deeply tap- rooted species” and considered as an important parameter in evaluating furrow irrigation system It is particularly useful in managing and about irrigation scheduling. The sugarcane root system is highly dependent on the physical soil conditions, the intensive use of machinery during cultivation and harvest induces soil compaction, affecting the sugarcane crop development [9] - [10]. Roots of sugarcane grow along lines of least resistance, often following old root and worm channels [11]. Moisture extraction patterns for successive ratoon crops were similar to that of the plant crop, indicating again that the old root system of the previous crop was not functioning, or at least not removing enough moisture. The old root system gradually ceases to function and decays, while a completely new root system is formed by the developing shoots of the ratoon crops [12].

1. MATERIALS AND METHODS

The root distribution at the different depths measured by the root grid system (50×60 ) [13] as total roots numbers counted in each small square (10×10 ) in the three locations, head, middle and end of the furrow, for the development (DEV), mid-season (MID), and maturity (MAT) growth stages of plant cane crop in the first season (2011/2012) and of the ratoon cane crop in the second season (2012/2013) in Field3 - Primary Canal13 (B13) and Field3 - Primary Canal 20 (E20) of locations 1 and 2, respectively.

1. RESULTS AND DISCUSSION

Table I presents the root distribution of the plant cane in the first season (2011/2012) for E20 of location 2. In the development (DEV) stage (June 2011), 5 months after planting, the total numbers of roots per plant were 134, 134 and 103 in the head, middle and end of furrow, respectively, with a mean of 123.7 roots confined to the top 40 cm soil depth. The average root percentages along the furrow profile were 29, 27, 26 and 18% in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At mid-season (MID) stage (October 2011), 9 months old crop, the total numbers of roots per plant at the three successive positions were 118, 128 and 116, with a mean of

120.7 roots confined in the top 50 cm soil depth. The average root percentages along the furrow profile were 25, 23, 34, 15

and 3% in 0-10, 10-20, 20-30, 30-40 and 40-50 cm soil depths, respectively.

At maturity (MAT) stage (December 2011), 11 months old crop, the total roots per plant at the head, middle and end of furrow were 132, 151 and 163 roots, respectively, with a mean number of 148.7 roots distributed in the 50 cm soil depth. The average root percentages along the furrow profile layer were 40, 36, 15, 4, and 5% in the successive soil layers 0-10, 10-20,

20-30, 30-40 and 40-50 cm, respectively.

Table I Vertical root distribution of plant cane in the head (Hed.), middle (Mid.) and end of the furrow at the developmental (DEV), mid-season (MID) and maturity (MAT) stages in field E20 at location 2 (2011/2012).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | Numbers of roots | | | | % | STD | CV  % |
| Hed. | Mid. | End | average |
| DEV Stage | | | | | | |
| 0 - 10 | 39 | 39 | 31 | 36.3 | 29.4 | 4.62 | 12.7 |
| 10=20 | 34 | 36 | 30 | 33.3 | 26.9 | 3.06 | 9.2 |
| 20 -30 | 37 | 33 | 25 | 31.7 | 25.6 | 6.11 | 19.3 |
| 30 -40 | 24 | 26 | 17 | 22.3 | 18.1 | 4.73 | 21.2 |
| Total | 134 | 134 | 103 | 123.7 | 100.0 | 17.90 | 14.5 |
|  | MID stage | | | | | | |
| 0 - 10 | 30 | 40 | 21 | 30.3 | 25.1 | 9.50 | 31.3 |
| 10=20 | 33 | 27 | 23 | 27.7 | 22.9 | 5.03 | 18.2 |
| 20 -30 | 33 | 40 | 49 | 40.7 | 33.7 | 8.02 | 19.7 |
| 30 -40 | 18 | 16 | 21 | 18.3 | 15.2 | 2.52 | 13.7 |
| 40-50 | 4 | 5 | 2 | 3.7 | 3.0 | 1.53 | 41.7 |
| Total | 118 | 128 | 116 | 120.7 | 100.0 | 6.43 | 5.3 |
|  | MAT stage | | | | | | |
| 0 - 10 | 43 | 51 | 85 | 59.7 | 40.1 | 22.30 | 37.4 |
| 10=20 | 60 | 49 | 52 | 53.7 | 36.1 | 5.69 | 10.6 |
| 20 -30 | 16 | 32 | 18 | 22.0 | 14.8 | 8.72 | 39.6 |
| 30 -40 | 6 | 8 | 3 | 5.7 | 3.8 | 2.52 | 44.4 |
| 40-50 | 7 | 11 | 5 | 7.7 | 5.2 | 3.06 | 39.8 |
| Total | 132 | 151 | 163 | 148.7 | 100.0 | 6.43 | 4.3 |

Table II presents the root distribution in the three locations, head, middle and end of the furrow, for the three stages of growth of the first ratoon cane growth, E20 of location 2, in the second season (2012/2013).

In DEV stage (July 2012), 5 months after ratooning the total number of roots per plant were 113, 100 and 112 in the

head, middle and end of the furrow, respectively, with a mean of 108.3 roots confined to the top 40 cm soil depth. The average root percentages along the furrow profile were 43, 35, 18 and 4% in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At MID stage (November 2012), 9 months old crop, the total numbers of roots per plant at the three successive positions were 117, 106 and 106, with a mean of 109.7 roots confined in the top 40 cm soil depth. The average root percentages along the furrow profile were 24, 29, 26 and 20%

in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At maturity (MAT) stage (January 2013), 11 months old crop, the total roots per plant at the head, middle and end of furrow were 125, 114 and 143 roots, respectively, with a mean number of 127.3 roots in the top 50 cm soil depth. The average root percentages along the furrow profile layer were 33, 29, 23, 12, and 3% in the successive soil layers: 0-10, 10-

20, 20-30, 30-40 and 40-50 cm, respectively.

Table II Vertical root distribution of the first ratoon cane in the head (Hed.), middle (Mid.) and end of the furrow at the developmental (DEV), mid-season (MID) and maturity (MAT) stages in field E20 at location 2 (2012/2013).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | Numbers of roots | | | | % | STD | CV  % |
| Hed. | Mid. | End | Average |
| DEV Stage | | | | | | |
| 0 - 10 | 50 | 35 | 56 | 47.0 | 43.4 | 10.82 | 23.0 |
| 10=20 | 42 | 36 | 35 | 37.7 | 34.8 | 3.79 | 10.1 |
| 20 -30 | 17 | 22 | 18 | 19.0 | 17.5 | 2.65 | 13.9 |
| 30 -40 | 4 | 7 | 3 | 4.7 | 4.3 | 2.08 | 44.6 |
| Total | 113 | 100 | 112 | 108.3 | 100.0 | 7.23 | 6.7 |
|  | MID stage | | | | | | |
| 0 - 10 | 32 | 19 | 29 | 26.7 | 24.3 | 6.81 | 25.5 |
| 10=20 | 30 | 35 | 30 | 31.7 | 28.9 | 2.89 | 9.1 |
| 20 -30 | 29 | 32 | 26 | 29.0 | 26.4 | 3.00 | 10.3 |
| 30 -40 | 26 | 20 | 21 | 22.3 | 20.4 | 3.21 | 14.4 |
| Total | 117 | 106 | 106 | 109.7 | 100.0 | 6.35 | 5.8 |
|  | MAT stage | | | | | | |
| 0 - 10 | 36 | 38 | 52 | 42.0 | 33.0 | 8.72 | 20.8 |
| 10=20 | 40 | 32 | 40 | 37.3 | 29.3 | 4.62 | 12.4 |
| 20 -30 | 29 | 28 | 31 | 29.3 | 23.0 | 1.53 | 5.2 |
| 30 -40 | 16 | 13 | 17 | 15.3 | 12.0 | 2.08 | 13.6 |
| 40-50 | 4 | 3 | 3 | 3.3 | 2.6 | 0.58 | 17.3 |
| Total | 125 | 114 | 143 | 127.3 | 100.0 | 6.43 | 5.0 |

Table III presents the root distribution in the three locations, head, middle and end of the furrow, for the DEV, MID, and MAT stages of the plant cane growth, in B13 of location 1 in the first season (2011/2012).

In the DEV stage (July 2011), 5 months after planting the total number of roots per plant were 132, 140 and 105 in the head, middle and end of the furrow, respectively, with a mean of 125.7 roots confined to the top 40 cm soil depth. The average root percentages along the furrow profile were 28, 31, 24 and 17% in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At MID stage (November 2011), 9 months old crop, the total numbers of roots per plant at the three successive positions were 129, 133 and 125, with a mean of 129 roots confined to the top 50 cm soil depth. The average root percentages along the furrow profile were 22, 29, 30, 16 and

3% in 0-10, 10-20, 20-30, 30-40 and 40-50 cm soil depths, respectively.

At MAT stage (January 2012), 11 months old crop, the total roots per plant at the head, middle and end of furrow were 140, 147 and 176 roots, respectively with a mean number of 154.3 roots in the top 50 cm soil depth. The average root percentages along the furrow profile layer were 37, 37, 16, 5,

and 5% in the successive soil layers: 0-10, 10-20, 20-30, 30-40 and 40-50 cm, respectively.

Table III Vertical root distribution of plant cane in the head (Hed), middle (Mid.) and end of the furrow at the developmental (DEV), mid-season (MID) and maturity (MAT) stages in field B13 at location 1 (2011/2012).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | Numbers of roots | | | | % | STD | CV  % |
| Hed. | Mid. | End | average |
| DEV Stage | | | | | | |
| 0 - 10 | 41 | 37 | 28 | 35.3 | 28.1 | 6.66 | 18.8 |
| 10=20 | 36 | 43 | 38 | 39.0 | 31.0 | 3.61 | 9.2 |
| 20 -30 | 33 | 34 | 24 | 30.3 | 24.1 | 5.51 | 18.2 |
| 30 -40 | 22 | 26 | 15 | 21.0 | 16.7 | 5.57 | 26.5 |
| Total | 132 | 140 | 105 | 125.7 | 100.0 | 18.34 | 14.6 |
|  | MID stage | | | | | | |
| 0 - 10 | 29 | 33 | 22 | 28.0 | 21.7 | 5.57 | 19.9 |
| 10=20 | 41 | 39 | 31 | 37.0 | 28.7 | 5.29 | 14.3 |
| 20 -30 | 33 | 38 | 46 | 39.0 | 30.2 | 6.56 | 16.8 |
| 30 -40 | 21 | 17 | 24 | 20.7 | 16.0 | 3.51 | 17.0 |
| 40-50 | 5 | 6 | 2 | 4.3 | 3.4 | 2.08 | 48.0 |
| Total | 129 | 133 | 125 | 129.0 | 100.0 | 4.00 | 3.1 |
|  | MAT stage | | | | | | |
| 0 - 10 | 41 | 51 | 81 | 57.7 | 37.4 | 20.8  2 | 36.1 |
| 10=20 | 58 | 48 | 63 | 56.3 | 36.5 | 7.64 | 13.6 |
| 20 -30 | 25 | 28 | 22 | 25.0 | 16.2 | 3.00 | 12.0 |
| 30 -40 | 10 | 10 | 5 | 8.3 | 5.4 | 2.89 | 34.6 |
| 40-50 | 6 | 10 | 5 | 7.0 | 4.5 | 2.65 | 37.8 |
| Total | 140 | 147 | 176 | 154.3 | 100.0 | 19.09 | 12.4 |

Table IV presents the root distribution in the three locations, head, middle and end of the furrow, for the DEV, MID, and MAT stages of the first ratoon cane growth, B13 of location 1 in the second season (2012/2013).

In the DEV stage (July 2012), 5 months after planting the total number of roots per plant were 109, 106 and 122 in the head, middle and end of furrow, respectively, with a mean of

112.3 roots confined to the top 40 cm soil depth. The average root percentages along the furrow profile were 44, 35, 17 and 5% in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At MID stage (November 2012), 9 months old crop, the total numbers of roots per plant at the three successive positions were 127, 108 and 102, with a mean of 112.3 roots confined in the top 40 cm soil depth. The average root percentages along the furrow profile were 26, 28, 26 and 20%

in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively.

At MAT stage (January 2013), 11 months old crop, the total roots per plant at the head, middle and end of furrow were 133, 126 and 139 roots, respectively with a mean number of 132.7 roots in the top 50 cm soil depth. The average root percentages along the furrow profile layer were 31, 30, 23, 12,

and 4% in the successive soil layers: 0-10, 10-20, 20-30, 30-40 and 40-50 cm, respectively.

Table IV Vertical root distribution of first ratoon cane in the head (Hed.), middle (mid.) and end of the furrow at the developmental (DEV), mid-season (MID) and maturity (MAT) stages in field B13 at location 1 (2012/2013).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | Numbers of roots | | | | % | STD | CV  % |
| Hed. | Mid. | End | average |
| DEV Stage | | | | | | |
| 0 - 10 | 50 | 37 | 60 | 49.0 | 43.6 | 11.53 | 23.5 |
| 10=20 | 40 | 37 | 41 | 39.3 | 35.0 | 2.08 | 5.3 |
| 20 -30 | 15 | 23 | 18 | 18.7 | 16.6 | 4.04 | 21.7 |
| 30 -40 | 4 | 9 | 3 | 5.3 | 4.7 | 3.21 | 60.3 |
| Total | 109 | 106 | 122 | 112.3 | 100.0 | 8.50 | 7.6 |
|  | MID stage | | | | | | |
| 0 - 10 | 38 | 24 | 26 | 29.3 | 26.1 | 7.57 | 25.8 |
| 10=20 | 32 | 33 | 31 | 32.0 | 28.5 | 1.00 | 3.1 |
| 20 -30 | 30 | 30 | 27 | 29.0 | 25.8 | 1.73 | 6.0 |
| 30 -40 | 27 | 21 | 18 | 22.0 | 19.6 | 4.58 | 20.8 |
| Total | 127 | 108 | 102 | 112.3 | 100.0 | 13.05 | 11.6 |
|  | MAT stage | | | | | | |
| 0 - 10 | 38 | 42 | 45 | 41.7 | 31.4 | 3.51 | 8.4 |
| 10=20 | 44 | 35 | 39 | 39.3 | 29.6 | 4.51 | 11.5 |
| 20 -30 | 31 | 28 | 32 | 30.3 | 22.9 | 2.08 | 6.9 |
| 30 -40 | 14 | 16 | 18 | 16.0 | 12.1 | 2.00 | 12.5 |
| 40-50 | 6 | 5 | 5 | 5.3 | 4.0 | 0.58 | 10.8 |
| Total | 133 | 126 | 139 | 132.7 | 100.0 | 6.43 | 4.8 |

It is evident that the root system development (Tables I & II) along the three locations have the highest values in the middle of the furrow for the DEV or MID stages, but it revealed the highest density in the end of the furrow at MAT stage of the plant cane in the in the two locations (2 and 1) as 163 and 176 roots per cane plant, respectively. Whereas the lowest values were recorded in head of the most furrows at all stages of crop growth, which indicate that the root system of crop in the head of the furrow suffer under irrigation, and the highest values in middle of the furrows indicates relatively moderate moisture stress in this location, but the end of the furrow to some extend similar to head of the furrow in the DEV and MID stages of plant cane, and this can be attributed to the stagnation of water in the end of the end-blocked furrow as a result of the lack of drainage system, which in turn creates an anaerobic condition and waterlogging. The adverse effect of soil moisture stress (under irrigation) that lead to low density of root in head of the furrows is the same to that takes place in the end of the furrows as a reason of (over irrigation) water logging. The harmful effect of soil moisture stress in the head of the furrow is to the plant when it is accompanied by the saline soils (i.e. more osmotic pressure). Then that of excess moisture in end of the furrow have two effects of osmotic pressure and water logging at which root system development of sugarcane crop has severely been affected due to both reasons.

In table (II & IV) of ratoon crop of the second season in the two locations (1 and 2), the root system development along the three locations have the highest values in the head of the furrow for the DEV and MID stages, in location 2. Then the similar rooting trend has been noticed as a highest root density

in the end of the furrow at MAT stage of growth as 143 and 139 roots per plant for location 2 and location 1, respectively.

It is noticeable that the final root density for the plant cane of the first season in the two locations (1 and 2) is better than those of ratoon cane in the second season. This result differs from those reported by Ali [14] in Kenana plantation at which the ratoon cane showed better root density and depth than that of plant cane for the two season 2000 and 2001.

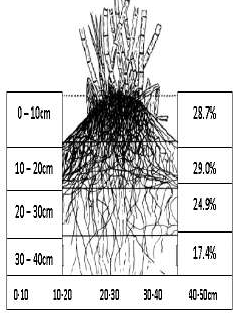
Table V shows the average of the numbers of roots for the three stages of the plant cane growth, for each of E20 and B13 in the first season (2011/2012). It is obvious that, the average numbers of roots of B13 was higher than that of E20, at all stages of plant cane growth. Then, in the two fields there were no significant increases in the average numbers of roots from the DEV sage to the MID stage of plant cane growth, however, a significant increases were recorded in crop progress from MID to MAT stage. The results showed that the plant cane of the first season for the two locations (1 and 2), in DEV stage about 82.6% of the overall average root distribution was confined to the top 30 cm depth, and the final depth reached by the root was 40 cm, in MID stage 81.2% was confined in 30 cm with a final depth reached of 50 cm and in MAT stage 90.6% was confined to the top 30 cm depth with a final rooting depth of 50 cm. In DEV stage, it is reasonably for the root to arrive 40 cm and reached more than 82% in the 30 cm depth, but it is not good for MID and MAT rooting depth to be more than 81 and 90%, respectively, in only 30 cm, then to be confined in

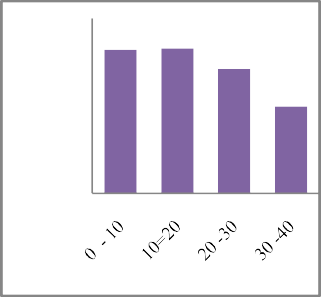
50 cm as final depth. Even in the (40-50 cm) depth, root percentages were only 3.2 and 4.8% for MID and MAT stages; these small percentages are considered to some extent as ineffective density of roots. These results were illustrated clearly in Fig. 1.

Table V Average root distribution of plant cane at the developmental (DEV), mid-season (MID) and maturity (MAT) stages of field number E20 and B13 (2011/2012).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | E20 | B13 | Mean | % | STD | CV% |
| Numbers of roots | | |
| DEV Stage | | | | | | |
| 0-10 | 36.3 | 35.3 | 35.8 | 28.7 | 0.71 | 2.0 |
| 10=20 | 33.3 | 39.0 | 36.2 | 29.0 | 4.03 | 11.1 |
| 20 -30 | 31.7 | 30.3 | 31.0 | 24.9 | 0.99 | 3.2 |
| 30 -40 | 22.3 | 21.0 | 21.7 | 17.4 | 0.92 | 4.2 |
| Total | 123.6 | 125.6 | 124.6 | 100.0 | 1.41 | 1.1 |
| MID stage | | | | | | |
| 0 -10 | 30.3 | 28.0 | 29.2 | 23.3 | 1.63 | 5.6 |
| 10=20 | 27.7 | 37.0 | 32.4 | 25.9 | 6.58 | 20.3 |
| 20 -30 | 40.7 | 39.0 | 39.9 | 31.9 | 1.20 | 3.0 |
| 30 -40 | 18.3 | 20.7 | 19.5 | 15.6 | 1.70 | 8.7 |
| 40-50 | 3.7 | 4.3 | 4.0 | 3.2 | 0.42 | 10.6 |
| Total | 120.  7 | 129 | 124.9 | 100.0 | 5.87 | 4.7 |
| MAT stage | | | | | | |
| 0 -10 | 59.7 | 57.7 | 58.7 | 38.7 | 1.41 | 2.4 |
| 10=20 | 53.7 | 56.3 | 55.0 | 36.3 | 1.84 | 3.3 |
| 20 -30 | 22 | 25 | 23.5 | 15.5 | 2.12 | 9.0 |
| 30 -40 | 5.7 | 8.3 | 7.0 | 4.6 | 1.84 | 26.3 |
| 40-50 | 7.7 | 7.0 | 7.35 | 4.8 | 0.49 | 6.7 |
| Total | 148.8 | 154.3 | 151.6 | 100.0 | 3.89 | 2.6 |

DEV Stage





%35.0

%30.0

%25.0

%20.0

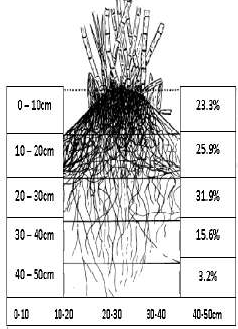
%15.0

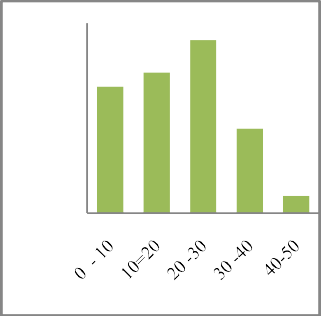
%10.0

%5.0

%0.0

MID Stage





%35.0

%30.0

%25.0

%20.0

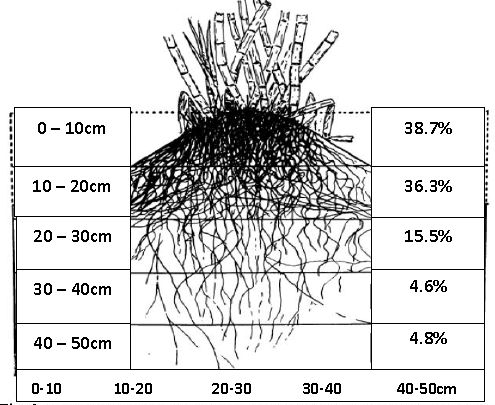
%15.0

%10.0

%5.0

%0.0

MAT Stage



%50.0

%40.0

%30.0

%20.0

%10.0

%0.0

Fig.1 Average root distribution percentages of plantcane at DEV, MID and MAT stages in fields E20 and B13 (2011/2012).

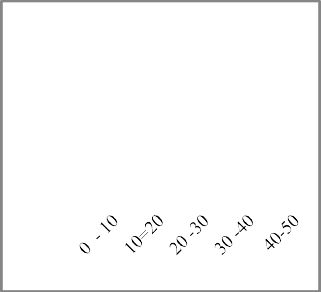
Table VI shows the overall mean of the total root density for each of the DEV, MID, and MAT stages of the ratoon cane growth, for locations 1 and 2, in the second season (2012/2013). It is obvious that, the overall mean of the total root density of location 1 was higher than that of location 2, at all stages of ratoon cane growth. At DEV stage were 108.3 and 112.3, at MID stage were 109.7 and 112.3 and at MAT stage were 127.3 and 132.6 roots per plants, for location 2 and location 1, respectively. There is also no significant increase from the DEV sage to the MID stage of ratoon cane growth, but a significant increase was recorded in crop progress from MID to MAT stage.

Table VI Average root distribution of first ratoon cane at the

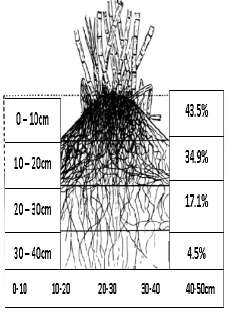
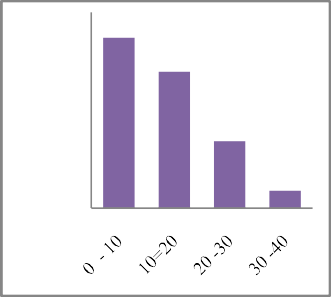
|  |  |  |
| --- | --- | --- |
| developmental (DEV), mid-season (MID) and (MAT) stages of field E20 and B13 (2012/2013). | maturity | %50.0 |
|  |  | %40.0 |
|  |  | %30.0 |
|  |  | %20.0 |
|  |  | %10.0 |
|  |  | %0.0 |
|  |  |  |
|  |  |  |
|  |  |  |
| %35.0  %30.0  %25.0  %20.0  %15.0  %10.0  %5.0  %0.0 | | |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Depth (cm) | E20 | B13 | Mean | % | STD | CV% |
| Numbers of roots | | |
| DEV Stage | | | | | | |
| 0-10 | 47 | 49 | 48 | 43.5% | 1.41 | 2.9 |
| 10=20 | 37.7 | 39.3 | 38.5 | 34.9% | 1.13 | 2.9 |
| 20 -30 | 19 | 18.7 | 18.85 | 17.1% | 0.21 | 1.1 |
| 30 -40 | 4.7 | 5.3 | 5 | 4.5% | 0.42 | 8.5 |
| Total | 108.  3 | 112.  3 | 110.3 | 100.0% | 2.83 | 2.6 |
| MID stage | | | | | | |
| 0 -10 | 26.7 | 29.3 | 28 | 25.2% | 1.84 | 6.6 |
| 10=20 | 31.7 | 32 | 31.85 | 28.7% | 0.21 | 0.7 |
| 20 -30 | 29 | 29 | 29 | 26.1% | 0.00 | 0.0 |
| 30 -40 | 22.3 | 22 | 22.15 | 20.0% | 0.21 | 1.0 |
| 40-50 | 0 | 0 | 0 | 0.0% | 0.00 | 0.0 |
| Total | 109.7 | 112.3 | 111.0 | 100.0% | 1.84 | 1.7 |
| MAT stage | | | | | | |
| 0 -10 | 42 | 41.7 | 41.85 | 32.2% | 0.21 | 0.5 |
| 10=20 | 37.3 | 39.3 | 38.3 | 29.5% | 1.41 | 3.7 |
| 20 -30 | 29.3 | 30.3 | 29.8 | 22.9% | 0.71 | 2.4 |
| 30 -40 | 15.3 | 16 | 15.65 | 12.0% | 0.49 | 3.2 |
| 40-50 | 3.3 | 5.3 | 4.3 | 3.3% | 1.41 | 32.9 |
| Total | 127.3 | 132.6 | 130.0 | 100.0% | 3.75 | 2.9 |

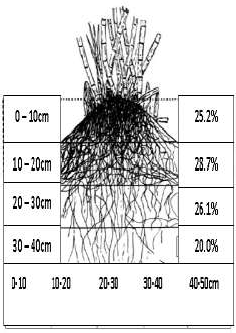
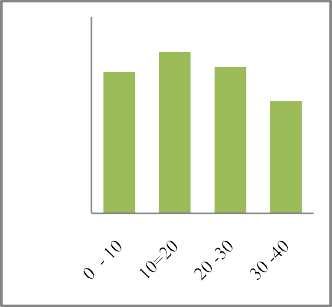
As illustrated in Fig. 2 ratoon cane of the second season for the two locations (1 and 2), it is clear that in DEV about 95.5% of the overall average root distribution was confined to the top 30 cm depth, and the final depth reached by the root was 40 cm, in MID stage 80% was confined in 30 cm with a final depth reached of 40 cm and in MAT stage 85% was confined to 30 cm depth with a final rooting depth of 50 cm.

In DEV stage, it is reasonably for the root to reach 40 cm and reached more than 95.5% in the 30 cm depth, but it is not good for MID and MAT rooting depth to be more than 80 and 85% in same respect in only 30 cm. The MID stage roots reached final depth of 40 cm in ratoon cane, whereas the same stage reached 50 cm in plant cane of the previous season, then even MAT stage roots still being confined in 50 cm as final depth. In the (40-50 cm) depth there were only 3% of roots for MAT stages, which are considered as ineffective density of roots.

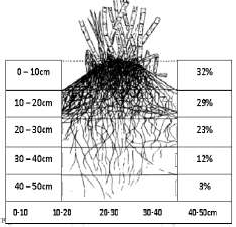
DEV Stage



MID Stage



MAT Stage



%35

%30

%25

%20

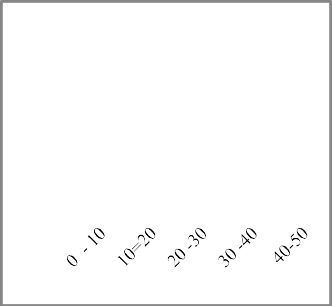
%15

%10

%5

%0

Fig. 2 Average root distribution percentages of the first ratoon cane at DEV, MID and MAT stages in fields E20 and B13 (2012/2013).

The data illustrated in Fig. 1 and 2 show a strong variation in average root distribution pattern between the plant cane in the first season and ratoon crop in the second season, particularly, in the DEV and MID stages of growth. So, when comparing the average root distribution of DEV stages between the two-crop cycle, their roots extended to reach 40 cm, but that of plant cane was well distributed with denser roots (17.4%) in the (30-40 cm) depth, whereas that of ratoon cane was only (4.5%) in the same depth. Also, in comparing the average root distribution of the MID stages, the root of plant cane extended to reach 50 cm while that of ratoon cane was confined only in the 40 cm depth.

These comparisons between the root distribution of the plant cane and ratoon crop, showed that most of the root density (> 80%) in all stages of growth confined only in the top 30 cm depth, however, the most two active growing stages DEV and MID of the ratoon cane showed a poor distribution of roots in density and length, this result completely contradict with the findings of Ali [14] on Kenana plantation,

in which it is evident that the root system developed more rapidly in DEV and MID of the first ratoon crop than the same stages of plant cane, moreover, the roots of the sugarcane in both cycles reached 60 cm depth in MAT stags in Kenana plantation, while it was poorly confined to 50 cm depth in WNSE. Subsequently, the plant cane and the first ratoon crop appeared a poorer distribution of roots in all stages of growth in WNSE than those of Kenana plantation,

Accordingly, since the plant cane varieties grown in WNSE was the same as that grown in Kenana sugarcane plantation ( mostly Co 6806 and Co 527) which revealed good pattern of rooting depth and density. The rooting depth and density in this study indicated that the sugarcane crop of WNSE is suffering a variety of limitations related mostly to physical and chemical soil properties, land preparation, field traffic of the management practices increasing bulk density hindering root length, the irrigation system and management practiced, as well as the drainage problems. Factors that can affect root growth directly are related to the root development, such as aeration, water, temperature and mechanical resistance to root penetration [15].

The importance of studying the root distribution of sugarcane crop is to determine to what extent the root system is efficient in both the uptake of soil water and nutrients. Accordingly, the root system of crop plants must be well developed to explore the entire soil profile and efficiently utilize stored soil water. The root system means the distribution of roots vertically deep in the soil depths and horizontally in a circle shape around the extended stem downward direction. Sugarcane roots are usually located in the upper soil surfaces with 60% in the 0 – 30 cm depth, but may penetrate to 180 cm in well-drained soils [16].

Field traffic of the management practices as equipment traffic in harvesting operation affects the bulk density in the soil horizons was found to resist root penetration and reduce root length density by as much as 60% at the 15 to 30 cm depth [17]. Soil compaction is a very important factor for the heterogeneity of root system distribution of sugarcane crop in the soil profile due to intense machine traffic between crop rows, leading to an increase in soil density and consequent reduction of porosity and oxygen diffusion. This compaction in the layer 20–40 cm may be the main reason why 65% of the roots were found above this layer [18]. As soil physical resistance increased, lateral root length to primary root length ratios increased [19]. This result would infer a greater amount of branching with greater soil resistance. The osmotic pressure due to soluble salts is the chemical barriers which limit the root development. Plant-water relationship s is affected by salinity [20]. The presence of salt decreases the water potential of the medium, so plants have problems with respect to absorption of water. In order to compensate for the negative values of the nutrient solution, plants have to decrease their water potential; this involves a decrease of the osmotic potential, to maintain turgor and achieve osmotic adjustment [21].

It has been reported that reductions in growth depend on the period of time over which the plants have grown in saline conditions, leading to the hypothesis that, on most occasions, there is a two-phase growth decrease in response to salinity [22]. The first phase of growth reduction is quickly apparent,

and is due to the salt outside the roots. It is essentially a water stress or osmotic phase. Then, there is a second phase of growth reduction, which takes time to develop and results from internal injury due to salts accumulating in transpiring leaves [23]. Water content of a soil is important to root growth and root modification. Plant roots are composed of 70 to 93% water by weight [24]. Most of this water is taken up during cell expansion, when the root actually extends into the soil. If water is limiting, no cell expansion can occur and roots will not grow into the soil mass.

The shallower the depth of the root system at the beginning of the season the shallower is the soil depth from which plant can take water, but as the roots grow they can take water from an increasing depth of soil, subsequently irrigation water should be applied frequently at the beginning and vice versa for late season stage. Gardener [7] reported that a greater rooting depth increases available water storage capacity, but the storage moisture at lower depths is less extractable because rooting density decreases with depth and a lower leaf potential or larger potential gradient is required to extract water. Hillel

[25] concluded that about 40% of the total moisture used is extracted from the first quarter of the root zone, 30% from the second, 20% from the third and 10% from the last quarter.

Generally, the distribution pattern of the sugarcane root system along the growing season determines the available water storage capacity, subsequently the irrigation depth to be applied, whereas the crop water requirements of different stages of growth for either plant cane or ratoon crop, determine the indenting of water application. On the other hand, the poor physical properties of the soil and the high soil moisture content in deeper soil make the roots develop laterally in shallow depth, subsequently, occupy a small volume of soil from which only small amount of water and nutrients can be taken, then these shallow roots can be considered as a weak anchorage and the stand of cane tend to lodge at later growth stage in high wind speed.

The short irrigation intervals prevent surface soil drying and encourage a higher percentage of roots to develop near the soil surface; however, poor soil aeration restricts root growth. Grable [26] stated that the excessive wetting of soils for period of time results in poor aeration and restricted root development, and as the soil dries, root that have developed under highly hydrated conditions can become poor conductors of water and thus limit water availability and water and nutrient transport into and through the root system. Trouse

[18] stated that the rate of elongation of the roots and rootlets is slower in denser soil.

Weiss [27] reported that the increase in the pre-irrigation soil moisture with depth is due to the fact that, most of the actively absorbing roots are near the surface of the soil, so that the soil water at top layers will be depleted faster. This finding also shows that the total amount of irrigation water entering the soil profile is higher at top layers where the root density is high. However, it is assumed that the potential evapotranspiration takes place from upper soil layer as long as some readily available moisture is present. If no readily available moisture is present, then takes place from deeper soil depth. The sugarcane root system distribution within the soil is highly dependent upon soil properties and moisture regime throughout the growing season, therefore it is of interest in

studying the soil physical and chemical properties and the irrigation management and their effect in root distribution of the different developmental stages of growth in plant cane and ratoon crop and subsequent effect in productivity. The effects of irrigation management on root growth were visually evident during observations of the standing cane crops. Most of the WNSE field suffering a lack of drains at the end of field, so that the tail water is let to accumulate at the end of furrow, otherwise, it can either spread in the in-between field roads or to go through another neighboring fields and damage crops. This water can stand at the end of the furrow for long period of time causing waterlogging condition. Most of these fields were re-irrigated while it still moist, subsequently, affecting the growth of crops in the end of furrow moreover leading to death of plants. Accordingly, the halophyte plants were spreading over many fields.

1. CONCLUSIONS

The rooting depths of plant cane in the first season for the DEV, MID and MAT stages were 40, 50 and 50 cm, and in the ratoon crop in the second season were 40, 40 and 50 cm, respectively. There was spatial variation of root density either along the furrow from head to end or from field to field as well as temporal variation between the plant cane and the ratoon of the same crop in the second year. The sugar cane generally appeared a poorer root density in WNSE than that studied by Ali [14] in Kenana plantation at which the rooting depth reached 60cm depth. The poor rooting depths at the end of most furrows can be attributed to the stagnation of water in the end of the end-blocked furrow as a result of the lack of drainage system, which in turn creates an anaerobic condition and waterlogging. A deleterious effect of soil moisture stress in the head of the furrow is a bad to the plant particularly in the saline soils (i.e. more osmotic pressure). However, root system development of sugarcane crop, have severely been affected due to both reasons. More than 80% of the root system confined to 30 cm depth. The rooting depth and density in this study area indicates that the sugarcane crop of WNSE had suffered a variety of limitations related mostly to physical and chemical soil properties, land preparation, the irrigation system and management practiced as well as in irrigation management and the drainage problems. The importance of studying the root distribution of sugarcane crop is to determine to what extent the root system is efficient in both the uptake of soil water and nutrients. Accordingly, the root systems of crop plants must be well developed to explore the entire soil profile and efficiently utilize stored soil water.

RECOMMENDATION

The decision of sugarcane irrigation in term of how much water to apply and in what frequency should be based on two factors, the crop water requirement (CWR) and available water (AW) in the root zone. The CWR should be determined from the climatic data (Reference Evapotranspiration (ETo) and Crop Coefficient (Kc), and AW should be determined as a difference between the Soil Field Capacity, FC, and Permanent Wilting Point, PWP, then the readily available moisture as a percentage of AW should be used as allowable moisture level so as not to make adverse soil moisture stress for the crop.

Accordingly, the rooting depths of the three stages of sugarcane crops ( plant cane and rations) is a main parameter for determination of the amount of available water depth that should be stored in corresponding rooting depth. Subsequently, to determine how much irrigation water amount should be applied to refill each soil depth to the field capacity, on the other hand, the CWR data should be used to indicate the duration that can be taken by the specific crop stage to consume this available moisture to the allowed level, this exactly determine the irrigation frequencies for each stage of sugarcane growth.

Appendix

Illustration of Root Grid System During Measurements Root Distribution in the White Nile Sugar Estate fields



References

1. Waisel, Y.; Eshel, A. & Kafkafi, U. 2002, eds. Plant roots – the hidden half. Madison, Marcel Dekker, 1120p.
2. VASCONCELOS, A.C.M.; CASAGRANDE, A.A.; PERECIN, D.;

JORGE, L.A.C. & LANDELL, M.G.A. 2003, Avaliaçao do sistema radicular de cana-de-aç◌ْcar por diferentes métodos. R. Bras. Ci. Solo, 27, 3:849-858.

1. Sperry J S, Stiller V and Hacke U 2002 Water uptake and water transport through root systems. In Plant Roots: The Hidden Half, Eds Y Waisel, A Eshel and U Kafkafi. pp 663-681. Marcel Dekker, Inc., New York.
2. Kramer, P. J, 1969. Plant and soil water relationships: A modern synthesis. McGraw-Hill, New York, p- 5,
3. Baver, L.D., H.S. Brodie, T. Tantimoto, and A.C. Trouse (1962). New approaches to the study of cane root systems. Int. Soc. Sugarcane Technol. Proc. 11th Congr. (ISSCT) p. 243-253.
4. Taylor, H. M., and Klepper. B. 1974. Water relations of cotton. I. Root growth and water use as related to top growth and soil water content. Agron. J, 66:584-588.
5. Gardener, W.R. (1965). Soil water movement and root absorption. In: Plant Environment and Efficient Water use, W.H. Pierre et al., (Eds). Am. Soc. Agrn. and Soil Sci. Soc. Am., Madison, W.I. pp. 127-149.
6. Wang, F.X., Kang, Y., Liu, S.P., 2006. Effects of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. Agri. Water Management, 79: 248-264.
7. Costa, M.C.G.; Mazza, J.A.; Vitti, G.C.; Jorge, L.A.C. 2007. Root distribution, plant nutritional status, and stalk and sugar yield in two

genotypes of sugarcane in distinct soils. Revista Brasileira de Ciência do Solo 31: 1503-1514. (in Portuguese, with abstract in English).

1. Monteith, N.H.; Banath, C.L. 1965. The effect of soil strength on sugarcane root growth. Tropical Agriculture 42: 293-296.
2. Humbert. R.P. 1968. The Growing of Sugarcane. Elsevier Publication Co. Amsterdam, Netherlands.
3. Yamasaki, Y. (1956). Root system development under different soil improvement and cultivation practices for main soil groups. Rep. Hawaiian Sugar Tech. 15: 10-12.
4. Abdel Wahab. D. M. 1988, Distribution and growth for four sugarcane cultivars irrigated by furrow urrigation system at Kenana Sugar Scheme, paper presented for the irrigation management seminar, Sudanese Sugar Co. Sudan.
5. Ali M. S. M., MSc. (2003). Appraisal of the long furrow irrigation system in Kenana sugar cane plantation.M.Sc. Department of Soil Science. Faculty of Agriculture. University of Khartoum.
6. Letey, J., Dinar, A., Knapp, K.C., 1985. Crop-water production function model for saline irrigation waters. Soil Sci. Soc. Am. J. 49, 1005–1009.
7. Gascho, G. J., and S. F. Shih. 1983. Sugarcane. Pages 445-479. In: Crop-Water Relations I.D. Teare and M.M. Peet, eds. John Wiley & Sons. New York.
8. Grimes, D. W., W. R. Sheesley, and P. L. Wiley. 1978. Alfalfa root development and shoot regrowth in compact soil of wheel traffic patterns. Agron. J. 70:955-958
9. Trouse JR., A.C. 1967, Effects of soil compression on the development of sugar cane roots. In: Congress of the International Society of Sugarcane Technplogists. 12., San Juan, Proceedings. Amsterdam,

International Society of Sugarcane Technologists, 1967. p.137-152

1. Voorhees, W. B., D. A. Farrell, and W. E. Larson. 1975. Soil strength and aeration effects on root elongation. Soil Sci. Soc. Am. Proc. 39:948- 953.
2. Hasegawa P M, Bressan R A, Zhu J K and Bohnert H J 2000 Plant cellular and molecular responses to high salinity. Ann. Rev. Plant Physiol. Plant Mol. Biol. 51, 463–499.
3. Blum A, Munns R, Passioura J B and Turner C 1996 Genetically engineered plants resistant to soil drying and salt stress: how to interpret osmotic relations? Plant Physiol. 110, 1051–1053.
4. Munns R 2002 Comparative physiology of salt and water stress. Plant Cell Environ. 25, 239–250.
5. Kawasaki S, Borchert C, Deyholos M, Wang H, Brazille S, Kawai K, Galbraith D and Bohnert H J 2001 Gene expression profiles during the initial phase of salt stress in rice. Plant Cell 13, 889–905.
6. Kramer P J 1983 Water relations of plants. Academic Press, New York. 489 p.
7. Hillel, D. (1971). The extraction patterns of soil water by the plant: Physical Principles and Processes, Academic Press, New York.
8. Grable, A.R. (1966). Soil aeration and plant growth. Adv. In Agron. 18: 57-106 Academic Press, Inc., New York.
9. Weiss, E.A. (1983). Tropical Crops. Longman Inc. New York. pp 402- 462.