Mesopotamia Journal of Agriculture

https://magrj.uomosul.edu.iq/

PREDICTING SOIL WATER CONTENTS UNDER SEMI-ARID CLIMATE

Khalid E. Al-Mastawi [1], Ahmed M. A. Saeed [2], Ghazwan A. Dahham [3], Mahmood H. Rafik [4]
Department of Agricultural Machines & Equipment, College of Agriculture and Forestry, University of Mosul, Iraq 1,2,3,4

Article information
Article history:
Received: 8/3/2024
Accepted: 24/12/2024
Published: 31/12/2024

Keywords:
Plowing methods, soil water contents, irrigation system.

DOI:
https://doi.org/10.33899/mja.2024.147569.1388

Correspondence Email:
khalid.allaf@uomosul.edu.iq

ABSTRACT

One of the world's critical challenges is the optimal use of water resources for agricultural production. Groundwater scarcity in semiarid conditions and still using traditional tillage systems without prior knowledge affect these tools on water consumption, tillage practices change many soil properties one of its void spaces which plays a significant role in the ability of soil water content, so the aim of this paper to study the effect of tillage methods on soil water content throughout growing season. The experiment included using Traditional Tillage methods (chisel, vertical disc, moldboard plow) and irrigation time (after tillage, after germination, after final irrigation) under two types of irrigation systems (Semi-solid system and center pivots). The data was analyzed by using the Design Expert program and the results showed a significant effect for type of irrigation system and soil tillage system in soil water content. The soil moisture content starts to increase gradually in all tillage methods until the end of the growing season and reaches to 20.14% in 20 cm depth after the final irrigation stages of the growing, soil water content depends on the type of plowing methods which reflects the way manipulation of the soil layers and as a result facilitate water irrigation to penetrate soil layers, some treatment recorded (21.04%) and other recorded (19.13%). The predicting models show significant differences with acceptable accuracy in predicting soil humidity in the growing season.

INTRODUCTION

Maize (Zea mays L.) can be classified as one of the most important cereal crops in the world, can be used as food for humans and animals and many populations in developing countries use as a source of revenue (Alkhoury; *et al.*, 2022; Ngoune and Mutengwa, 2020). In Iraq Maize is the fourth important crop after wheat, barley, and rice, it is planted in two seasons (spring and autumn). In the autumn planting season from Jun. to Oct. Maize depends on irrigation due to scarcity of precipitation. The lack of water is becoming the primary constraint for agricultural production globally. In the semi-arid zone of north Iraq, maize planting in the autumn season depends on irrigation by solid set or pivotal systems, rain has scarcely reflected on groundwater storage in the last decades, so water conservation in the growing season is critical. Nineveh is one of the most arable provinces in Iraq and produces much of the country's grain and produce however, farmers face challenges that depend on agriculture to preserve their livelihood, inappropriate government policies, rarity, and unevenness of rain (IOM, 2019). Nineveh contains arid and semi-arid zones with annual precipitation ranging from below 200 mm to above 400 mm (Jawad *et al.*, 2018). Water scarcity is defined as a shortage in water moisture content due to a lack in precipitation that causes increased transportation and evaporation from the soil (Sarker *et al.*, 2020; Alobaidy and Hesham, 2024). Now it is critical to adopt a tillage and irrigation system that sustainable water uses for maize production in north Iraq. Tillage systems affect the physical, chemical and biological environment for the soil, but their results for crop growth depend also on several interactions including climate, soil and the crop itself so different plowing regimes will have different effects on the crop growth (Patanita *et al.*, 2020).

Tillage is an important factor in controlling soil water content, tillage systems directly or indirectly affect on soil hydraulic traits such as hydraulic conductivity, water infiltration, and water preservation which are defined as the ability of the soil to pick up and retent water in rainfall or irrigation (Houshyar and Esmailpour, 2020; Indoria *et al.*, 2020; Yang *et al.*, 2018). Under primary tillage (using chisel, disk , moldboard, or vertical disk plow), as soil porosity increases the infiltration will be increased due to the re-formation of voids by tillage effects in the upper soil layers that conducts water into the other soil layers (Amami *et al.*, 2021). Irrigation systems (center pivot and solid sit) are widely used in many countries due to they allow applying a small amount of water, the Solid-set irrigation system can be more adjustable than center pivots in irrigation control, easily allowing selecting the irrigation time (day or night) and repetitions (Franco-Luesma *et al.*, 2019; Eskander *et al.*, 2020). To enhance crop growth, increase yields, and improve soil moisture content, effective tillage systems are critical (Kiboi *et al.*, 2019). Tillage practices and depth of plow play a significant role in switching the porosity and infiltration of soil surface runoff and soil water Abundance (Berhe *et al.*, 2013; Huang, *et al.*, 2021; Torabian *et al.*, 2019).

Soil's ability to relent water depends on the soil pores structure which is affected by the soil texture, organic matter, type of crop, soil tillage regimes and other factors (Steponavičienė *et al.*, 2022). There is a relation between soil water retention and pore size distribution which is directly affected by soil tillage practices (Jabro,2022), some studies detected apparent deficiency in a number of large pores in unplowed soils compared with conventionally plowed soil (Weninger *et al.*, 2019; Yahya, 2023). In contrast, Conservation tillage (reduced tillage, no-tillage, and keeping crop residues) has been suggested as an effective way to conserve soil water in dryland agriculture (Farahani *et al.*, 2022; Zhang *et al.*, 2021). Study conducted to assess the effect of no-tillage (NT) and conventional tillage (CT) systems on soil water availability found that (CT) has major impact on plant water availability (soil water retention) due soil loosening soil by various tillage tools (Jabro and Stevens, 2022). In north Iraq due to scarcity of precipitation and water resources and adoption traditional methods in cultivation, it is crucial to adopted a reliable tillage system that kept water irrigation system more penetrate soil layer and retention moisture through planting season. The aim of this research was to predicting soil water content for tillage methods which is widely use in north Iraq during corn growing season.

MATERIALS AND METHODS

The field experiment was conducted in two sites located in Talfer, Nineveh province, north Iraq, which was classified as a semi-arid zone (Ahlström *et al.*, 2015), the first site (36°18’24.2’’N °19’55.8’’E) was irrigated by the semi-solid set system and second site (36°19’30.8’’N 2°19’04.8E) was center pivot irrigation system, the distance between them 1300 m as mentioned in (Figure 1).

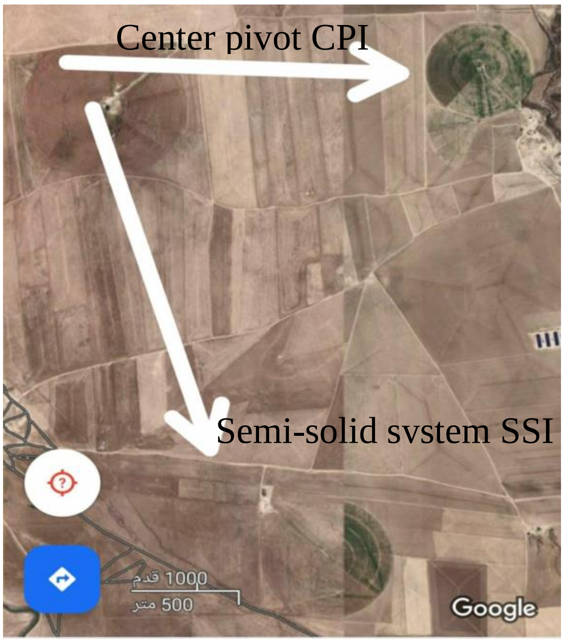

Figure (1): Site location in Nineveh province, Iraq- https://maps.app.goo.gl/urwQqxLVVXDkbnbSA

The study location climate mentioned in Table (1) was Mediterranean weather (a hot semi-arid climate) with a long period, very hot and dry summer, brief and moderate autumn, spring, and mild wet, relatively cool winter.

Table (1): Monthly climate at the experiment location in 2019 (Meteoablue weather, 2024)

Month	Mean Daily Minimum Temperature (C°)	Mean Daily Maximum Temperature (C°)	Mean Total Rainfall (mm)	Mean Number of Rain Days
Jan	2.2	12.4	62.1	11
Fab	3.4	14.8	62.7	11
Mar	6.8	19.3	63.2	12
Apr	11.2	25.2	44.1	9
May	16.2	32.7	15.2	6
Jun	21.3	39.2	1.1	0
Jul	25	42.9	0.2	0
Aug	22.2	42.6	0.0	0
Sep	19.1	38.2	0.3	0
Oct	13.5	30.6	11.8	5
Nov	7.2	21.1	45	7
Dec	3.8	14.1	57.9	10

Irrigation systems specification

Two types of irrigation systems were used in this investigation, center pivot (CPI) instilled in site 2 and semi-solid-system (SSI) in site 1. The specifications are mentioned in Table (2).

Table (2): Specification of irrigation systems

semi solid-system (SSI)		**center pivot (CPI)**	
Main line length	450 m	Total spans length	305 m
Lateral line length	120 m	Number of towers	5 spans
Intervales between lateral lines in the main line	18 m	Space between towers	61m
Space between nozzles	18 m	Space between nozzles	1.5 m
Mainline dia.	15.24 cm	Nozzle height	1.5 m
Lateral line dia.	7.62 cm	Pump discharge	187 m^3/h.
Nozzle height	180 cm		
Number of lateral lines	25 lines		
Number of nozzle in lateral line	7 nozzles		
Nozzle irrigation dia.			
Discharge irrigation	125 m3/hr.		

Plow specification

The tillage equipment used in this investigation is mentioned in Table (3) chisel, vertical, and moldboard plows are widely used in local corn cultivations.

Table (3): The specification of plows used in experiments

Chisel plow	Vertical Disc	Moldboard plow
Number of row 3 Number of chisels 11 Total working width 216cm	Number of discs 8 Number of row 2 Disc thickness 6.5 cm Total working width 172 cm	Number of bottoms 3 Body width 35cm Total working width 105cm

Soil test

Soil samples were taken from depths (0-5), (5-10), (10-15), (15-20), (20-25), (25-30), (30-35), (35-40), (45-50) cm and repeated during three periods (after tillage, after germination and final irrigation) of plant growing season in the two sites for soil moisture content test. The samples were oven-dried at 105 °C for 24 hours to reach a constant weight for calculating the humidity (Houshyar and Esmailpour, 2020). Other soil properties (texture, bulk density, penetration resistance) were analyzed according to (Dane and Topp, 2020) which is depicted in Table (4).

The investigation was established in early June in two sites, each 122 m long and 36 m wide. Every site was irrigated by one irrigation system (center pivot or semi-solid irrigation system). The experiment consisted of two factors: the irrigation system type (center pivot and semi-solid) and the tillage methods (chisel, vertical disc, moldboard plow).

Table (4): Soil test results at sites experiment

Soil properties	Site 1	Site 2
Clay %	47.6	45.5
Sand %	11.4	10.8
Silt%	41	43.7
texture	Silty clay	Silty clay
Bulk density Mg/m^3	1.527	1.551
Porosity %	41.269	39.576
Penetration resistance kg/cm^2	4.458	4.331

First of all the field was irrigated to reach suitable moisture content for tillage operation (15-18%) (Ahmadi and Mollazade, 2009). Three types of conventional tillage (chisel plow, vertical disc, moldboard plow) were used in this investigation. Tillage operation was conducted from 10-20 cm depth and total treatments were 18. To estimate soil water content during the growth season, soil samples were taken from different depths through soil profiles (0-5,5-10,10-15,15-20,20-25,25-30,30-35,35-40,40-45,45-50) at three different times (after tillage, after germination, after final irrigation), Design-Exper software was used to analyze all data and build up the mathematical model to predict the SWC (soil water content) in different plant growth stages.

RESULTS AND DISCUSSION

Soil water contents were measured at different periods of the corn growing season, including after tillage (land preparation), seed germination, and final irrigation in the two sites presented in Figures 2 and 3. It was noticeable that SWC started to increase in the upper layer until it reached the highest value of more than 15 % in soil depth 20 cm for vertical disc and tended to decrease in soil lower layer and recorded the lowest value of less than 7 % in 40 cm depth for the vertical disc in site irrigated by SSI, in Figure 3 which depicted the soil water content in the site which irrigated by CPI which is shown the same influence in site 1, the ability of soil to hold water depending on many influences which can be classified to factors related to weather such temperature and humidity other factors related to the soil such as texture, organic matter, aggregate and residue coverage. The type of irrigation system affects the ability of water to penetrate the soil layer. The tillage system works on soil in different modes depending on the tool used; the moldboard plow cuts and reverses the soil layer, whereas the chisel plow penetrates the soil without reversing the soil layer as the vertical disc.

In Figures 4 and 5, it depict the SMC after the germination stage which reflects the ability of plowed soil to reserve water during the plant growth stage. In Figure 4 and Figure 5 measured SWC rates in all plots were initially high in the upper layers compared to the last stage and start declined gradually toward lower in the deep soil layers which are out of irrigation system target due to the effects of tillage on the upper layer more than in the down soil layer. In this stage we can see that SMC little bit increased in site CPI compared to site SSI, especially after 15 cm depth, all the treatments that were tilled in the CPI site showed higher water retention than others in SSI site which were used the same types of equipment and this agreement with

(Sandin *et al.*, 2017) which mentions that soil water retention varied significantly with tillage systems in terms of time and space.

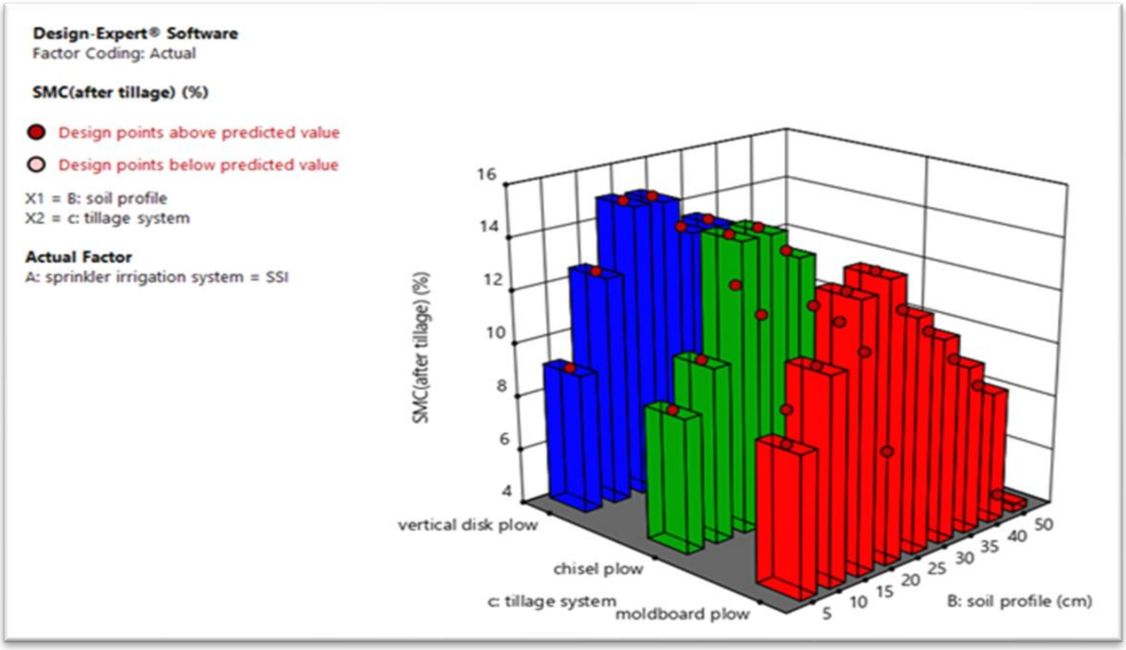

Figure (2): Effect of plowing method on soil moisture content in site SSI after tillage stage

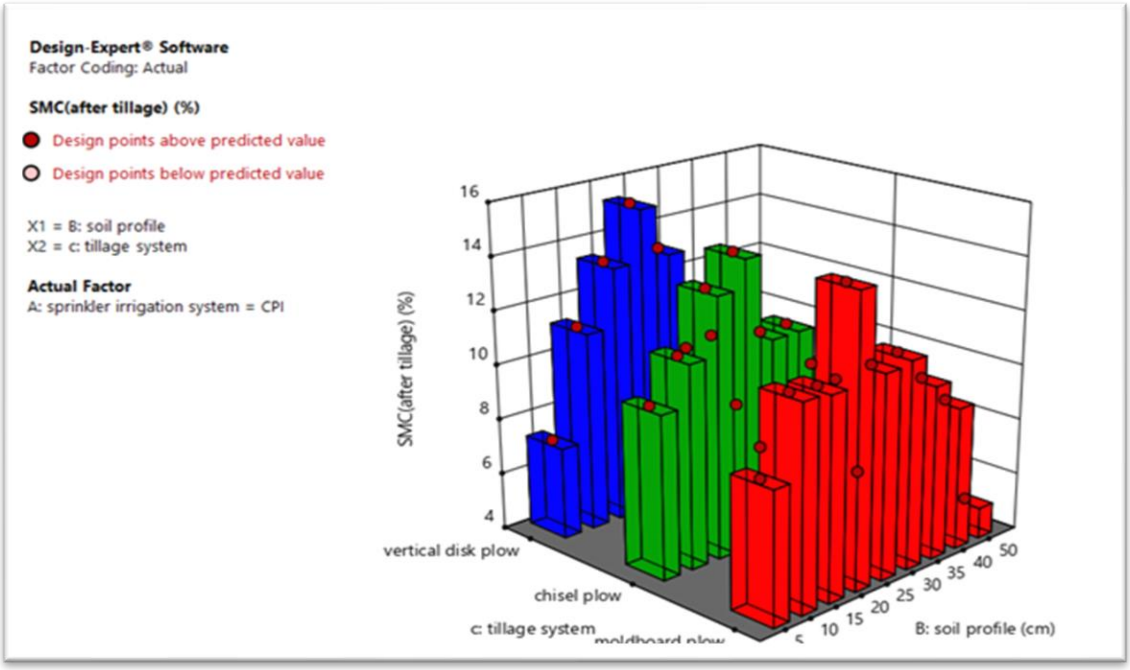

Figure (3): Effect of plowing methods on soil moisture content in site CPI after tillage

The vertical disc shows the highest ability to conserve water than a chisel and moldboard plow in the two sites, in general, tillage-caused fluctuations in pore size distribution switch the characteristics of the distribution of functional porous groups (Steponavičienė *et al.*, 2022) also manipulation such as plowing and subsoiling reorder soil particles physically, break the connective pores, and switch pore size distributions, which directly changes the soil water content (Zúñiga *et al.*, 2019).

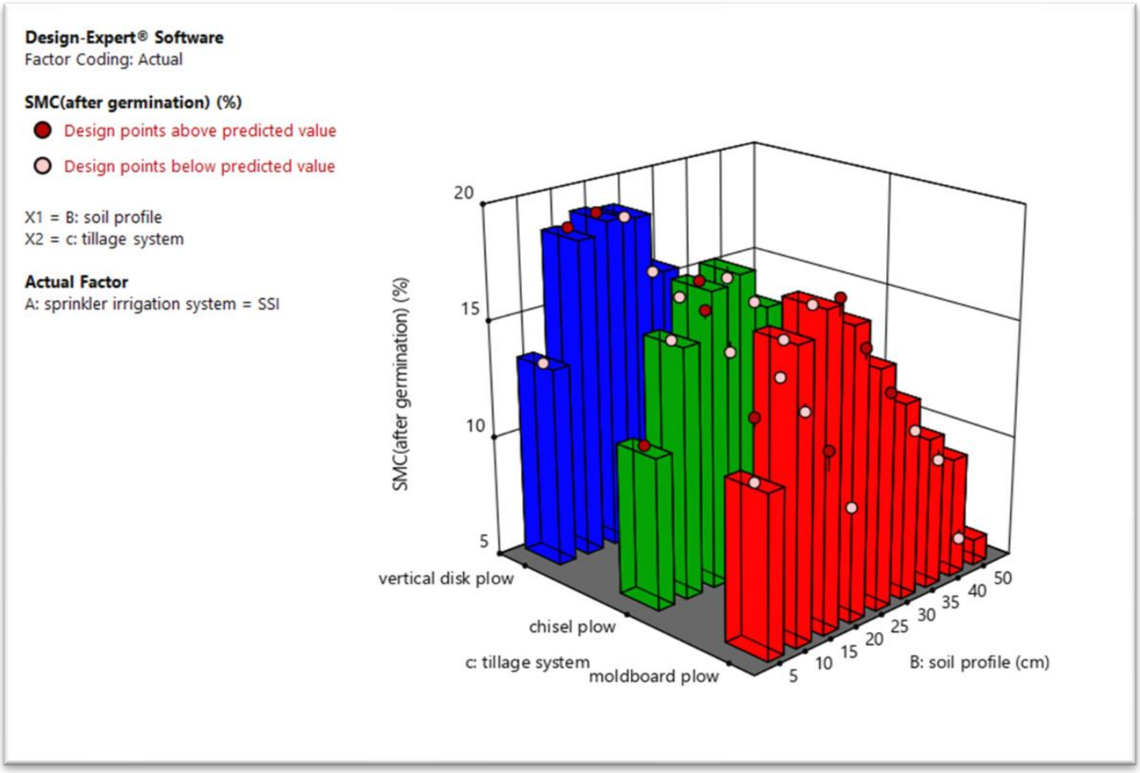

Figure (4): Effect of plowing method on soil moisture content in site SSI after germination

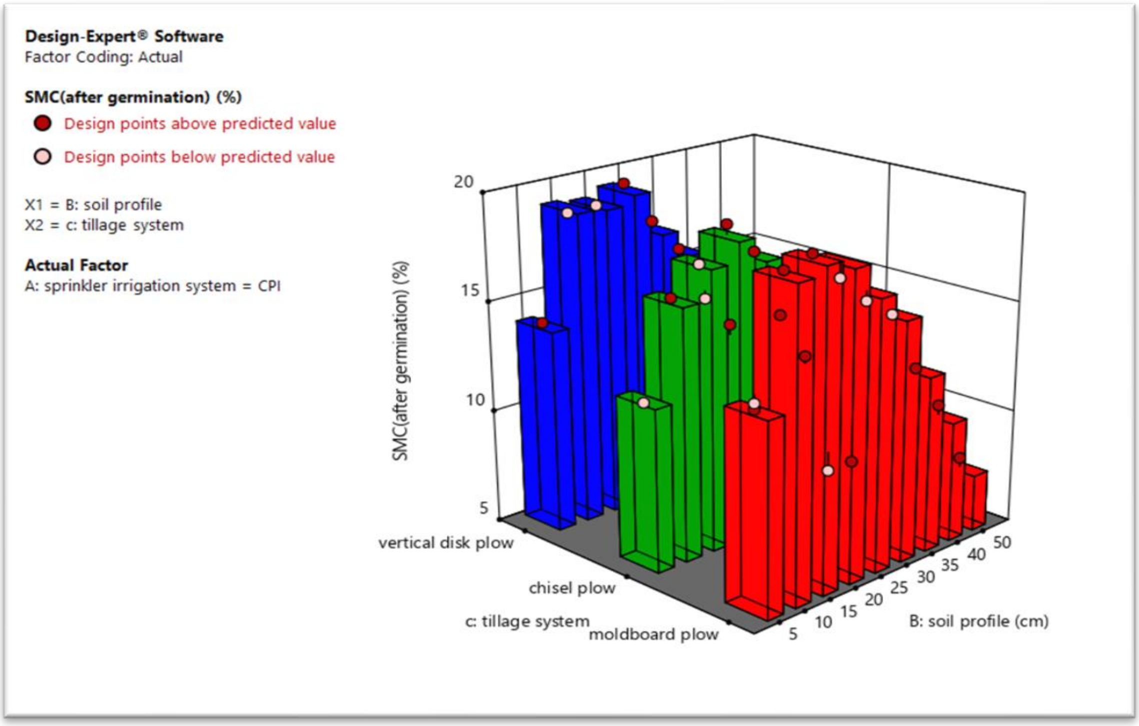

Figure (5): Effect of tillage method on soil moisture content in site CPI after germination stage

In Figures 6 and 7, which depicted soil water content after the final irrigation stage in the end of the growing season, the effect of tillage and irrigation system was more evident, SMC was higher values compared with after the germination stage in two sites where still highest in CPI site, the averages of SMC for CPI site were higher than SSI site, this due to the advantages of CPI compared with other irrigation systems (Baiamonte, 2022). Also, there are variations in SMC values between the tillage system in the different depths especially between the chisel and moldboard plow and vertical disc in the SSI site as opposite in the previous figure (after tillage, after germination). In Figure 6 all the plows used to tillage the CPI site saved the highest SMC than the SSI site, in all past stages of growth, the plots that were plowed by vertical disc recorded the highest SMC than other plots plowed by chisel of moldboard plow, this due to the vertical disc is loosening soil in relatively vertical lines with a minimal soil aggregate disturbance which enhance water-holding capacity (Zeng *et al.* , 2021), (Chen *et al.*, 2016). Also, plots plowed by chisel plow showed a high ability to hold water after final irrigation compared with moldboard plow, these results agree with (Parkhomenko *et al.*, 2020) were clarified that tillage equipment for soil cultivation in arid or semi-arid conditions should not bring the deeper layers to the surface of the soil because this leads to the loss of humidity since it's evaporated.

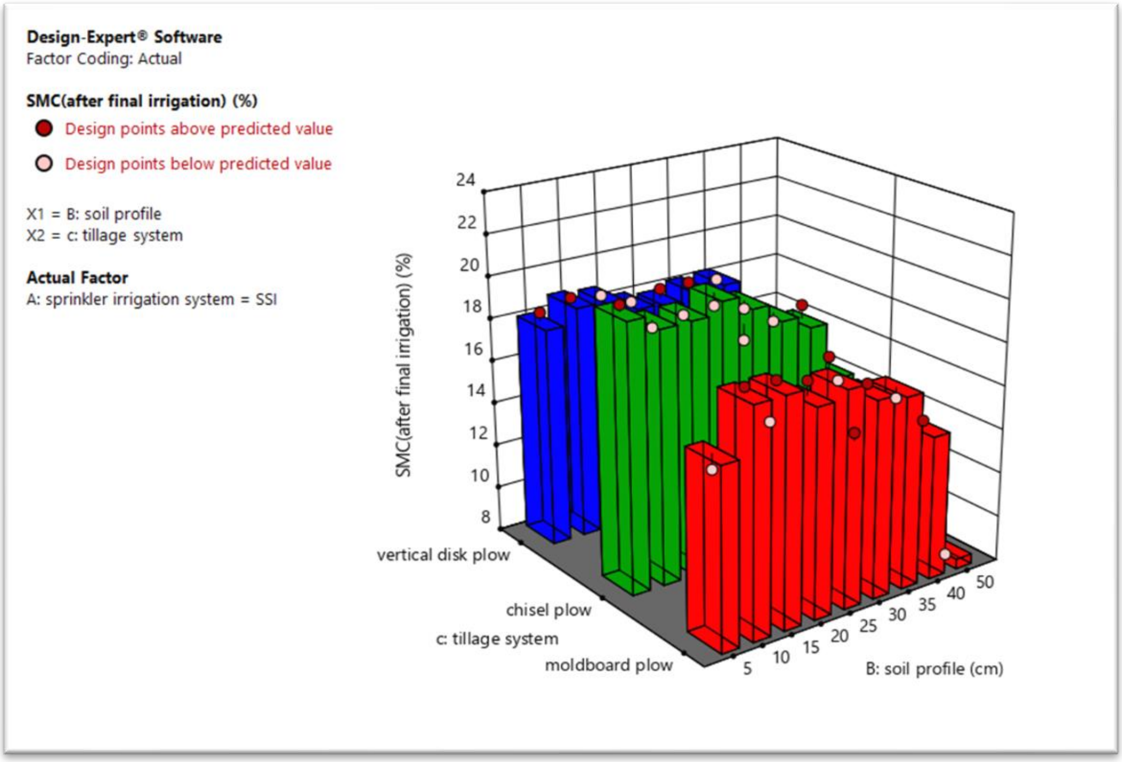

Figure (7): Effect of tillage method on soil moisture content in site SSI after final irrigation

The relationship and modeling between irrigation system, tillage depth, tillage system, and SMC

Due to a lack of data about soil water moisture through the growing season in Iraqi semi-arid areas, it is crucial to make a simplified methodology to determine SMC in different stages of the growing season. (Hilal *et al.*2022; Hilal *et al.* 2023). Figure (8) shows the resulting models (liner, 2FI, quadratic) the values of R^2 are 0.986, 0.973, 0.989 respectively which means that model does well for SMC equations. Also, the linear relationship between the predicted (Pred. R^2) and actual

(Adj. R^2) showed higher significant differences at $p < 0.0001$. The F-Values model 20.40, 57. 83 and 26. 09 and the corresponding p-value less than 0.05 show that these conditions are significant in this model. It is noticeable that the difference between Adj. R^2 values and Pred. R^2 in the 2FI model is 0.2 so the Pred. R^2 Agrees with Adj. R^2 values.

Table (4): Mathematical models for soil water content in different growing stages

MODEL	F-Value	*p*-Value	R^2	Adj. R^2	Pred. R^2	Std. Dev.
Model 1	20.40	<0.0001	0.986	0.9171	0.9781	0.0811
Model 2	26.09	<0.0001	0.989	0.9364	0.9832	0.0758
Model 3	26.09	<0.0001	0.989	0.9364	0.9832	0.0758

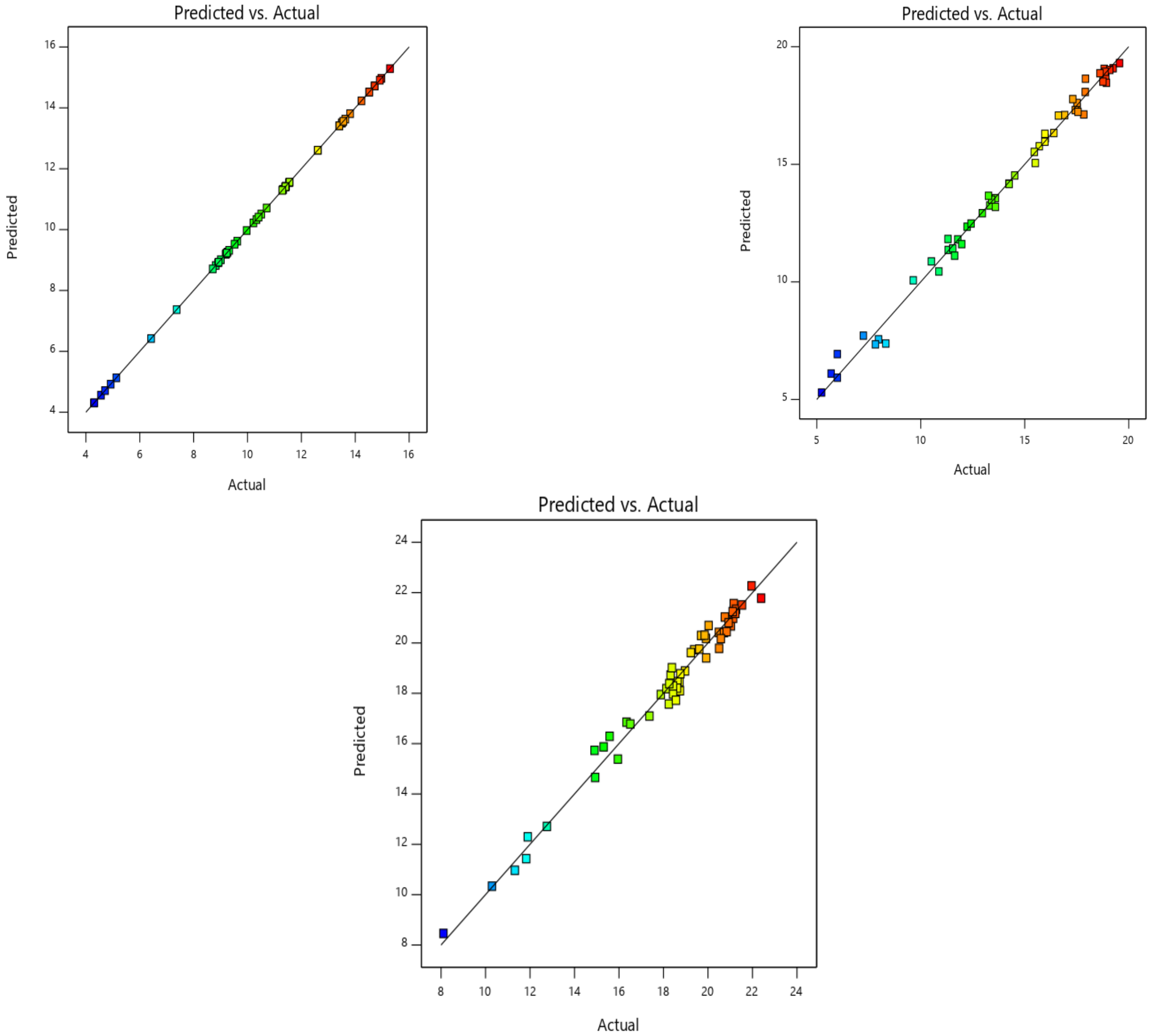

Figure (8): Model Scatter plot for Liner (A), 2FI (B), and Quadratic (C)

CONCLUSIONS

Summarizing our research results allows us to conclude that the water content in the soil is affected by how water is added to the soil (water irrigation systems), CPI irrigates soil by adding water with the smallest particles to soil than SSI this made water penetrate deeper in soil layers, on other hand plowing method have big role in facilitating water penetration through soil layer by making holes and crakes through soil layers, choosing plowing method without soil layer revers and keeping soil construction and aggregate play an effective roll in soil water conserve.

ACKNOWLEDGMENT

The authors are very grateful to the University of Mosul / College of Agriculture and Forestry for the facilities it provided, which improved the quality of this work.

CONFLICT OF INTEREST

There is no conflict of interest.

التنبؤ بالمحتوى المائي للتربة في ظل المناخ شبه الجاف

خالد عصام احمد [1]، احمد محمد امين [2]، غزوان احمد دحام [3]، محمود حسن رفيق [4]
قسم المكائن والآلات الزراعية / كلية الزراعة والغابات / جامعة الموصل / الموصل / العراق [1،2،3،4]

الخلاصة

من الامور المهمة والمحددة للزراعة في المناطق الجافة هي قلة مصادر المياه والتذبذب بالسواقط المطرية والاعتماد على نظم حراثة تقليدية من دون معرفة تأثيرها على استهلاك الرطوبة. تعد الحراثة أحد العوامل المؤثرة في خصائص وقابلية التربة على الحفظ الرطوبي، الغرض من الدراسة هو لمعرفة تأثير طرائق الحراثة التقليدية في الحفظ الرطوبي للتربة. تضمنت التجربة استخدام نظم حراثة تقليدية (محراث حفار، قرص عمودي، محراث مطرحي) و وقت الري (قبل الحراثة، بعد الانبات، بعد الرية الاخيرة) تحت نظم الري (الري شبه الثابت، والري المحوري). اظهرت النتائج تفوق معنوي لطرق الحراثة ونظم الري في الحفظ الرطوبي للتربة حيث بدء المحتوى الرطوبي بالارتفاع في كل نظم الحراثة المستخدمة حتى نهاية موسم الانبات وصل الى 20,14% عند العمق 20 سم بعد الرية الاخيرة. اظهرت نتائج البحث ان نوع نظام الحراثة المستخدم له تأثير معنوي على الحفظ الرطوبي من خلال التأثير على طبقات التربة واعادة تركيبها لتسهيل اختراق المياه لتلك الطبقات حيث سجلت بعض المعاملات محتوى رطوبي وصل الى 21,04 % و 19,13%. اظهرت معادلات تحليل التباين معنوية كبيرة حيث بالإمكان التنبؤ بالمحتوى الرطوبي خلال اي فترة من موسم النمو بدقة مقبولة.

الكلمات المفتاحية: نظم الحراثة، المحتوى الرطوبي، نظم الري.

REFERENCES

Ahlström, A., Raupach, M. R., Schurgers, G., Smith, B., Arneth, A., Jung, M., Reichstein, M., Canadell, J. G., Friedlingstein, P., Jain, A. K. (2015). The dominant role of semi-arid ecosystems in the trend and variability of the land CO2 sink. *Science, 348*(6237), 895-899. https://doi.org/10.1126/science.aaa1668

Ahmadi, H., & Mollazade, K. (2009). Effect of plowing depth and soil moisture content on reduced secondary tillage. *Agricultural Engineering International: The CIGR EJournal*, 11, 1-9. https://shorturl.at/eLuNP

Amami, R., Ibrahimi, K., Sher, F., Milham, P., Ghazouani, H., Chehaibi, S., Iqbal, H. M. N. (2021). Impacts of different tillage practices on soil water Infiltration for sustainable agriculture. *Sustainability*, *13*(6), 3155. https://doi.org/10.3390/su13063155

Alobaidy,T.S. & Hesham M.H.(2024). Predction of soil moisture charactric curve by using van genuchten model (1980) and soilpar2 for some soil at nineveh governorate. *Mesopotamia Journal of Agriculture*,52(2), 46-57. http://doi.org/10.33899/mja.2024.146131.134018

Alkhoury,S.G.Y. , Adel, A. A. , Anas O. E.(2022).Evaluating the performance of a hammer mill through using different types of locally manufactured hammers, *Mesopotamia Journal of Agriculture*, 50(3), 1-18. http://doi.org/10.33899/mja.2022.13416.1177

Baiamonte, G. (2022). Dual-Diameter Laterals in Center-Pivot Irrigation System. *Water*, *14*(15). http://doi:10.3390/w14152292

Berhe, F. T., Fanta, A., Alamirew, T., & Melesse, A. M. (2013). The effect of tillage practices on grain yield and water use efficiency. *CATENA*, *100*, 128-138. https://doi.org/10.1016/j.catena.2012.08.001

Chen, Y., Damphousse, S., & Li, H. (2016). Vertical tillage and vertical seeding. Paper presented at the Paper No. CSBE16-090. CSBE/SCGAB 2016 Annual Conference, Halifax, NS, Canada. https://goto.now/EqiBy

Dane, J. H., & Topp, C. G. Methods of Soil Analysis, Part 4: physical methods. (1 January 2020) *John & Sons*. https://shorturl.at/z5C37

Eskander H. Alqysy; Muna A. ALamadani; Sura S. Alaidham (2020). Meta – analysis for agricultural researches (review). *Mesopotamia Journal of Agriculture*,48(4), 2020,23-34. http://doi.org/10.33899/magrj.2014.88439

Farahani, E., Emami, H., & Forouhar, M. (2022). Effects of tillage systems on soil organic carbon and some soil physical properties. *Land Degradation & Development, 33*(8), 1307-1320. https://doi.org/10.1002/ldr.4221

Franco-Luesma, S., Álvaro-Fuentes, J., Plaza-Bonilla, D., Arrúe, J. L., Cantero-Martínez, C., & Cavero, J. (2019). Influence of irrigation time and frequency on greenhouse gas emissions in a solid-set sprinkler-irrigated maize under Mediterranean conditions. *Agricultural Water Management, 221*, 303-311. https://doi.org/10.1016/j.agwat.2019.03.042

Hilal, Y. Y. , Khessro, M. K. , van Dam, J. , & Mahdi, K. (2022). Automatic water control system and environment sensors in a greenhouse. *Water, 14*(7). http://doi:10.3390/w14071166

Hilal, Y. Y., EliÇIn, A. K., Sedeeq, A. M. A., & Shahin, A. A. (2023). Developing a model using neural networks to predict wheat production in the Kirkuk governorate. *Mesopotamia Journal of Agriculture, 51*(4), 106-118. https://doi.org/10.33899/mja.2023.140455.1238

Houshyar, E., & Esmailpour, M. (2020). The impacts of tillage, fertilizer and residue managements on the soil properties and wheat production in a semi-arid region of Iran. *Journal of the Saudi Society of Agricultural Sciences, 19*(3), 225-232. https://doi.org/10.1016/j.jssas.2018.10.001

Huang, X., Wang, H., Zhang, M., Horn, R., & Ren, T. (2021). Soil water retention dynamics in a mollisol during a maize growing season under contrasting tillage systems. *Soil and Tillage Research, 209*, 104953. https://doi.org/10.1016/j.still.2021.104953

Indoria, A. K., Sharma, K. L., & Reddy, K. S. (2020). Chapter 18 - hydraulic properties of soil under warming climate. In M. N. V. Prasad & M. Pietrzykowski (Eds.), *Climate Change and Soil Interactions* (pp. 473-508): Elsevier. https://doi.org/10.1016/B978-0-12-818032-7.00018-7

IOM. (2019). International Organization for Migration (IOM), Iraq, "Rural Areas in Ninewa Legacies of Conflict on Rural Economies and Communities in Sinjar and Ninewa Plains," August 2019. https://goto.now/1qFY6

Jabro, J.D. (2022). Soil-water characteristic curves and their estimated hydraulic parameters in no-tilled and conventionally tilled soils. *Soil & tillage research, v. 219*(no.), pp. 105342--102022 v.105219 no. http://doi.org:10.1016/j.still.2022.105342

Jabro, J. D., & Stevens, W. B. (2022). Pore size distribution derived from soil–water retention characteristic curve as affected by tillage intensity. *Water*, *14*(21), 3517. https://doi.org/10.3390/w14213517

Jawad, T. K., Al-Taai, O. T., & Al-Timimi, Y. K. (2018). Evaluation of drought in Iraq using DSI. by remote sensing. *The Iraqi Journal of Agricultural Science*, *49*(6), 1132. https://shorturl.at/aVHU8

Kiboi, M. N., Ngetich, K. F., Fliessbach, A., Muriuki, A., & Mugendi, D. N. (2019). Soil fertility inputs and tillage influence on maize crop performance and soil water content in the central highlands of Kenya. *Agricultural Water Management*, *217*, 316-331.https://doi.org/10.1016/j.agwat.2019.03.014

Meteoblue Weather ,Swiss, avalible at https://www.meteoblue.com/en.

Parkhomenko, G., Bozhko, I., Kambulov, S., Boyko, A., Polushkin, O., Lebedenko, V., Olshevskaya, A. (2020). Methodology and results of studying soil moisture after the interaction with the operating devices. *E3S Web Conf.,175.* https://doi.org/10.1051/e3sconf/202017509006

Patanita, M., Campos, M. D., Felix, M. D. R., Carvalho, M., & Brito, I. (2020). Effect of tillage system and cover crop on Maize mycorrhization and presence of magnaporthiopsis maydis. *Biology (Basel), 9*(3). http://doi.org/10.3390/biology9030046

Sandin, M., Koestel, J., Jarvis, N., & Larsbo, M. (2017). Post-tillage evolution of structural pore space and saturated and near-saturated hydraulic conductivity in a clay loam soil. *Soil and Tillage Research, 165*, 161-168. https://doi.org/10.1016/j.still.2016.08.004

Sarker, K. K., Hossain, A., Timsina, J., Biswas, S. K., Malone, S. L., Alam, M. K., Bazzaz, M. (2020). Alternate furrow irrigation can maintain grain yield and nutrient content, and increase crop water productivity in dry season maize in sub-tropical climate of South Asia. *Agricultural Water Management, 238*, 106229. https://doi.org/10.1016/j.agwat.2020.106229

Steponavičienė, V., Bogužas, V., Sinkevičienė, A., Skinulienė, L., Vaisvalavičius, R., & Sinkevičius, A. (2022). Soil water capacity, pore size distribution, and CO2 emission in different soil tillage systems and straw retention. *Plants, 11*(5). http://doi.org/10.3390/plants11050614

Torabian, S., Farhangi-Abriz, S., & Denton, M. D. (2019). Do tillage systems influence nitrogen fixation in legumes? A review. *Soil and Tillage Research, 185*, 113-121. https://doi.org/10.1016/j.still.2018.09.006

Weninger, T., Janis, K., Parvathy, C., Stefan J., Karl-Heinz, F., Kai, S., Gernot, B., Andreas, S. (2019). Effects of tillage intensity on pore system and physical quality of silt-textured soils detected by multiple methods. *Soil Research, 57*(7), 703-711. https://doi.org/10.1071/SR18347

Yahya, L. M. (2023). Evaluation of the performance of new rotary plow blades (t-shape) under different levels of soil moisture and plowing depths at some field indicators. *Mesopotamia Journal of Agriculture, 51*(3), 67-78. http://doi:10.33899/mja.2023.141041.1249

Yang, Y., Ding, J., Zhang, Y., Wu, J., Zhang, J., Pan, X.,He, F. (2018). Effects of tillage and mulching measures on soil moisture and temperature, photosynthetic characteristics and yield of winter wheat. *Agricultural Water Management, 201*, 299-308. https://doi.org/10.1016/j.agwat.2017.11.003

Zeng, Z., Thoms, D., Chen, Y., & Ma, X. (2021). Comparison of soil and corn residue cutting performance of different discs used for vertical tillage. *Scientific Reports, 11*(1), 2537. http://doi.org/10.1038/s41598-021-82270-9

Zhang, Y., Tan, C., Wang, R., Li, J., & Wang, X. (2021). Conservation tillage rotation enhanced soil structure and soil nutrients in long-term dryland agriculture. *European Journal of Agronomy, 131*, 126379. https://doi.org/10.1016/j.eja.2021.126379

Zúñiga, F., Horn, R., Rostek, J., Peth, S., Uteau, D., & Dörner, J. (2019). Anisotropy of intensity–capacity parameters on Aquands with contrasting swelling–shrinkage cycles. *Soil and Tillage Research, 193*, 101-113. https://doi.org/10.1016/j.still.2019.05.019