IMPROVEMENT OF CENTER PIVOT IRRIGATION SYSTEM MANAGEMENT USING WATER-SAVING TILLAGE

Harby Mostafa[1] & Yano Antar[2]

ABSTRACT

The study aimed to improve the management of center pivot irrigation system. This was achieved by evaluating the use of deficit irrigation (100%, 85% and 70% Etc.) with water saving tillage systems (mulch and strip tillage compared to full tillage) under center pivot irrigation system for corn silage production. Soil moisture content, starch content and agronomic parameters e.g. plant height, leaves area and stem diameter were measured. The experiment was in a "split plots design" with three replicates. The results indicated that aggregate soil water contents in the top ٤0 cm of the soil profile followed the same patterns and relative positions for each tillage treatment. Moisture contents of soil in the strip and the mulch practices were mostly statistically similar. Full tillage system and the reduced irrigation regime (70% ETc) were significant (P < 0.05) inferior for agronomic attributes of corn plants in contrast with its corresponding treatments, and that, the 100% and 85% water regimes were statistically similar for almost all parameters. Mean corn silage yields were 9.4% and 6% greater for the strip tillage practice than for the full practice with 70% and 85%ETc, respectively, but for mulch tillage the yield 4.7% greater than full tiled with 100% ETc. The results indicated that deficit irrigation has a positive effect when applying with strip tillage followed by mulch tillage where 15 to 30% of water can be saved.

Keywords: *Deficit irrigation, tillage system, corn silage yield*

INTRODUCTION

The impacts of environmental change, the promotion of bioenergy, rising agricultural prices and the associated increase in agricultural intensity make water increasingly an important factor in the production process.

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Enhancing crop water productivity through inventive irrigation, tillage and plant residue management techniques that have been axial to agricultural sustainability in many parts of the world may be progressively basic if decision makers are to avoid uneconomic reductions in production due to shortage of water availability.

Precision irrigation technology that can be coupled with water use efficient plough and plant residue management systems and regulated deficit irrigation approaches may be preserving the competitive agricultural capacity of forage systems (**Lamm and Aiken, 2007; Mitchell, 2014)**.

The potential to conserve water at the farm scale depends on the strength of the irrigation system and the obligation of the worker to implement water-saving practices and technologies (**Mostafa and Thormann, 2015**).

The development of movable sprinkler systems has supplied more than suitable irrigation methods. For all irrigation systems, these tools offer the highest potential for orderly applications as well as being easily adaptable for adaptive control of spatially varied applications. Significant progress has been made in hardware development for the control of center pivots to deliver a precision irrigation system (**Evans *et al.*, 2013, Mc-Carthy *et al.*, 2010**).

Tillage is considered as one of the most important farming practices in the plant production because it ease seed germination, controls soil erosion, and improves water infiltration and aeration of soil for good production conditions **(Mohamad, 2013).**

Minimum-tillage systems, with the purpose of retaining the moisture content of soil, decreasing time needed and reducing fuel consumption, have recently been replacing traditional tillage practices. Furthermore, retaining crop residue on the soil surface can provide a resource of crop nutrients, mend organic matter, increase soil moisture content and infiltration rate **(Chaorakam *et al.*, 2009).**

Yang *et al.* (2016) concluded that minimum-tillage with residue mulch resulted in higher yields as compared with deep tillage with residue removal probably because of higher topsoil water content. Minimum-tillage with residue mulch with low irrigation maintained high grain yields in spite of eliminating one round of irrigation; therefore, it was more beneficial for wheat crop production.

Iqbal *et al.* (2007) reported that minimum/reduced tillage coupled with irrigation at or more than 50% soil moisture depletion level an appropriate practice for the study area.

Conservation tillage is well known as a favorable tillage system that focuses on reducing soil erosion and boost water conservation in soil **(Mannering and Fenster, 1983; Yang *et al.* 2016).**

In various national and international practice attempts have been made to reduce the loss of water by means of non-turning soil processing methods against plowing methods, e.g. **(Bischoff, 2005; Cantero-Martinez *et al.*, 2007).** However, there is still no clear-cut insight into the improvement of water storage capacity and the resulting potential reduction in irrigation.

The aim of this work is to optimize the management of center pivot irrigation system by evaluating the use of deficit irrigation with water saving tillage systems under center pivot irrigation system for corn silage production in order to ultimately save water during irrigation also to adjust the expected higher water demand in the event of a future climate change.

Within the framework of a series of experiments, approaches using adapted soil processing, irrigation technology and irrigation control were investigating to further optimize the yield and water use.

MATERIALS AND METHODS

The experimental study was done in two succesive seasons (2014 and 2016) at Thuenen Institute for Agricultural Technology (TI), Braunschweig, Germany. It is located between latitudes of 52°1752, 80”N - 52°1803”N, and longitudes of 10°271”E-10°27370,27”E, respectively. The characteristics of the soil at the experimental site are 1.4% organic matter, 6.3% clay, 48.7% silt, 45% sand and 6.3 pH. The soil type was characterized by a loamy sand texture. The weather data in this region are shown in Table 1.

Table 1: The average weather data at the experimental site (the German Weather Station “DWD”, www.dwd.de)

Parameters	Average from 1965 to 2015				
	May	June	July	August	Sep.
Precipitation [mm]	51	70	47	58	50
Temperature [° C]	13.1	15.9	20.4	19	16
Potential ET [$mm.month^{-1}$]	88	91	94	99	97

1. Experimental Setup

The technical implementation on the trial field was carried out with an existing center pivot system machine with 90 m length. For water distribution, the center pivot was equipped with rotating plate nozzles (Nelson R3000) mounted at a spacing of 5 m. To keep the flow rate of the nozzle constant over the entire width of the machine, pressure reducing valves (Nelson High Flow 1.38 bar) were placed in front of each nozzle.

The trial was arranged in a split plot design with three irrigation levels in the main plots and three tillage treatments in subplots with three replications. The area was previously cultivated with wheat.

The area of center pivot was divided into four quarters, three of them were used as the main plots (one quarter for each irrigation treatment) under the second tower. The three different soil processing each have a width of 18 m and extend over a length of 50 m as subplot. Each subplot was divided to three replicats (6 x 50 m) with 6 m separation line between subplots as shown in fig (1).

The treatments were as follows:

Tillage: (i) Full tillage (FT) with 30 cm depth,

(ii) Mulch tillage (MT) with 10 to 12 cm depth, and

(iii) Strip tillage (ST) with 20 cm wide and 10 to 12 cm depth.

Irrigation: (i) irrigation at 100 % of water requirements,

(ii) irrigation at 85% of water requirements, and

(iii) irrigation at 70% of water requirements.

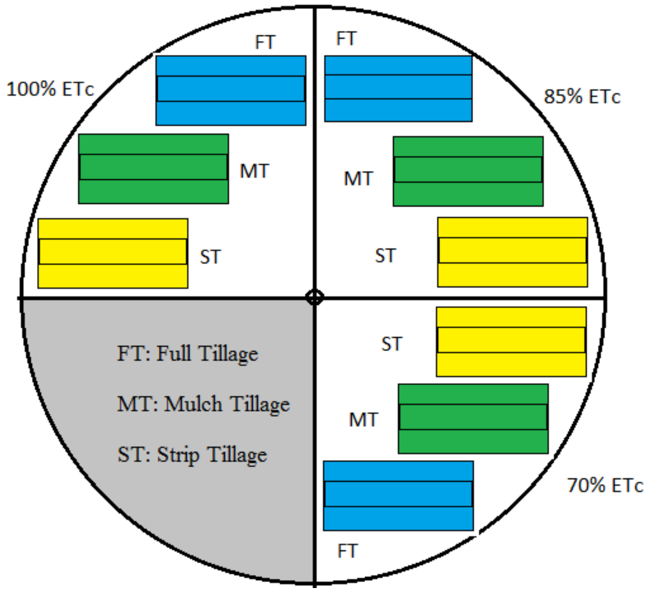

Fig.1: Schematic experimental field systems

The irrigation amount was adapted by controlling the center pivot speed for each quarter to irrigate the require depth.

The full tillage plots were tilled to approximately 30 cm depth by a rotary cultivator machine attached with underground plow to ensure full incorporation of the preceding crop residue. Mulch tillage (shallow) treatment was tilled to 10 to 12 cm depth using a three-row heavy cultivator with a double-row short disc harrow follower for mixing and cutting plant residues and a large-sized rod roll for height guidance and re-consolidation. Strip tillage treatment was designed to minimize soil disturbance using a tilling depth of only 10 to 12 cm and a width of 20 cm for seed by using a small rotary tiller (Fig 2).

Sufficient irrigation was applied to keep the soil water profile of root zone between critical moisture content and field capacity. Factors for starting and controlling the irrigation system serve the available water capacity (AWC) of the soil which is controlled by the irrigation controller model AMBER that managed by the German Meteorological Service (DWD). The five-day prediction of water demand was created daily and allowed the further specific irrigation. The irrigation starts on all treatments when 75 % of AWC under 100% ETc irrigation treatment is consumed.

Fig 2: Soil tillage treatments (Full tillage, mulch tillage and strip tillage).

All plots were planted with corn (for silage production) in the second week of May for both two seasons. Corn seeds were planted at a spacing of 0.13 m within row and 0.75 m between rows. The soil was tested for needed fertilizer requirements and was added accordingly.

The harvest was done when whole plants moisture was between 65 and 70% moisture (at the end of September to beginning of October) according to **Mostafa and Derbala (2013).**

2. Measurements

For each plot, the daily moisture content of soil (M.C) was measured using a hand-held 0.40 m soil moisture probe (Hydrosense probe). By using the data of weather station located next to the experimental site, AMBER modell was used to monitor the daily changes of precipitation rate, temperature, evapotranspiration and create the irrigation requirements. Agronomic parameters e.g. plant height, leaves area and stem diameter were measured directly before harvesting.

To start the harvesting, whole plant moisture at harvest has to be between 65 and 70 %. The way to accurately evaluate whole-plant moisture was to collect plant samples and have them tested. The materials were put in the drier at a constant weight. Equation 1 was used to calculate the plant MC (%) (**ASHRAE ,1997**):

$$MC\ (\%) = \frac{(W_m - W_d)}{W_d} \times 100 \qquad [1]$$

Where:

MC = Moisture content in % db.,
W_m = Moist weight in kg and
W_d = Dry weight in kg.

The starch content is presented as an essential quality criterion for animal feeding. The method of starch investigation depends on the principle that starch is totally separated to its constituent glucose sugars while still physically located in the sample. This degradation step is carried out using starch degrading enzymes (α-amylase, β-amylase and several dextrinases etc), collectively known as 'amyloglucosidase', and which are specific for starch only. The starch content is then calculated from the amount of glucose produced (**Rasmussen and Henry, 1990**).

On determination of yield and starch content of corn silage, all plots were harvested separately by harvesting machine (which cut and chop plants and placed on containers that can be weighed).

All data collected were statistically analyzed as described by **Snedcor and Cochran (1982).** Means among treatments were compared using Least Significant Difference (LSD) at P 0.05 probability.

RESULTS AND DISCUSSION

1. Moisture Content of Soil

Soil moisture measurements were collected before irrigation events, thus the data represent a lower boundary of moisture content values. Water contents in soil tended to be the similar trend for all tillage treatments under each irrigation regime from the beginning until the end of the growing season of the study periods.

As shown in Figs (3, 4 and 5), soil moisture contents within the crop root zone were affected by the tillage practices. The strip and mulch tillage practices tended to have the highest soil water content and the full tillage practice the lowest under all irrigation regimes. Mean moisture contents for the full tillage practice were between 25 and 27% under full irrigation (100% ETc) and for both mulch and strip tillage practices were between 28 and 31% (Fig 3).

A statistical analysis of the data indicated that there are no-significant differences between all tillage practices under 100% irrigation regime.

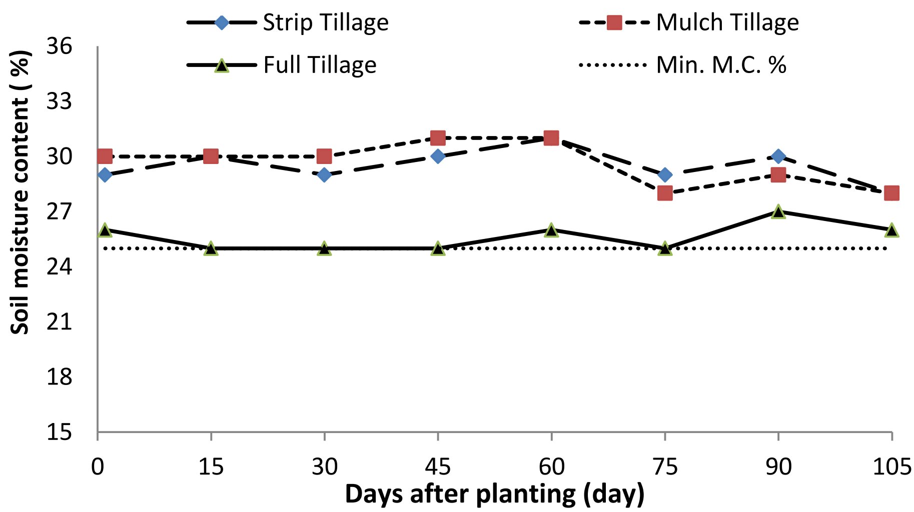

Fig (3): Change in moisture content of soil during growth period at 100% ETc

With water regimes 85% and 70% ETc, the data take the same trend. There were no-statistical differences between the mulch and strip tillage treatments with 85% ETc, where moisture content of soil were 26 to 28% and 27 to 29%, respectively (Fig 4). Also, the moisture content with 70% Etc ranged between 21 to 25% for mulch tillage and between 23 to 25% for strip tillage (Fig 5). On the contrary, soil moisture content showed the lowest values in the full tillage in both 85% and 70% ETc irrigation regime. The statistical analysis indicated that soil moisture content was significantly influenced by tillage practices and water regimes. These results agreed with (**Mitchell, 2014),** after sustained conservation tilled production, soils may store more water than traditionally ploughed soils because of the upkeep of macropores. Moreover, soils with stubble cover additionally decrease wind speeds and temperatures at the surface, which may decrease evaporation from the soil, saving water and enhancing the production efficiencies in cropping systems. Likewise **Gozubuyuk *et al.* (2014) and (2015); Badalikova (2010)** and **Romaneckas *et al.* (2013)** detailed that reduction of soil tillage intensity from annual deep tiled to shallow tiled, deep, shallow and no tillage save soil moisture content and the micropores could increment because of the reduction in macroporosity under no tillage conditions.

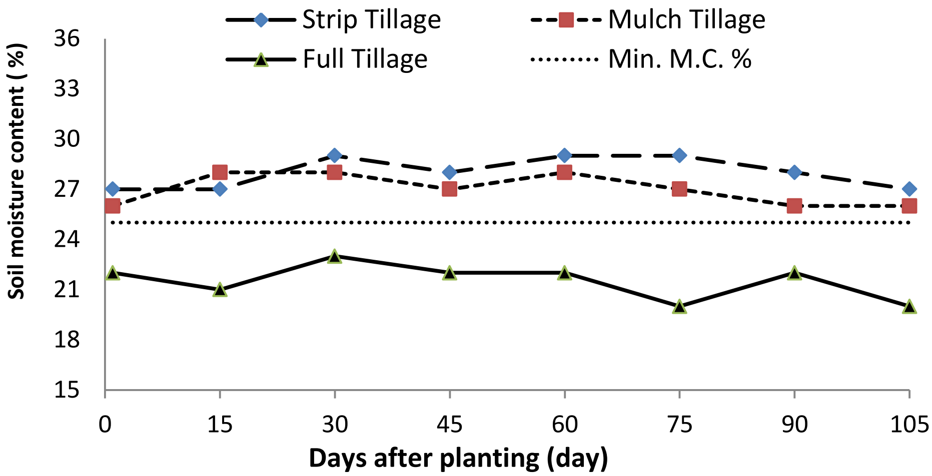

Fig (4): Change in moisture content of soil during growth period at 85% ETc

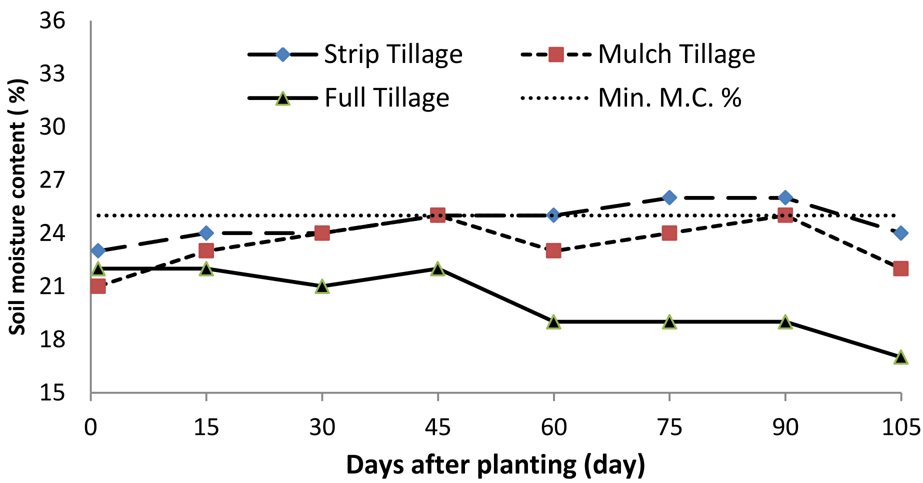

Fig (5): Change in moisture content of soil during growth period at 70% ETc

2. Effect of water regimes and tillage treatments on agronomic growth parameters

Data in Table (2) contain the effect of water regimes and tillage treatments on agronomic growth parameters (plant height, leaves area and stem diameter). Data in the aforementioned tables indicated clearly that irrigation water regimes affected significantly corn agronomic growth parameters under full and mulch tillage systems. Generally, it could be safely concluded that changing the irrigating corn plants from 70 to 100% of Etc led to obtaining significant values of the aforementioned agronomic growth parameters in most sampling data. It is noteworthy to mention that the 100% Etc treatment exhibited similar effect on agronomic growth parameters as the 70% Etc with strip tillage. Also, tillage systems affected significantly the agronomic growth parameters. Mulch tillage treatment showed a highest value with 100% Etc for all parameters, while strip tillage treatment showed a highest values with 85% and 70% Etc. Results indicated that interaction had significant effects on most studied growth parameters. The highest values of plant height (225 cm) and stem diameter (3.22 cm) were observed by applying 100% Etc under mulch tillage system and with 85% and 70% Etc strip tillage showed the highst valoues. On the other hand, the irrigation with 70% Etc under full tillage system showed the lowest values.

Table (2): Effect of water regime and tillage types on plant length (cm), stem diameter (mm) and leaf area.

Till. System	Plant length (cm)			stem diameter (cm)			Leaf area* (cm^2)		
	70%	85%	100%	70%	85%	100%	70%	85%	100%
Full Tillage	198 a	210 a	220	2.52 a	2.96	3.15	602.1 a	675.2 a	742.5 a
Mulch Tillage	207 ab	214 ab	225	2.71 a	3.12	3.22	671.3 b	692.1 ab	789.7 b
Strip Tillage	217 b	222 b	222	3.1 b	3.22	3.15	731 c	746.3 b	747.8 a
LSD (0.05)	11	10	7	0.36	0.4	0.29	38.1	70.5	40.6

*Leaf area = 0.75 (max. width x length of the leaf) **(Abou Kheira, 2009)**

3. Starch Contents

In the case of the differences in the starch content between the three soil tillage treatments, it can be seen in Fig (6) that the strip tillage plots have achieved the highest yields and the full tillage variants the lowest yields with all irrigation regimes. In the case of the 70% Etc, the strip tillage has the highest starch content followed by mulch tillage treatments with non-significant effects, but the full tillage showed a significant reduction. The same trend was happend in the case of 85% Etc. There is no-significant effects between 70% and 85% Etc for each tillage treatment, but 100% Etc showed significant deferances between all tillage treatments and also comparable with the other irrigation regimes.

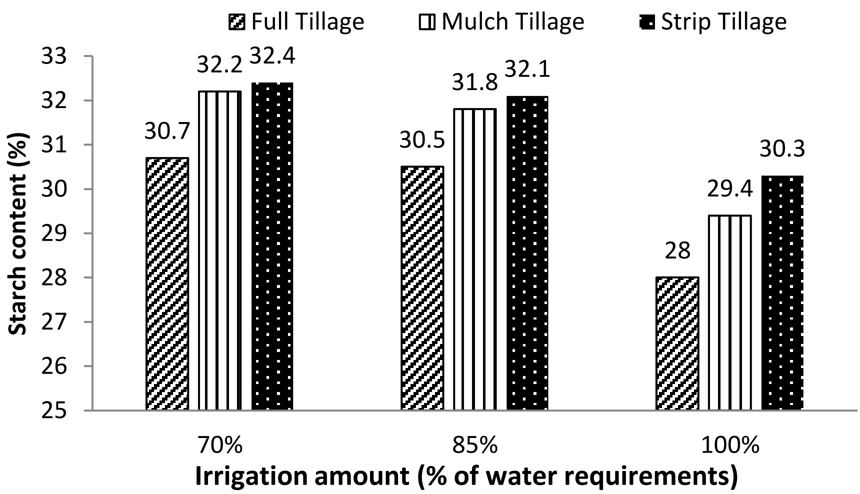

Fig (6): Change in starch content (%) in corn silage.

4. Silage Yield and Water use efficiency (WUE, kg/m^3)

The final yield of the silage was affected by both irrigation regimes and tillage types as shown in Fig (7). Mulch tillage gave statistically significant (p 0.05) higher silage yield than full and strip tillage under 100% ETc reaching 24.2 t ha^{-1} compared to 23.1 and 23 t ha^{-1} of the full and strip tillage, respectively. Strip tillage system also resulted to statistically significant higher yield than mulch tillage system (p 0.01) and full tillage system (p 0.05) reaching 23.4 t ha^{-1} compared to 22.8 and 22.1 t ha^{-1} with 85% ETc, and 22.3 t ha^{-1} compared to 21.6 and 20.2 t ha^{-1} with

70% ETc of the mulch and full tillage, respectively. As it was expected, silage yield was influenced by irrigation regime, where the yield reduction was 2.9 and 2.6 t ha^{-1} for both full and mulch tillage, respectively but the less reduction was 0.7 t ha^{-1} for strip tillage when the irrigation was reduced from 100 to 70% ETc. These results agreed with those obtained by **Yang *et al.* (2016**).

It is obvious that WUE (kg/m^3) was lower in plots that got 100% ETc water regime (average of 8.6 kg/m^3). On the other hand, the highest values for WUE were accounted for regarding 70% ETc water regime (averaged 10.8 kg/m^3). These results agreed with those obtained by **Mostafa and Derbala (2013).**

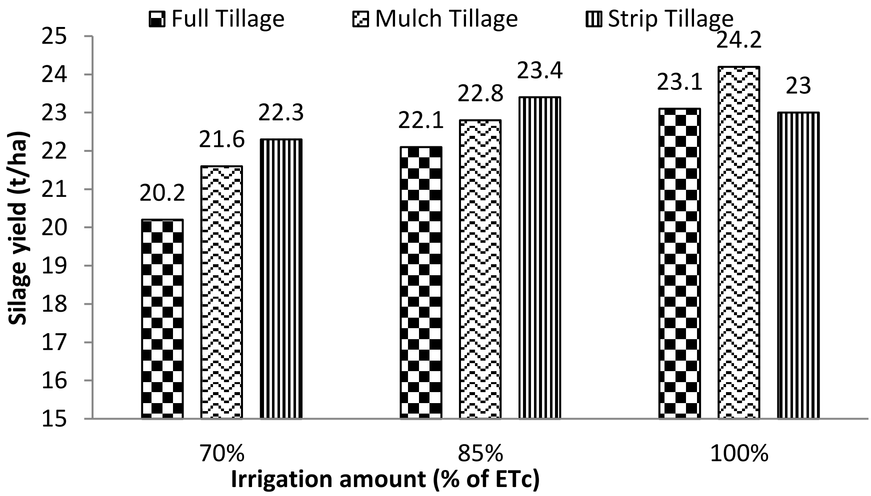

Fig (7): Average yield of corn silage under different tillage methods and irrigation regimes.

CONCLUSION

All Investigation of the moisture content data demonstrates that water content values for mulch and strip tillage practices tend to be interchangeableness in rank and that the full tillage values were the most reduced to all irrigation regimes. Aggregate moisture contents of soil in the top 40 cm of the soil profile followed the same patterns and relative positions for each treatment. Water contents of soil in the strip and the mulch practices were mostly statistically similar.

Full tillage and the reduced irrigation regime (70% ETc) were significant ($P < 0.05$) inferior for agronomic attributes of corn plants in contrast with its corresponding treatments, and that, the 100% and 85% water regimes were statistically similar for almost all parameters. Mean corn silage yields were 9.4% and 6% greater for the strip tillage practice than for the full practice with 70% and 85%ETc, respectively, but for mulch tillage the yield 4.7% greater than full tillage with 100% ETc. The results indicate that deficit irrigation was well effective when applying with strip tillage followed by mulch tillage where 15 to 30% of water can be saved.

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الملخص العربى

تحسين إدارة نظام الرى المحورى باستخدام الحراثة الموفرة للمياه

حربى مصطفى[1] ، يانو أنتر[2]

تم إجراء التجارب الحقليه فى معهد التكنولوجيا الزراعية بالمركز الفيدرالى للبحوث الزراعية بهدف دراسة تأثير استخدام الرى الناقص (١٠٠% ، ٨٥%، ٧٠% من الاحتياجات المائية) مع نظم الحراثة الموفرة للمياه (الحراثة العميقة – حراثة سطحية مع بقايا المحصول السابق – حراثة الشرائح مع بقايا المحصول السابق) تحت نظام الرى المحورى على توزيع الرطوبة فى التربة وكذلك انتاجية سيلاج الذرة. ولدراسة ذلك، وزعت المعاملات بنظام القطع المنشقة وثلاثة مقررات. أوضحت النتائج أنه لم يكن هناك تأثير معنوى للمعاملات على توزيع الرطوبة فى التربه فى عمق منطقة الجذور (٤٠ سم). المحتوى الرطوبى لنظامى حراثة الشرائح والحراثة السطحية كان متشابهاً تحت كل معاملة رى. اوضحت النتائج أيضا أن نظام الحراثة العميقة أظهر اختلافات معنويه فى القياسات الخضرية للنباتات مع استخدام الرى الناقص (٧٠%) أما الرى بمعدلات ٧٠%، ٨٥% و ١٠٠% أعطى فروق غير معنويه فى معظم القياسات مع نظم الحراثة السطحية والشرائح. متوسط انتاجية الهكتار من السيلاج ازداد بنسبة ٩.٤% و ٦% فى حالة حراثة الشرائح عن الحراثة العميقة مع الرى ب ٧٠% و ٨٥% على الترتيب، فى حين أن الحراثة السطحية مع الرى ب ١٠٠% من الاحتياجات المائية اعطت أعلى انتاجيه بزيادة ٤.٧% عن كل من نظامى الحراثة العميقة والشرائح. فى النهائيه اتضح أن استخدام الرى الناقص له تأثير إجابى فى الحفاظ على معدل الانتاجيه مع توفير مياه الرى بنسبة ١٥% و ٣٠ % تحت نظم الحراثة السطحية والشرائح مع بعض بقايا المحصول السابق على الترتيب.

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