Using the Response Surface Methodology to Predict the Effect of Different Moisture Levels on the Bulk Density and Penetration Resistance of Soil Under Different Operating Conditions

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Abstract

Soil properties play a fundamental role in the success of agricultural operations through their impact on crop growth and quality, as they determine their ability to retain water and absorb nutrients, and affect soil aeration and the root system. The aim of this study is to predict bulk density and resistance to soil penetration under different moisture levels during tillage operations. It includes four moisture levels: 7, 14, 22, and 28%, and three types of plows: the moldboard plow, chisel plow, and disc plow. Moreover, soil samples were collected at two depths: 15 cm and 30 cm. The change in the physical properties of the studied soil is also measured during the growth periods of wheat crop (after tillage, beginning of the season and end of the season). The study is conducted in Al-Qurna district, north of Basra Governorate, Iraq, in clay loam soil. The results are analyzed and mathematical equations are obtained to predict the studied properties using the response surface methodology. The obtained results indicate that soil moisture during plowing, plow type, soil depth, and crop growth periods have a significant effect on soil bulk density and penetration resistance. The 14% moisture treatment is superior, recording the lowest bulk density and lowest penetration resistance of 1.12 Mg m^{-3} and 1133 kN m^{-2}, respectively. While the 28% moisture treatment provided the highest bulk density and highest penetration resistance of 1.22 Mg m^{-3} and 1379 kN m^{-2}, respectively. The results also show that increasing the soil depth from 15 to 30 cm increases the bulk density and soil penetration resistance, by 12 and 45.70%, respectively. Plowing with a disc plow improves soil properties, giving the lowest bulk density and penetration resistance of 1.12 Mg m^{-3} and 1074 kN m^{-2}, respectively. While using the chisel plow leads to recording the highest bulk density and penetration resistance, which reached 1.22 Mg m^{-3} and 1442 kN m^{-2}, respectively. As for the moldboard plow, the bulk density and soil penetration resistance reached 1.18 Mg m^{-3} and 1282 kN m^{-2}, respectively. The growth periods have a significant effect on the studied soil properties where the beginning of the growing season provided the lowest bulk density. The bulk density reached 1.17, 1.13, and 1.23 Mg m^{-3} for the periods after plowing, at the beginning of the season and its end, respectively. While the penetration resistance after plowing is superior with the lowest resistance compared to the beginning of the season and its end, as it reached 897, 1327, and 1573 kN m^{-2}, respectively. The results of data analysis show that the obtained mathematical models accurately and efficiently predict bulk density and soil resistance to penetration under the experimental conditions, with a high coefficient of determination (R^2) of 0.6460 and 0.8114 for the bulk density and penetration resistance, respectively.

Keywords: Bulk density, Moisture level, Prediction, Soil penetration resistance, Tillage equipment

Introduction

Tillage greatly affects many physical properties of soil, such as bulk density and porosity. It breaks up the soil to reduce its compaction and increase its porosity, thereby aiding in weed control and increasing crop production. However, improper tillage may lead to soil hardening and deterioration of its physical properties, which negatively affects aeration, root growth, and microorganism activity, thus reducing production. Therefore, choosing the appropriate type of tillage is essential to achieve the best productivity (Boydas & Turgut, 2007; Shabanpour, Fekri, Bagheri, Payman, & Rahimi-Ajdadi, 2022). Agricultural work greatly affects the physical properties of soil and the moisture level during tillage. Tillage under conditions of high or low moisture can lead to the formation of large soil clods and deterioration of the physical properties of soil (Shittu, Oyedele, & Babatunde, 2017). On the other hand, tillage contributes to improving the physical properties of soil, such as reducing bulk density, increasing porosity, and improving soil resistance to penetration.

Bulk density is an important physical property of soil, and it is greatly affected by tillage and moisture level. According to a study by Nassir (2018), the optimum soil moisture content of 16.47% achieved the best results for bulk density (1.16 Mg m^{-3}) and soil penetration resistance (678.57 kN m^{-2}), compared to moisture levels of 10.23% and 24.68%, which resulted in bulk density of 1.36 and 1.20 Mg m^{-3} and penetration resistance of 788.16 and 835.86 kN m^{-2}, respectively. Ahmadi and Ghaur (2015) showed that soil bulk density increases with soil moisture at 12, 15, 17, 19, and 21%. Soil compaction is influenced by various factors, such as tractor movement across the field, the number of passes made, the type of tillage employed, the inherent properties of the soil, and its moisture content during tillage. Soil compaction is usually expressed in terms of bulk density, porosity, or soil resistance to penetration (Javadi & Spoor, 2006; Rashidi, Tabatabaeefar, Keyhani, & Attarnejad, 2007). According to Ahmadi and Mollazade (2009), tillage at 13-15% soil moisture reduced soil resistance to penetration by 40%, whereas at 15-18% moisture, the reduction was only 4.9%. Soil resistance to penetration depends on soil type, water content, clay content, bulk density, soil depth, and tillage system. Tillage equipment has a significant impact on soil physical properties, such as bulk density and penetration resistance (Naderi-Boldaji, Azimi-Nejadian, & Bahrami, 2024; Tahmasebi, Gohari, Sharifi Malvajerdi, & Hedayatipour, 2023). A study by Kostić, Rakić, Savin, Dedović, and Simikić (2016) showed that the type of tillage affects the bulk density of soil, with density being 1.50, 1.47, and 1.45 Mg m^{-3} for the moldboard plow, chisel plow, and disc plow, respectively. Bulk density increases with increasing soil depth due to higher soil strength, with bulk density ranging from 1.33 to 1.38 Mg m^{-3} when the depth increases from 15 to 50 cm (Salim, Almaliki, & Nedawi, 2022).

Soil penetration resistance is an indicator of soil hardness, as soil with high resistance can hinder root spread, lead to waterlogging, and decrease aeration, which negatively affects crop growth. Therefore, tillage operations are carried out to break up the soil and reduce penetration resistance, which promotes root spread and improves soil physical properties (Kuroyanagi, Kaneko, Watanabe, Fujita, & Odahara, 1997). Several studies have shown that tillage reduces soil penetration resistance compared to no tillage (Hajabbasi, 2010; Kahlon, Lal, & Varughese, 2013), and that the plow contributes to increased penetration resistance compared to other conventional tillage methods. In addition, increasing tillage depth increases soil penetration resistance (Biberdzic *et al*., 2020; Dekemati *et al*., 2019; Kuhwald *et al*., 2016).

Neural networks have been used in several studies on agricultural tillage equipment to predict energy requirements and evaluate the performance of tillage equipment based on variables such as moisture, tillage depth, and plow type (Almaliki, Himoud, & Al-Khafajie, 2019), showing high agreement with field experimental data. This method is fast, accurate, and low-cost compared to conventional methods. Therefore, these techniques can be used to predict soil properties under different conditions. Neural networks have also been used to predict soil disintegration during tillage and its effects on water movement, bulk volume, water drainage, moisture content, and soil bulk density (Taghavifar & Mardani, 2014). The tillage process is influenced by both the type of plow used and the soil moisture content at the time of tilling. Given that assessing soil properties after tillage and throughout the growing season can be both labor-intensive and costly, this research seeks to predict two critical soil characteristics—bulk density and penetration resistance. These factors are essential indicators of tillage quality and favorable growth conditions. This study will investigate the impact of varying moisture levels on soil conditions, utilizing three types of plows including moldboard, chisel, and disc and examining two soil depths of 15 cm and 30 cm. Measurements will be taken at three key intervals: immediately after tillage, at the start of the growing season, and at its conclusion.

Materials and Methods

Field experiments

The field experiment was conducted in Al-Qurna district in Basra governorate in Iraq on clay loam soil. The work began with determining the moisture content of the soil at plowing by experimenting with enclosing a certain area of the soil and flooding it with water, then samples are taken every two days to measure the change in soil moisture. Based on the data obtained, the required moisture levels for the experiment are determined. The field is divided into four sectors, each with an area of 1600 m^2, and each sector is irrigated at different intervals according to the specified moisture levels, which are 7%, 14%, 22%, and 28% (depending on the limits of plasticity). Three types of plows are used for each sector: a three-furrow moldboard plow with a working width of 1 m, a three-furrow disc plow with a working width of 1.0 m, and a chisel plow with 11 shanks arranged in three rows with a working width of 2.2 m. Plowing speed of 3.06 km h^{-1}. Soil samples are taken to measure the apparent density and penetration resistance after plowing at two depths of 15 and 30 cm. After preparing the field for cultivation, it is divided into 36 experimental units. Each unit area is 12 m^2 (6 × 2 m), suitable for using four moisture levels, three types of plows, and three replicates for each treatment. The field is planted with wheat (*Triticum aestivum* L.) of the research variety 22. Soil samples are collected after plowing, at the beginning of the growing season, and at the end of the season before harvest to evaluate the changes in the studied physical properties during the season.

Table 1- Primary soil properties

Characteristics	Bulk density ($Mg\ m^{-3}$)		Penetration resistance ($kN\ m^{-2}$)		Electrical conductivity ($ds\ m^{-1}$)		Cohesion ($kN\ m^{-2}$)		Adhesion ($kN\ m^{-2}$)
	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	
1	1.42	1.44	1700	1800	14.98	14.96	10.7	10.78	0.0867
2	1.11	1.25	1200	1333	13.3	7.55	5.34	6.99	0.1263
3	1.24	1.28	1066	1133	10.71	7.36	7.71	8.75	0.1362
4	1.35	1.45	820	850	3.66	9.03	9.58	9.92	0.304

Studied characteristics

Bulk density

Bulk density is measured by taking undisturbed soil samples using a core sampler, following the method described by Black, Evans, White, Ensminger, and Clark (1965). The soil samples are weighed before drying, then dried in an oven at a temperature of 105°C until a constant weight is reached. Bulk density (ρb) is calculated using Equation (1):

$$\rho_b = \frac{M_S}{V} \quad (1)$$

where: ρ_b = Bulk density of the soil (Mg m^{-3}); M_S = Mass of the solid particles (Mg); V = Total volume of the soil, which is the volume of the cylinder (m^3).

Soil penetration resistance

To assess soil penetration resistance, we utilize a Dutch-made field cone penetrometer from Eijkelkamp Agrisearch Equipment. This device applies variable pressure vertically onto the soil surface, and each treatment is tested using three replicates. The cone index (CI) is calculated mentioned in ASABE Standards (2009) as:

$$Cone\ Index\ (CI) = \frac{Penetration\ force}{Cone\ base\ area} \quad (2)$$

where Cone Index (kN m^{-2}); Penetration force (kN); Cone base area (m^2).

Mathematical model

The response surface methodology is used to develop mathematical models and analyze data to predict the bulk density and soil penetration resistance. In this study, 216 experiments are conducted, including the use of three types of tillage machines (moldboard plow, chisel plow, and disc plow), four moisture levels (7%, 14%, 22%, and 28%), and three crop growth stages (after tillage, beginning of the season, and end of the season), and measurements are made at two different soil depths. The study aims to develop accurate models for the bulk density and soil penetration resistance to evaluate the effect of these factors on soil properties during the growing season.

Results and Discussion

Bulk density

The results of the statistical analysis are shown in Table 2, demonstrating a significant effect of soil moisture on the bulk density of the soil. Figure 1 shows that the bulk density of the soil increases with increasing moisture content from 7% to 28%. Soil with 14% moisture exhibited the lowest bulk density, measuring 1.12 Mg m^{-3}, while soil with 7% moisture had a slightly higher density of 1.17 Mg m^{-3}. While there is no significant difference between the moisture at 22% and 28%, as the bulk density reached 1.20 and 1.22 Mg m^{-3}, respectively. The superior bulk density achieved by the soil at 14% moisture is due to the improvement of the mechanical properties of the soil, such as reduced cohesion and adhesion, which facilitated the disintegration of the soil during plowing, thus reducing its apparent density. As for the moisture content of 22% and 28%, the cohesion and adhesion of the soil increased, which led to soil compaction and an increase in its bulk density. This is in line with the results of the study by Nassir (2018), which indicated that higher moisture levels lead to increased soil cohesion.

Table 2- Analysis of variance for the effect of study factors on the bulk density of soil

Source	Sum of squares	df	F-Value	p-value (Prob > F)
Model	2.85	19	18.82	< 0.0001
A-Moisture content	0.15	1	19.45	< 0.0001
B-Depth	1.19	1	150.89	< 0.0001
C-Growing season	0.40	2	25.38	< 0.0001
D-Plow type	0.38	2	24.19	< 0.0001
AB	0.025	1	3.12	0.789
AC	1.647E-003	2	0.10	0.9011
AD	0.018	2	1.15	0.3175
BC	0.55	2	34.75	< 0.0001
BD	0.087	2	5.51	0.0047
CD	0.016	4	0.50	0.73771

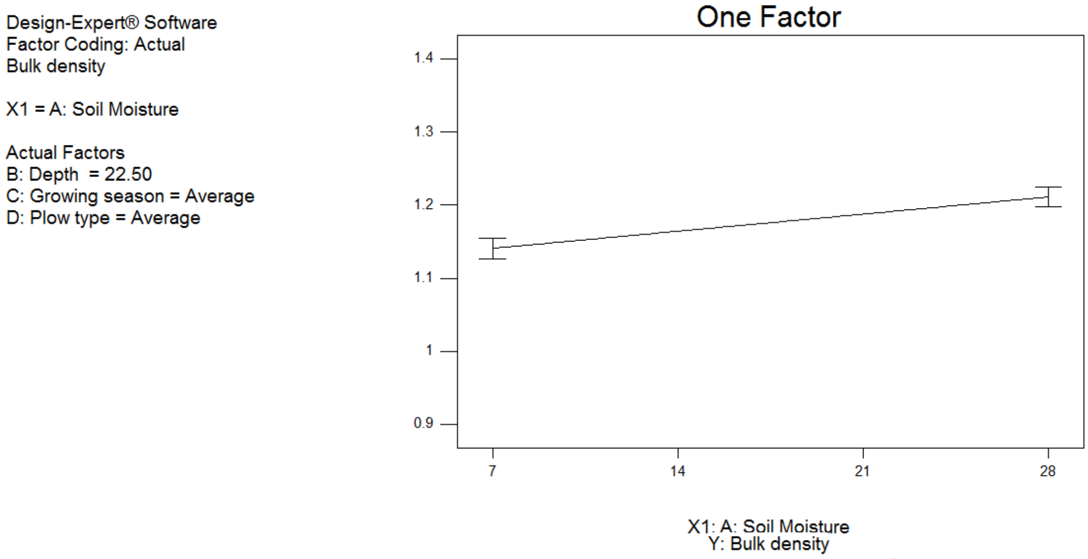

Fig. 1. Effect of soil moisture on the bulk density of soil (Mg m^{-3})

Figure 2 and the variance analysis table (Table 2) show that soil depth has a significant effect on bulk density. At a depth of 15 cm, the lowest bulk density was observed, measuring 1.10 Mg m^{-3}, in contrast to the 30 cm depth where the density increased to 1.25 Mg m^{-3}. This difference is due to the effects of tillage, crop growth, and root spread at a depth of 15 cm, which contributes to soil loosening and helps reduce bulk density. In contrast, the depth of 30 cm is relatively far from the root zone, and smoothing equipment did not reach it, which led to an increase in soil density at this depth. These results are consistent with the findings of Salim *et al*. (2022), where they found that the bulk density of soil increases with increasing depth from 15 to 50 cm, ranging between 1.33 and 1.38 Mg m^{-3}.

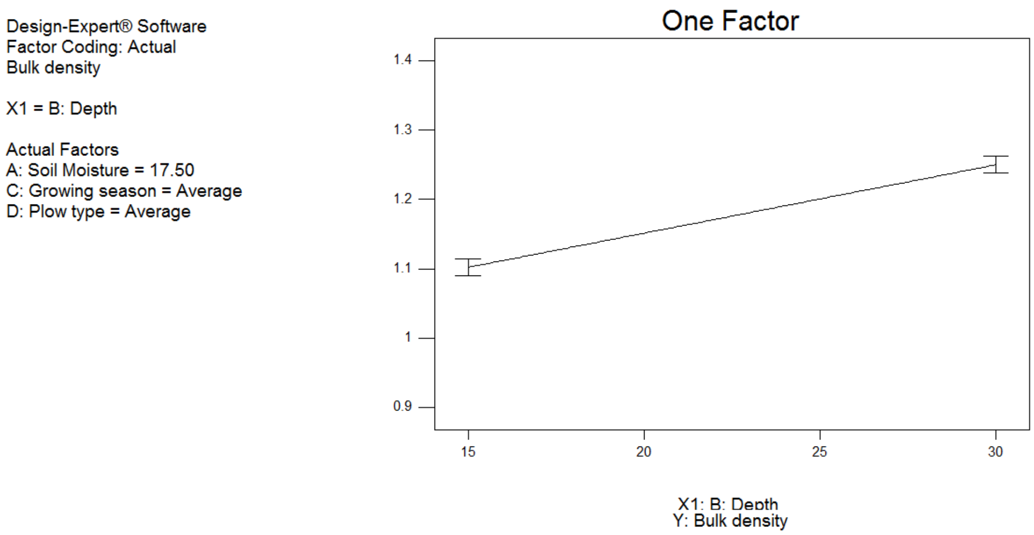

Fig. 2. Effect of soil depth on soil bulk density (Mg m^{-3})

The crop growth periods clearly affect the bulk density of the soil. As shown in Table 2 and Figure 3, the growth period has a significant effect on the change in bulk density. The soil recorded the lowest bulk density at the beginning of the growing season, reaching 1.13 Mg m^{-3}, while this density increased to 1.23 Mg m^{-3} at the end of the season. After the plowing process, the density reached 1.17 Mg m^{-3}. The decrease in density at the beginning of the season is due to the effect of smoothing and leveling processes carried out after plowing, in addition to the spread of crop roots, which contributed to reducing the bulk density. On the other hand, the bulk density increased at the end of the growing season as a result of repeated irrigation processes, which led to the movement of soil particles and their settlement in the pores, in addition to the stability of the soil over time. The bulk density following plowing is higher than at the start of the season, because the soil surface remains uneven from the plowing process. These results are consistent with the findings of Shabanpour *et al.* (2022), where an increase in the bulk density of the soil is observed after harvest compared to the beginning of the growing season.

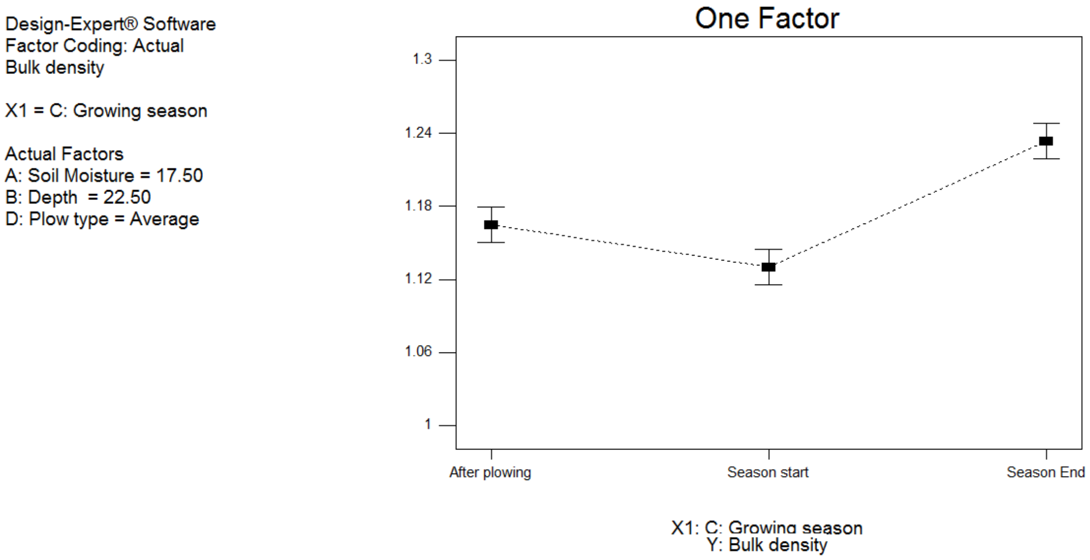

Fig. 3. Effect of growth periods on soil bulk density (Mg m^{-3})

The results of the statistical analysis in Table 2 show a significant effect of the type of plow on the bulk density of the soil. As shown in Figure 4, plowing with a disc plow recorded the lowest bulk density of 1.12 Mg m^{-3}, which is attributed to the nature of the disc plow's work, which is characterized by its ability to work in different field conditions. As it works to split and loosen the soil by rotating the discs, which leads to raising, turning, and loosening the soil. In contrast, the moldboard plow recorded a higher density of 1.18 Mg m^{-3}, due to its method of operation that depends on turning the soil using the plow, which leads to an increase in the weight applied to the soil and the formation of more cohesive blocks compared to the disc plow. As for the chisel plow, it recorded the highest bulk density of 1.23 Mg m^{-3}, due to its work on splitting the soil without turning it, which leads to loosening the soil locally and increasing its density compared to the reversible plows. These results are consistent with those of AbdulSada and Almaliki (2023).

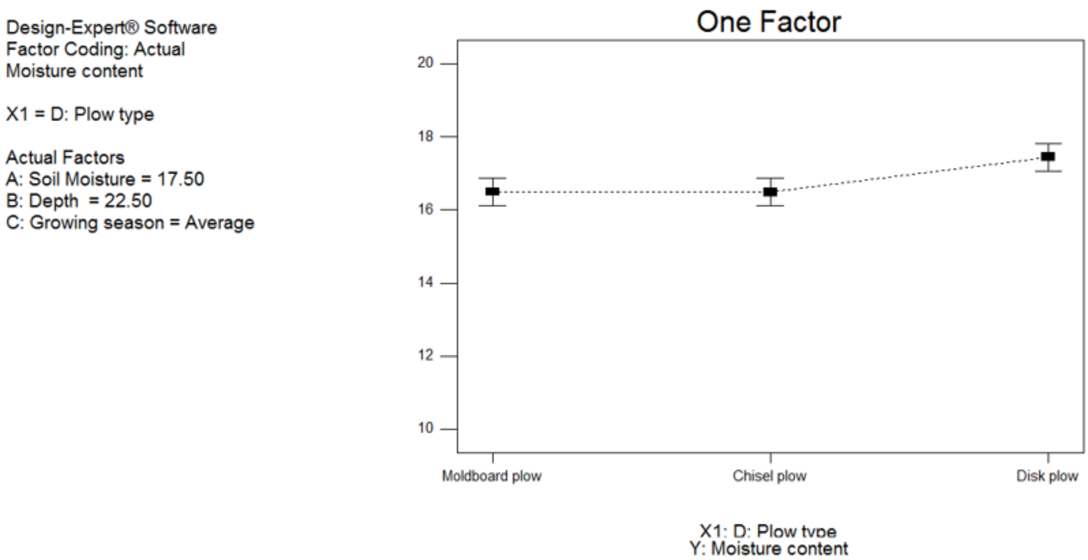

Fig. 4. Effect of plow type on soil bulk density (Mg m^{-3})

The analysis presented in Table 2 indicates that there are no significant effects arising from the interactions between soil moisture and soil depth, soil moisture and growth periods, or soil moisture and plow type. Additionally, there is no significant interaction between growth periods and plow type with respect to bulk density. However, the results in Table 2 and Figure 5 indicated that there is a significant effect on the interaction between soil depth and growth periods on the bulk density. The depth of 15 cm at the beginning of the growing season recorded the lowest bulk density of 0.99 Mg m^{-3}, while the depth of 30 cm at the beginning of the growing season recorded the highest bulk density. There is no significant difference between the depth of 15 cm and the depth of 30 cm at the end of the growing season, where the density reached 1.28 and 1.26 Mg m^{-3}, respectively.

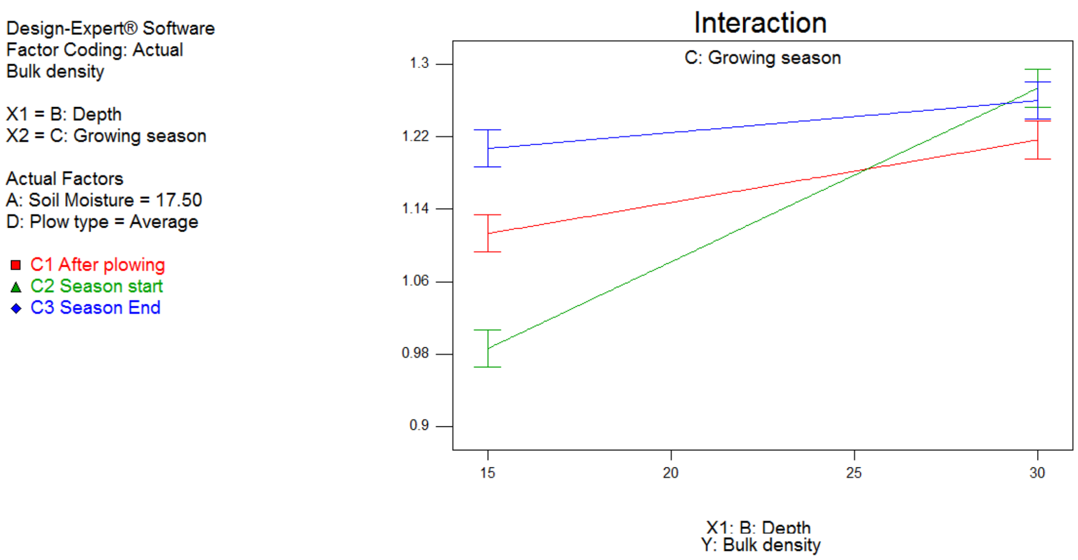

Fig. 5. Effect of the interaction between growth periods and soil depth on the bulk density of soil (Mg m^{-3})

The results of the statistical analysis show a significant effect on the interaction between the type of plow and soil depth. As shown in Figure 6, plowing with a disc plow at a depth of 15 cm recorded the lowest bulk density of 1.07 Mg m^{-3}, without a significant difference compared to plowing with a moldboard plow at the same depth (1.08 Mg m^{-3}). On the other hand, plowing with a chisel plow at a depth of 30 cm recorded the highest bulk density, with measurements of 1.29 Mg m^{-3}. This value was not significantly different from that obtained with a moldboard plow at the same depth, which reached 1.28 Mg m^{-3}.

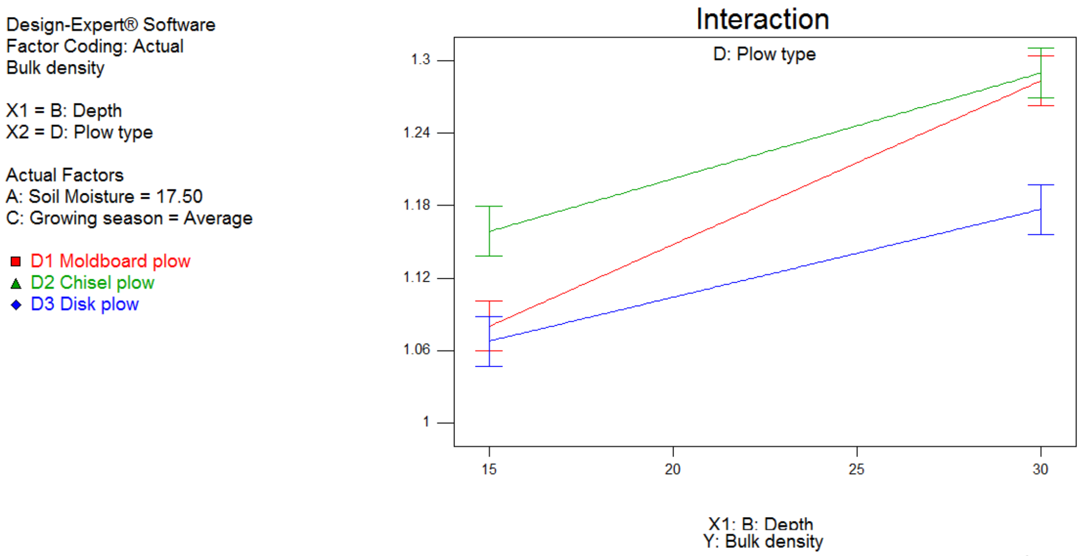

Fig. 6. Effect of interaction between plow type and soil depth on soil bulk density (Mg m^{-3})

Table 3 shows the mathematical models for each plow during the crop growth periods to predict the bulk density of the soil under different field conditions. Through these equations, the bulk density of the soil can be predicted by entering the variables of soil moisture and soil depth.

Table 3- Equations for predicting bulk soil density depending on the type of plow and growing season periods

Measurement time	Plow type	Bulk density equation
After plowing	Moldboard	0.94716 − 1.30326E-003 × Soil moisture + 7.44398E-003 × Depth + 1.79299E-004 × Soil moisture × Depth
	Chisel	1.08638 + 4.07646E-004 × Soil moisture + 2.63842E-003 × Depth + 1.79299E-004 × Soil moisture × Depth
	Disc	1.05377 − 2.40310E-003 × Soil moisture + 1.17546E-003 × Depth + 1.79299E-004 × Soil moisture × Depth
Start of the growing season	Moldboard	0.63644 − 8.87002E-004 × Soil moisture + 0.019731 × Depth + 1.79299E-004 × Soil moisture × Depth
	Chisel	0.76336 + 8.23900E-004 × Soil moisture + 0.014925 × Depth + 1.79299E-004 × Soil moisture × Depth
	Disc	0.73159 − 1.98685E-003 × Soil moisture + 0.013462 × Depth + 1.79299E-004 × Soil moisture × Depth
End of the growing season	Moldboard	1.09289 − 4.52339E-004 × Soil moisture + 4.08287E-003 × Depth + 1.79299E-004 × Soil moisture × Depth
	Chisel	1.18898 + 1.25856E-003 × Soil moisture − 7.22686E-004 × Depth + 1.79299E-004 × Soil moisture × Depth
	Disc	1.19387 − 1.55219E-003 × Soil moisture − 2.18565E-003 × Depth + 1.79299E-004 × Soil moisture × Depth

Soil penetration resistance

The results of the analysis of variance given in Table 4 display a significant effect of soil moisture on soil resistance to penetration. As shown in Figure 7, the soil recorded the lowest resistance to penetration at 14% moisture, reaching 1133 kN m^{-2}. The resistance increased at soil moistures of 7%, 22%, and 28%, reaching 1257, 1294, and 1379 kN m^{-2}, respectively. The decrease in resistance at 14% moisture is due to the decrease in soil strength and resistance as a result of reducing molecular cohesion and cohesion of water films in the brittle state of the soil at this moisture, which makes the cohesion between soil particles weak and easy to disintegrate and penetrate. In contrast, resistance increases at 7% moisture due to the increase in molecular cohesion, which enhances the strength and resistance of the soil to penetration. As for moistures of 22% and 28%, the increase in resistance is due to the increase in cohesion resulting from water films and soil pressure resulting from the overlap of its particles and the blockage of pores, which increases the soil resistance to penetration. These results are consistent with those of Ahmadi and Mollazade (2009), who found that soil moisture between 13% and 15% reduced soil resistance to penetration by 40%.

Table 4- Analysis of variance for the effect of study factors on soil resistance to penetration

Source	Sum of squares	df	F-Value	p-value (Prob > F)
Model	6.177E+007	19	44.37	< 0.0001
A-Moisture content	7.501E+005	1	10.24	0.0016
B- Depth	3.032E+007	1	413.79	< 0.0001
C-Growing season	1.686E+007	2	115.04	< 0.0001
D-Plow type	4.895E+006	2	33.41	< 0.0001
AB	12585.54	1	0.17	0.6790
AC	3.117E+006	2	21.27	< 0.0001
AD	1.875E+005	2	1.28	0.2804
BC	4.614E+006	2	31.49	< 0.0001
BD	3.113E+005	2	2.12	0.1223
CD	7.023E+005	4	2.40	0.0517

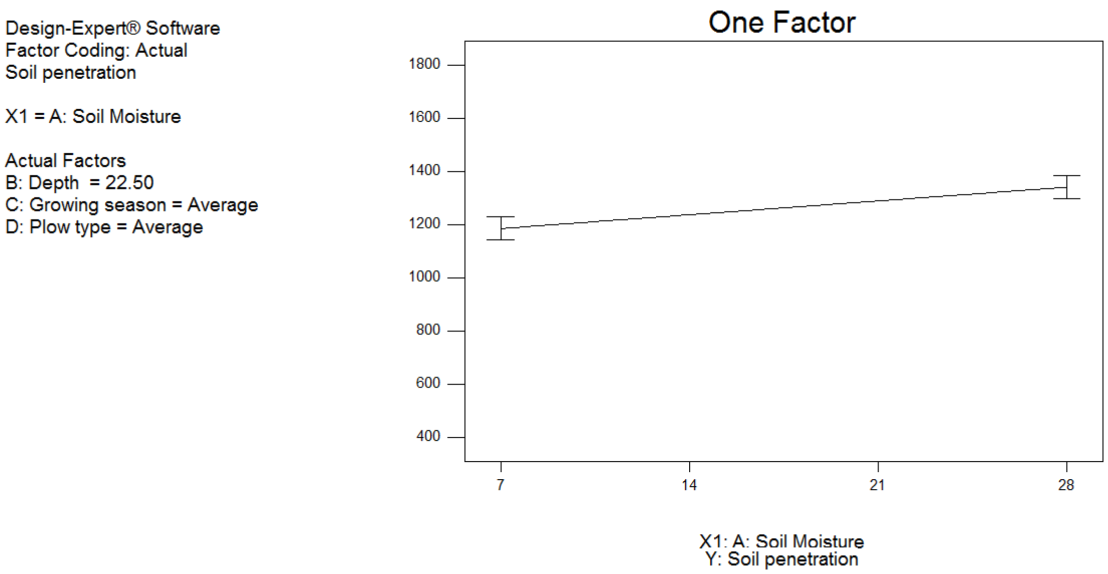

Fig. 7. Effect of soil moisture on soil resistance to penetration (kN m^{-2})

The analysis results given in Table 4 illustrate a significant effect of soil depth on soil penetration resistance. As shown in Figure 8, soil penetration resistance increases with increasing soil depth from 15 to 30 cm, where the resistance reached 891 and 1641 kN m^{-2}, respectively. This is attributed to the increase in soil strength and cohesion with depth, in addition to the effect of smoothing and root spread processes at a depth of 15 cm, which reduces soil density and thus reduces its penetration resistance. These results are consistent with the findings of Amin *et al.* (2014), who found that soil penetration resistance increases with increasing soil depth.

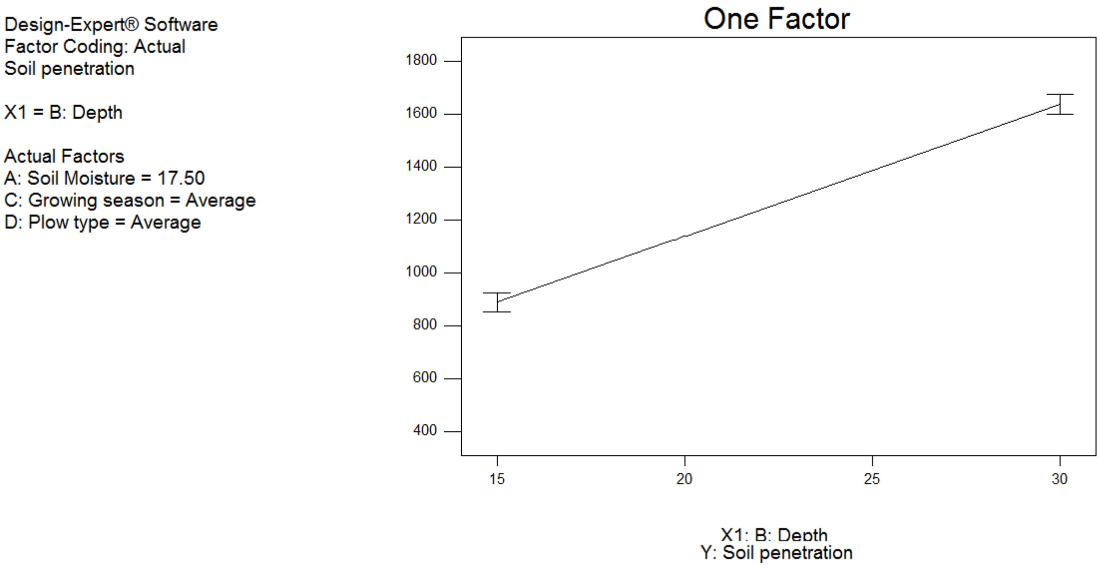

Fig. 8. Effect of soil depth on soil resistance to penetration (kN m^{-2})

The effect of crop growth period on soil penetration resistance is significant, as given in Table 4 and Figure 9. The results show that the lowest penetration resistance is recorded after the tillage process, reaching 897 kN m^{-2}. As the growth period progressed, the resistance increased at the beginning and end of the season, reaching 1327 and 1573 kN m^{-2}, respectively. The decrease in resistance after tillage is attributed to soil disintegration, increased porosity, and decreased density, which reduces its resistance to penetration. However, after planting and irrigation, wetting and drying increased soil density, soil aggregates were broken, and pores were clogged, resulting in increased soil penetration resistance during the growing season. These results are consistent with the findings of Martins *et al.* (2021), who observed an increase in soil penetration resistance at the end of the growing season compared to the beginning.

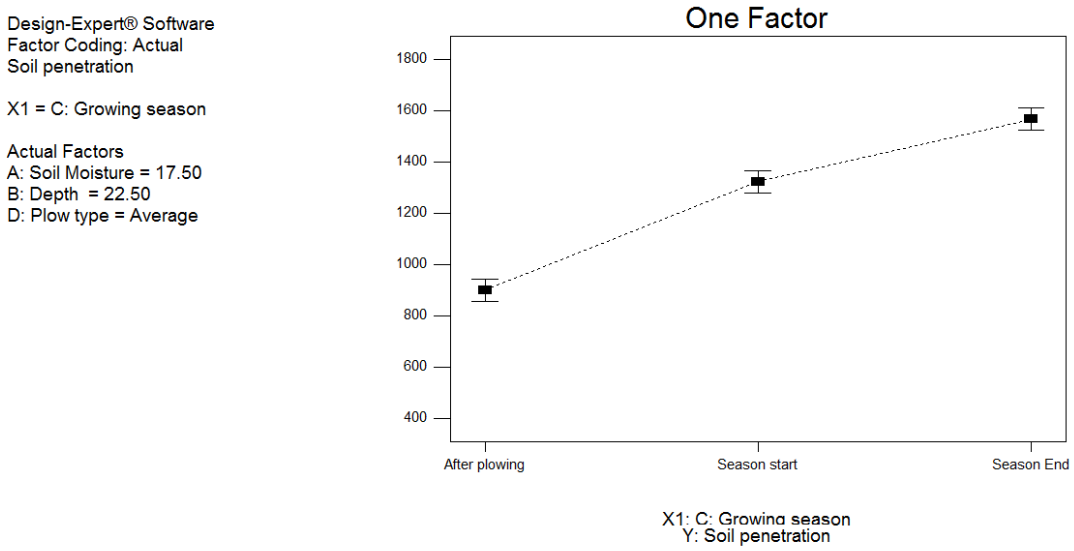

Fig. 9. Effect of growth periods on soil resistance to penetration (kN m^{-2})

The results shown in Figure 10 and Table 4 display a significant effect of the type of plow on soil penetration resistance. It is found that plowing with a disc plow under field conditions recorded the lowest penetration resistance, reaching 1074 kN m^{-2}. It is followed by plowing with a moldboard plow, which recorded a penetration resistance of 1282 kN m^{-2}, while plowing with a chisel plow recorded the highest penetration resistance, reaching 1442 kN m^{-2}. This is attributed to the fact that the disc plow contributed to reducing the bulk soil density due to its efficiency in working under field conditions compared to the moldboard plow and chisel plow. These results are consistent with what was indicated by Dekemati *et al*. (2019) and Boydas and Turgut (2007).

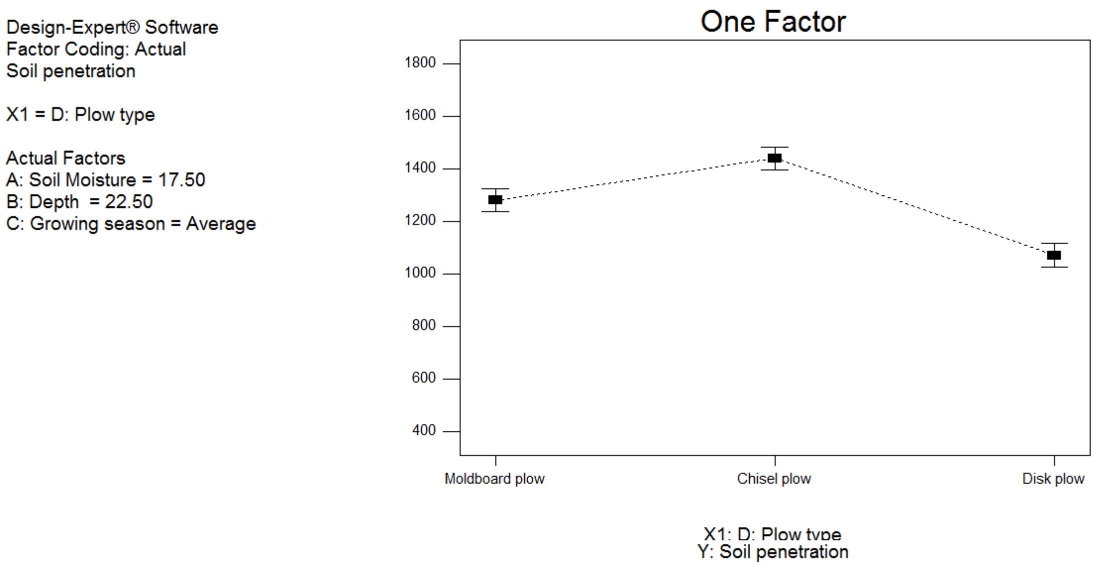

Fig. 10. Effect of plow type on soil penetration resistance (kN m^{-2})

Table 4 shows that the interaction between soil moisture and soil depth, the interaction between soil moisture and plow type, the interaction between soil depth and plow type, and the interaction between growth periods and plow type, do not have a significant effect on soil penetration resistance. However, the table shows a significant effect to the interaction between soil moisture and growth periods. As shown in Figure 11, the lowest penetration resistance is recorded at soil moisture 28% after plowing, reaching 728 kN m^{-2}, which is attributed to the high moisture content after plowing, as soil penetration resistance is inversely affected by moisture at the time of work. In contrast, the highest penetration resistance is recorded at soil moisture 28% at the end of the growing season, reaching 1871 kN m^{-2}.

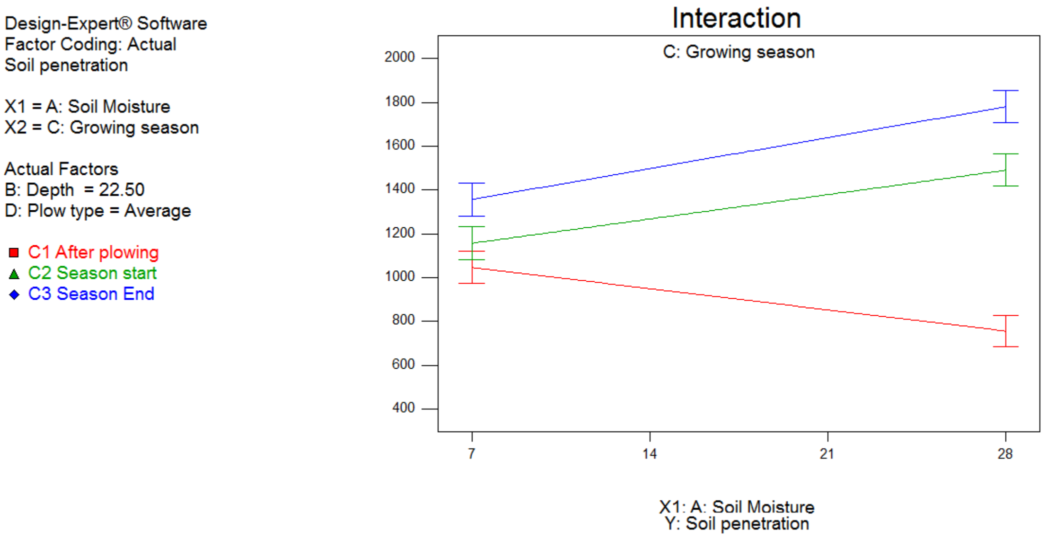

Fig. 11. Effect of interaction between soil moisture and growth periods on soil resistance to penetration (kN m^{-2})

The results of the statistical analysis in Table 4 also show that there is a clear effect to the interaction between soil depth and growth periods. It is noted from Figure 12 that the 15 cm depth treatment after plowing recorded the lowest soil penetration resistance, reaching 454 kN m^{-2}, while the 30 cm depth at the end of the growing season gave the highest penetration resistance, reaching 2083 kN m^{-2}.

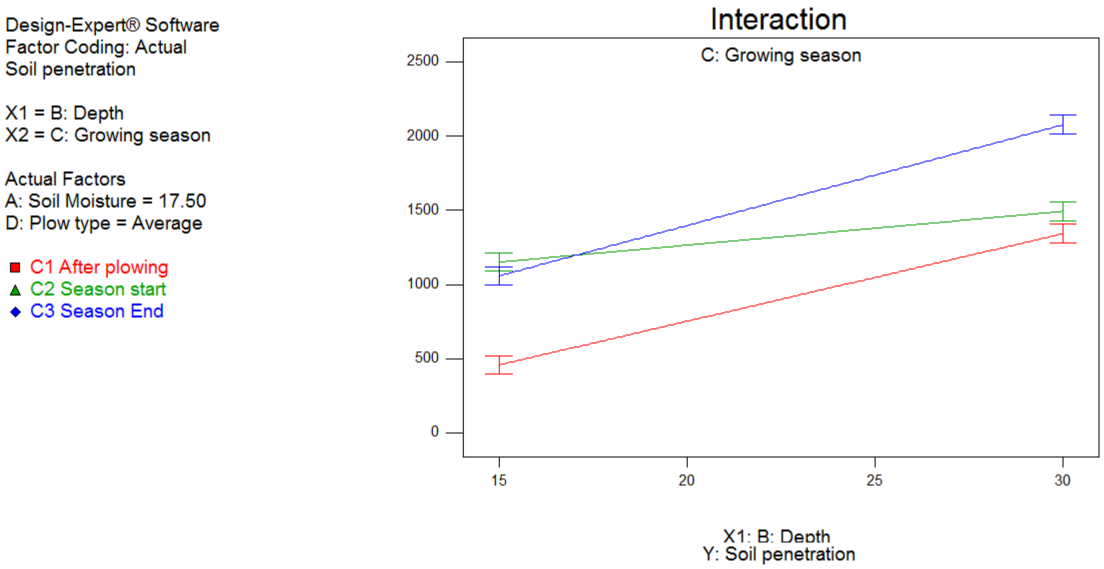

Fig. 12. Effect of interaction between soil moisture and growth periods on soil resistance to penetration (kN m^{-2})

Table 5 shows the mathematical models for each plow during the crop growth periods to predict the soil resistance to penetration under different field conditions. Through these equations, it is possible to predict the soil resistance to penetration by entering the variables of soil moisture and soil depth.

Table 5- Equations for predicting soil resistance to penetration depending on the type of plow and the growing season periods

Measurement time	Plow type	Soil penetration equation
After plowing	Moldboard	− 170.41239 − 19.80071 × Soil moisture + 59.81069 × Depth +0.12804 × Soil moisture × Depth
	Chisel	1.41900 − 18.80060 × Soil moisture + 60.92180 × Depth + 0.12804 × Soil moisture × Depth
	Disc	− 237.80372 − 11.48524 × Soil moisture + 49.67180 × Depth + 0.12804 × Soil moisture × Depth
Start of the growing season	Moldboard	585.87333 + 9.89211 × Soil moisture + 23.60699 × Depth + 0.12804 × Soil moisture × Depth
	Chisel	624.37138 + 10.89222 × Soil moisture + 24.71810 × Depth + 0.12804 × Soil moisture × Depth
	Disc	535.14867 + 18.20759 × Soil moisture + 13.46810 × Depth + 0.12804 × Soil moisture × Depth
End of the growing season	Moldboard	− 220.63425 + 14.19066 × Soil moisture + 68.65329 × Depth + 0.12804 × Soil moisture × Depth
	Chisel	− 80.05287 + 15.19077 × Soil moisture + 69.76440 × Depth + 0.12804 × Soil moisture × Depth
	Disc	− 484.90058 + 22.50614 × Soil moisture + 58.51440 × Depth + 0.12804 × Soil moisture × Depth

Conclusion

The study concludes that the use of smart computing programs such as Design Expert shows a high ability to predict the bulk density and penetration resistance of soil with great accuracy, as the coefficient of determination (R^2) reached 0.8460 for the bulk density and 0.8114 for the penetration resistance, indicating the efficiency of mathematical models in predicting soil properties compared to field results. The results show that soil moisture at 14% recorded the lowest bulk density and penetration resistance, reaching 1.12 Mg m^{-3} and 1133 kN m^{-2}, respectively, followed by soil moisture at 7%, then 22% and 28%. The disc plow also outperformed in reducing the bulk density and penetration resistance, recording 1.12 Mg m^{-3} and 1074 kN m^{-2}, followed by the moldboard and then the chisel. The results indicate that increasing the soil depth leads to an increase in the bulk density and penetration resistance by 12% and 45.70% when moving from a depth of 15 cm to 30 cm. It also shows that the beginning of the growing season is associated with the lowest bulk density of 1.13 Mg m^{-3}, followed by after tillage and end of season. While the lowest penetration resistance is recorded after tillage, reaching 897 kN m^{-2}, followed by the beginning of the season and end of season.

It is recommended that further studies be conducted on soils of different textures, under different climatic conditions, and for other crops to predict changes in soil properties during the growing season.

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Authors Contribution

M. Almoosa: Conceptualization, Data acquisition, Data pre and post-processing, Validation, Text mining, Review and editing services.

S. Al-Atab: Supervision, Methodology,

Technical advice.
S. Almaliki: Supervision, Statistical analysis, Numerical/computer simulation, Software services, Visualization.

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استفاده از روش سطح پاسخ برای پیش‌بینی تاثیر سطوح مختلف رطوبت بر چگالی ظاهری و مقاومت نفوذ خاک در شرایط عملیاتی مختلف

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چکیده

خواص خاک از طریق تاثیر بر رشد و کیفیت محصول، نقش اساسی در موفقیت عملیات کشاورزی ایفا می‌کنند، زیرا توانایی آن‌ها در حفظ آب و جذب مواد مغذی را تعیین کرده و بر تهویه خاک و سیستم ریشه تاثیر می‌گذارند. هدف از این مطالعه، پیش‌بینی چگالی ظاهری و مقاومت در برابر نفوذ خاک در سطوح مختلف رطوبت در طول عملیات خاک‌ورزی است. این مطالعه شامل چهار سطح رطوبت: ۷، ۱۴، ۲۲ و ۲۸ درصد و سه نوع گاوآهن: گاوآهن برگردان‌دار، گاوآهن قلمی و گاوآهن بشقابی است. علاوه بر این، نمونه‌های خاک در دو عمق ۱۵ سانتی‌متر و ۳۰ سانتی‌متر جمع‌آوری شدند. تغییر در خواص فیزیکی خاک مورد مطالعه نیز در طول دوره‌های رشد محصول گندم (پس از خاک‌ورزی، ابتدای فصل و پایان فصل) اندازه‌گیری می‌شود. این مطالعه در منطقه قرنه، شمال استان بصره، عراق، در خاک لوم رسی انجام شده است. با تحلیل نتایج، معادلات ریاضی پیش‌بینی خواص مورد مطالعه با استفاده از روش سطح پاسخ به‌دست آمدند. نتایج به‌دست‌آمده نشان می‌دهند که رطوبت خاک در زمان شخم زدن، نوع شخم، عمق خاک و دوره رشد محصول تاثیر معنی‌داری بر چگالی ظاهری خاک و مقاومت نفوذ دارند. تیمار رطوبت ۱۴٪ با ثبت کمترین چگالی ظاهری و کمترین مقاومت نفوذ به‌ترتیب با مقادیر ۱/۱۲ مگاگرم در مترمکعب و ۱۱۳۳ کیلونیوتن در متر مربع، تیمار برتر است. در حالی‌که تیمار رطوبت ۲۸٪ بالاترین چگالی ظاهری و بالاترین مقاومت نفوذ به‌ترتیب با مقادیر ۱/۲۲ مگاگرم در مترمکعب و ۱۳۷۹ کیلونیوتن در مترمربع را به دنبال داشت. نتایج همچنین نشان می‌دهند که افزایش عمق خاک از ۱۵ به ۳۰ سانتی‌متر، چگالی ظاهری و مقاومت نفوذ خاک را به‌ترتیب ۱۲ و ۴۵/۷۰ درصد افزایش می‌دهد. شخم زدن با گاوآهن بشقابی خواص خاک را بهبود می‌بخشد و کمترین چگالی ظاهری و مقاومت نفوذ به‌ترتیب با مقادیر ۱/۱۲ مگاگرم در مترمکعب و ۱۰۷۴ کیلونیوتن در مترمربع را دارد. در حالی‌که استفاده از گاوآهن قلمی منجر به ثبت بالاترین چگالی ظاهری و مقاومت نفوذ شد که به‌ترتیب به ۱/۲۲ مگاگرم بر مترمکعب و ۱۴۴۲ کیلونیوتن بر مترمربع رسید. در مورد گاوآهن برگردان‌دار، چگالی ظاهری و مقاومت نفوذ خاک به‌ترتیب به ۱/۱۸ مگاگرم بر مترمکعب و ۱۲۸۲ کیلونیوتن بر مترمربع رسید. دوره‌های رشد تاثیر معنی‌داری بر خواص خاک مورد مطالعه دارند، به‌طوری‌که در ابتدای فصل رشد کمترین چگالی ظاهری ثبت شد. چگالی ظاهری برای دوره‌های پس از شخم، در ابتدای فصل و پایان آن به‌ترتیب به ۱/۱۷، ۱/۱۳ و ۱/۲۳ مگاگرم بر مترمکعب رسید. در حالی‌که کمترین و مناسب‌ترین مقاومت نفوذ پس از شخم به‌دست آمد، در مقایسه با ابتدا و پایان فصل، مقادیر به‌ترتیب به ۸۹۷، ۱۳۲۷ و ۱۵۷۳ کیلونیوتن بر مترمربع رسیدند. نتایج تجزیه و تحلیل داده‌ها نشان می‌دهد که مدل‌های ریاضی به‌دست‌آمده نتایجی با دقت و کارایی بالا در پیش‌بینی چگالی ظاهری و مقاومت خاک در برابر نفوذ تحت شرایط آزمایشگاهی ارائه می‌دهند، با ضریب تعیین (R^2) بالا به‌ترتیب با مقادیر ۰/۶۴۶۰ و ۰/۸۱۱۴ برای چگالی ظاهری و مقاومت نفوذ خاک.

واژه‌های کلیدی: پیش‌بینی، تجهیزات خاک‌ورزی، چگالی ظاهری، سطح رطوبت، مقاومت نفوذ خاک

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