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OPTIMISATION AND MODELLING OF SOIL PULVERISATION INDEX USING RESPONSE SURFACE METHODOLOGY FOR DISK HARROW UNDER DIFFERENT OPERATIONAL CONDITIONS

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The study aimed to determine the optimal pulverisation index of soil for disk harrow by modelling. A mathematical model was developed using a Design-Expert software and response surface methodology. Experiments were carried out in silty loamy soil with three different levels of soil moisture content of 9.25%, 17.56%, and 22.32%, operating depths of 10 cm, 15 cm, and 20 cm, and operating speeds of 3.17, 4.85, and 5.47 km·h^{-1}. The quadratic model proposed by the Design-Expert software was statistically significant (P <0.01), with a strong correlation relationship (R^2 = 0.989) between actual and predicted soil pulverisation index values. The adequacy precision achieved at 41.84 showed the models' ability to navigate the design space. However, statistical analysis, using the *t*-test and *P*-value, showed the actual and predicted values have no significant differences in the pulverisation index of soil. The optimal soil pulverisation index (8.61 mm) was achieved with a desirability of 1.00, at a soil moisture content of 14.43%, an operating depth of 11.64 cm, and a forward speed of 5.30 km·h^{-1}. Model validation confirmed acceptability (R^2 = 0.974) and a 99% accuracy in predicting the soil pulverisation index.

Keywords: Design-Expert software; soil moisture; operating depth; forward speed; quadratic model. Model validation

Modern agriculture is witnessing significant transformations aiming to improve the efficiency of resource utilisation. Among these transformations is the issue of energy consumption in tillage operations to preparing the suitable seedbed. This aspect is considered one of the main challenges facing agriculture currently (Natsis et al., 1999). The pulverisation of soil to the extent required for the germination of seed required repeated ploughing operations by conventional ploughs and disk harrows, particularly in hard soils. The improvement of the performance of primary and secondary tillage machines required many tests to determine the suitable tillage machine for the type of soil and the size of the power source (tractor), which in turn increased production costs (Al-Hamed et al., 2014). The selection of tillage machines had to be studied in terms of operating conditions, operating width, and the degree of soil softening. Computer programs facilitated predicting the requirements of machine operation in terms of the field evaluation performance of tillage machines, such as the soil pulverisation index. Computer simulation and modelling could be used to determine the relative importance of factors in field performance without costly field tests. Computer programs for modelling have been broadly developed. Consequently, researchers have utilised these models to predict the performance of soil bed preparation equipment based on operation circumstances and type of tillage machines (Cviklovič et al., 2021; Abrahám et al., 2022; Dahham et al., 2023). The regression model created by Abbaspour-Gilandeh and Sedghi (2015) based on a fuzzy modeling method produced an R^2 of 0.787%, e of 17.6%, and RMSE of 0.706% for soil pulverisation for disk harrows. On the other hand, Al-Janobi et al. (2020) found an R^2 value of 0.68 when employing ANN models and Excel spreadsheets to estimate effective field capacity. To determine what type of agriculture machines would suit a field in terms of performance efficiency and earth pulverisation; some factors such as machine type, treatment width, speed, and operation depth need to be also considered in addition to conditions of soil such as the content of water and texture class of soil (Oduma, 2019). Agriculturalists and agronomists can take advantage of design expert software to select operating factors that optimise the performance of agriculture machines such as disk harrow, without needing to carry out the field testing, thereby decreasing lost time, costs, and the dissipation of tractors and the equipment tillage (Al-Maliki et al., 2021; Udoma et al., 2023). Based on this, the soil crushing index was forecasted using design expert software. The objective of the current investigation was to assess and model the soil pulverisation index of the disk harrow and to determine the best operating conditions for the disk harrow in silty clay soils in southern Iraq.

Material and methods

Field experiment site

The experiments were carried out in the fields of the Agricultural Research Station of the College of Agriculture, University of Basrah, situated at coordinates 47° 44′ 53″ N and 14° 33′ 30″ E in the Basrah province of Iraq. The experimental site soil is silty clay with 49% of silt, 20% of sand, 31% of clay content and flat contour, with an average soil bulk density of 1.32 Mg·m^{-3} and a porosity of 50.19%.

Field and laboratory measurements

An offset disk harrow (Table 1) was used in preparing the seedbed of soil. The three different operation depths of 10, 15, and 20 cm, speeds of 3.17, 4.85, and 5.47 km·h^{-1}, and three different soil moisture content levels of 9.25%, 17.56%, and 22.32% were used to determine their effect on the soil pulverisation index. Each treatment was replicated three times. The plot area for each experiment unit was 10 × 50 m. After the experiments, the data was collected and analysed statistically using the Design Expert software version 13.00.

Table 1 Specifications of offset disk harrow used in study

Specifications	Offset disk harrow
Number of rows	2
Types of disk	serrate in the first row and smooth in the second row
Diameter of disk	58 cm
Number of disks in two rows	24
Working width	264 cm
Disk spacing	22 cm
Mass of the disk harrow	527 kg
Tractor power	55–75 kW

Forward speed and tillage depth measurement

The operating speed in the field was determined from the time required to treat a 50 m. This procedure was repeated three times for each forward speed. The average operating speed for each repetition was then computed by dividing the length of the plot (50 m) by the time required to cover it.

The tillage depth was measured using a steel measuring tape with an undisturbed surface as a reference.

Soil moisture content

From each plot, three samples of soil were randomly collected, at soil layers of 0–10 cm and 10–20 cm. The core samples, measuring 5 cm in length and 5 cm in diameter, were used to take soil samples from the specific depths. These soil samples underwent oven-drying at 105 °C for 24 hours (until the weight was fixed). The moisture content of the soil was determined by the mass of moisture using Eq. (1) according to methods mentioned in Black (1965).

$$MC = \frac{W_{Wet} - W_{Dry}}{W_{Dry}} \cdot 100 \tag{1}$$

where: MC – moisture content (%); W_{Wet} – the wet soil sample mass (g); W_{Dry} – the dried soil sample mass (g)

Soil pulverisation index determination

Soil samples were collected randomly with three replicates for each tillage treatment by disk harrow after 20 days of air drying to determine the soil pulverisation index (PI). The primary metric for evaluating the degree of soil pulverisation involved measuring the mean weight diameter (MWD) of soil clods resulting from tillage practices. The soil samples after drying were transmitted into the laboratory. The soil samples were sieved in the laboratory by a set of eight sieves with different mesh sizes (100, 70, 50, 35.7, 25, 12.50, 7.5, and 1.75 mm). The sieve analysis was executed using an electrical sieve. The soil pulverisation index was obtained from Eq. (2) (Nassir et al., 2022).

$$PI = \frac{\sum Wi \cdot d}{W_{total}} \tag{2}$$

where: PI – pulverisation index (mm); W_i – the soil mass between two sieves (kg); W_{total} – the total mass weight (kg); d – the average sieves size (mm)

Experimental design

In this study, three levels – three factors of complete factorial design were adopted. It included three factors carried out at three levels of soil moisture content of 9.25%, 17.56%, and 22.32%, three ploughing depths of 10, 15, and 20 cm, and three forward speed levels of 3.17, 4.85, and 5.47 km·h^{-1}. A central composite response design that generates 36 observations was conducted for each experimental unit according to Eq. (3) (Umani et al., 2019).

$$N = 2^x + 2x + C_p \tag{3}$$

where: N – the number of test runs; x – test factors; C_p – a centre point

When the figures for each of the studied factors were obtained, an array of statistics was assessed (Table 2). To assess the soil pulverisation index (mm), independent parameters including ploughing depth, ploughing speed, and moisture content were employed. The study was performed using a randomised technique with three replications of centre points used to calculate a fit and a terse error estimate.

Table 2 The experiment design based on codes, levels, and the experimental variables

Factors	Unit	Symbols	Codes and levels		
			-1	0	1
Soil moisture content	%	A	9.25	17.56	22.32
Operating depth	m	B	10	15	20
Forward speed	km·h^{-1}	C	3.17	4.85	5.47

Response surface methodology (RSM)

As per the definition, RSM is a statistical technique that is commonly used in experimental design and experimental factor optimisation. The Design Expert software, Version 13.0 was employed to analyse the research. To start with, this program simplified the process of designing and analysing data, optimising experimental parameters, and constructing models that aimed at evaluating soil pulverisation index of disk harrow. With regards to how the disk harrow works in relation to soil pulverisation index, there were a variety of mathematical models applied. It is from these models therefore that we selected model families which included cubic, quadratic, linear, and two factorial interaction (2F1) models. These models underwent a matching process by mathematical formulas using experimental results from each stage of the investigation. This provides an evaluation of the data collected using the RSM as an effective tool for evaluating complex relationships between variables. Accordingly, this procedure entails looking for a quadratic polynomial equation employing Design Expert tool as denoted by Eq. 4 (Oduma et al., 2023). Hence, those operational characteristics related to various factors affecting on soil pulverisation index can be systematically analysed through such a procedural method.

$$y = \lambda_{0.} + \sum_{i=1.0}^{2} \lambda i fi + \sum_{i=1}^{2} \lambda ii fi^2 + \sum_{i=1.0}^{2} \sum_{j=i+1.0}^{2} \lambda ij\, fifj \quad (4)$$

where: y – the responding variable; $\lambda_{0.}$ – constant; $\sum_{i=1.0}^{2} \lambda i$ – the collection of the coefficient of linear terms; $\sum_{i+1.0}^{2} \lambda ii$ – the collection of quadratic terms; $\sum_{i.=1.0}^{2} \sum_{j=1.0+1.0}^{2} \lambda ij$ – coefficient interaction terms collection; $fifj$ – variable (independent)

Design Expert software

Stat-Ease developed a computer software called Design Expert that assisted in forecasting tillage machinery performance and helped in designing and analysing experiments. Upon the conclusion of the practical part of the study and the acquisition of required data, the subsequent phase involves the initiation of data processing using the Design Expert software version 13.0 (Stat-Ease Inc., Minneapolis, MN, USA). By contrasting the field experiment findings' response value with the Design Expert software prediction, the optimisation data is validated. The coefficient of determination (*R*2) indicates the validity of polynomial equation selecting models, and the *F*-test and *p*-value assess the significance of regression coefficients (Almaliki, 2018).

Results and discussion

The tillage practices were carried out at three levels of soil moisture content (9.25%, 17.56%, and 22.32%) with an operating depth of 10, 15, and 20 cm and three levels of forward speed (3.17, 4.85, and 5.47 km·h^{-1}). Figure 1 presents the results of the soil pulverisation index for the disk harrow. The results showed that the highest soil pulverisation index value of 40.53 mm (indicating low soil pulverisation) was recorded at the highest soil moisture content, and operating depths of 22.32% and 20 cm, respectively, and the least forward speed of 3.17 km·h^{-1}. Conversely, the lowest soil pulverisation index value of 10.44 mm (indicating high soil pulverisation) was recorded at a medium soil moisture content of 17.56%, the lowest operating depth of 10 cm, and the highest forward speed of 3.17 km·h^{-1}. The variation in the values of the soil pulverisation index with soil moisture content can be attributed to two important factors. The first factor is soil cohesion, where the cohesion force between soil particles is higher in dry soil. This, in turn, makes the process of breaking down soil aggregates into smaller particles more difficult. The second factor is the adhesion of soil. In the case of wet soil, the fragmentation of soil aggregates into smaller clods is considered highly challenging due to the increased adhesion of soil to the disks of a disk harrow. As a result, there is an increase in the size of soil aggregates, which leads to an increase in the value of the soil pulverisation indexin both cases. These results agree with the findings of Nassir (2018), who found that the soil moisture content of 16.47% recorded the highest soil pulverisation index values compared to the soil moisture content of 10.23 and 24.68% by 18.75 and 21.28%, respectively. In general, the soil pulverisation index values decreased (high soil pulverisation) with increasing operation speed. This can be explained by the fact that at high operation speeds, soil blocks accelerate more and collide with one another, breaking up into smaller pieces. This has an apparent effect on increasing the pulverisation of soil. These findings were consistent with those of Muhsin (2017), who reported that the increasing forward speed from 2.54 to 5.77 km·h^{-1} led to a rise in the soil pulverisation index value by 10.89%. However, the increase in operating depth leads to a rise in the soil pulverisation index values (indicating low soil pulverisation). This escalation in the soil pulverisation index can be attributed to the expanding volume of manipulated soil with increasing operating depth. Additionally, the soil exhibits high resistance to loosening due to the heightened strength of soil adhesion and cohesion at greater operating depths, resulting in elevated soil pulverisation index values. This is in agreement with Alwen (2019), as the soil pulverisation index increased from 14.88 to 21.44 mm when the ploughing depth was increased from 15 to 20 and 25 cm.

Validation of the model

A quadratic model was suggested by the Design Expert software to predict the effect of moisture content, operating depth, and forward speed on the soil pulverisation index (Table 3). The *P*-values, *F*-values, the coefficients of determination (R^2), adjusted R^2, predicted R^2, and Adeq Precision statistics for the soil pulverisation index are shown in Table 4. The model equation's adequacy was verified using the coefficient of regression, or R^2. The soil pulverisation index had a high R^2 value of 0.98. The suggested model confirmed that the prediction of the experimental data was perfectly satisfactory and thereby applied to the soil pulverisation index.

"Adeq Precision" measures the signal-to-noise ratio, with a noise ratio greater than 4 considered desirable. Table 4 shows that the soil pulverisation index of disk harrows had a noise ratio of more than 4. The noise ratio

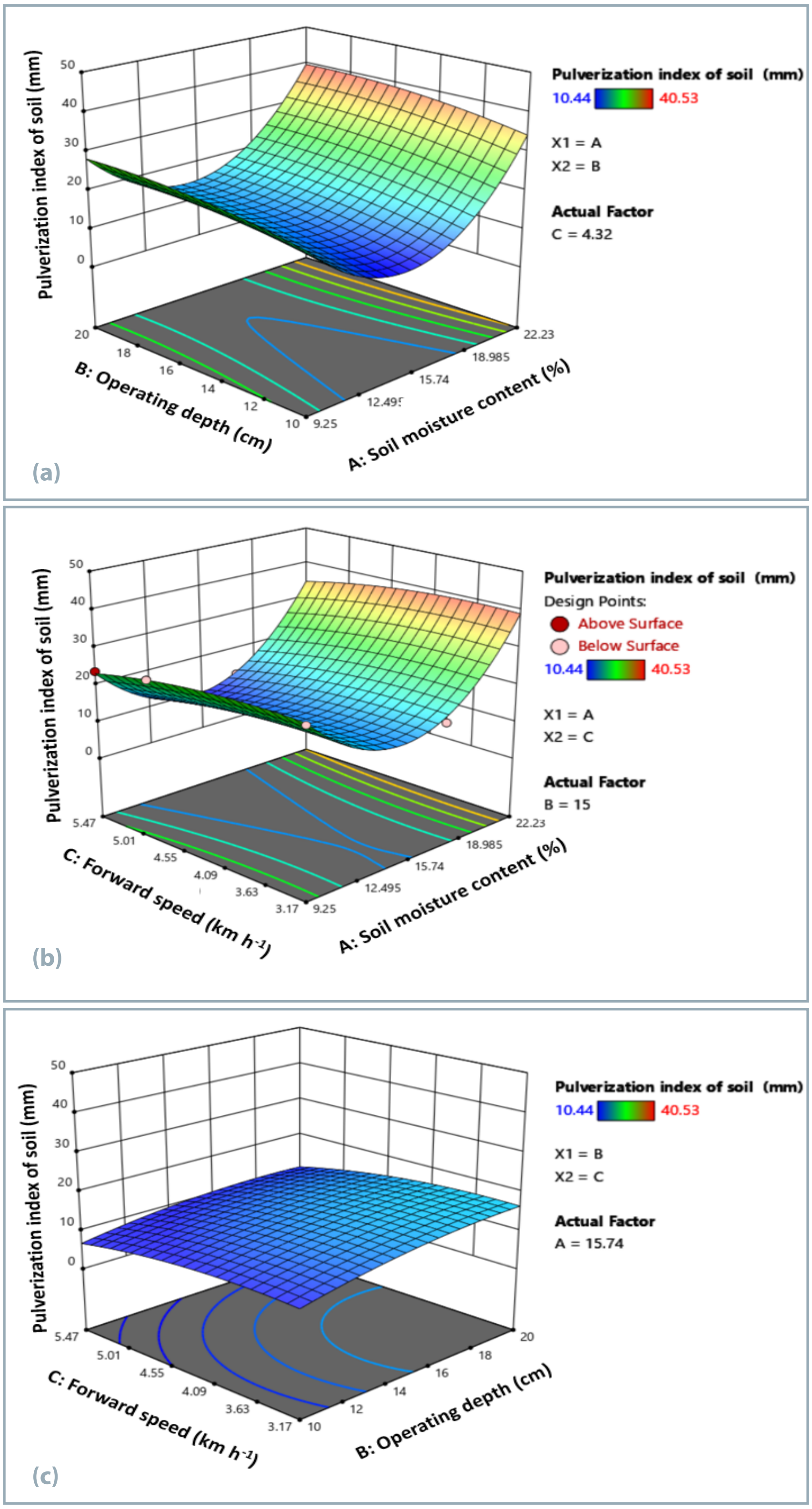

Fig. 1 The 3D plot of response surface for the optimisation of tillage operation of the soil pulverisation index (mm) for the disk harrow (a – effect of soil moisture content and operating depth on the soil pulverisation index, b – effect of soil moisture content and forward speed on the soil pulverisation index, c– effect of operating depth and forward speed on the soil pulverisation index)

of the soil pulverisation index for the disk harrow recorded a value of 41.84, indicating an adequate signal (more than 4) (Lenth, 2009). This model can be used to navigate the design space. Also, the predicted R^2 is in reasonable agreement with the adjusted R^2; the difference between them is less than 0.20. In contrast, the soil pulverisation index achieved values of the difference between predicted R^2 and adjusted R^2 that were less than 0.20. A significance level of 95% was used. The soil pulverisation index for disk harrows had *p*-values less than 0.05, as shown in Table 3. This means the quadratic models of the parameters are significant. The software is also used to conduct tests for the lack of fit, model coefficient significance, and the suitability of the regression models. In order to comprehend the pattern of the reciprocal interactions between the test variables, the *P*-values were utilised to assess each coefficient's significance. The significance of the associated coefficient increases with increasing *F*-test value and decreasing *P*-value (Oduma et al., 2022), where the *F*-value was greater than the *P*-value for the soil pulverisation index. The quadric model is presented in Eq. (5). The independent variable in an equation of regression with a positive sign indicates that a rise in the variable will result in an increase in the response; on the other hand, a negative sign would cause a decrease.

$$PI = +18.18 - 11.08A + 1.52B - 3.12C - 0.013AB - 0.2241AC + 0.13BC + 15.65A^2 - 1.29B^2 - 1.88C^2 \quad (5)$$

where: PI – the soil pulverisation index(mm); A – soil moisture content (%); B – operating depth (cm); C – operation speed (km·h^{-1})

Comparison of predicted data with actual data

To compare the actual and predicted data for the disk harrow, a paired *t*-test was used. The results of the paired *t*-test of the soil pulverisation index for the disk harrow are shown in Table 5. According to the *t*-test, the soil pulverisation index had a *P*-value higher than 0.05; therefore, there were no significant differences between

Table 3 The analysis of variance (ANOVA) of the model of the soil pulverisation index(mm)

Source	Sequential *p*-value	Adjusted R^2	Predicted R^2	
Linear	0.1019	0.1322	-0.0056	
2FI	0.9977	0.0042	-0.2276	
Quadratic	<0.0001	0.9833	0.974	suggested
Cubic	0.883	0.9778	0.9345	aliased

Table 4 Fit statistics of the quadratic model

Standard deviation	Mean	Coefficient of variation (%)	R^2	Adjusted R^2	Predicted R^2	Adeq precision
1.24	25.28	4.9	0.989	0.983	0.974	41.84

Table 5 Results of paired samples *t*-test for two-disk harrow

	Mean	Standard deviation	Standard error mean	*T*	*p*-value
Pulverisation index	0.11	1.53	0.01	1.26	0.22

the actual values and the predicted values at a significant level of 0.05 for the disk harrow. The standard deviations are very low for the soil pulverisation index, which indicates the homogeneity of the predicted value with the actual values.

The soil pulverisation index for the disk harrow had low standard deviation of 0.53. The value indicated the differences between the predicted and actual values. The differences between the actual and predicted values for the soil pulverisation index are very slight (Table 6). For example, at a soil moisture content of 17.56%, a depth of 10 cm, and a speed of 5.47 km·h^{-1}, the values of the actual and predicted soil pulverisation index of 10.44 and 9.73 mm, respectively, imply that there is a 0.71 mm variation between the soil pulverisation index's actual and predicted values. Furthermore, the data in Table 6 shows that the actual values of the soil pulverisation index are very close. The statistical indications refer to the accuracy of the model proposed by the program to predict the values of the soil pulverisation index for the disk harrow.

Perturbation plot and scatter plot analysis

The perturbation plot of the independent factors influencing the pulverisation indexes shown in Fig. 2a. The use of the perturbation (or trace) plot enabled the examination of the effects of each independent variable on a specific point inside the design space, namely at the midway (coded 0) of all components. The findings of the study indicate that soil moisture content has the most impact on the pulverisation index, followed by operating depth.

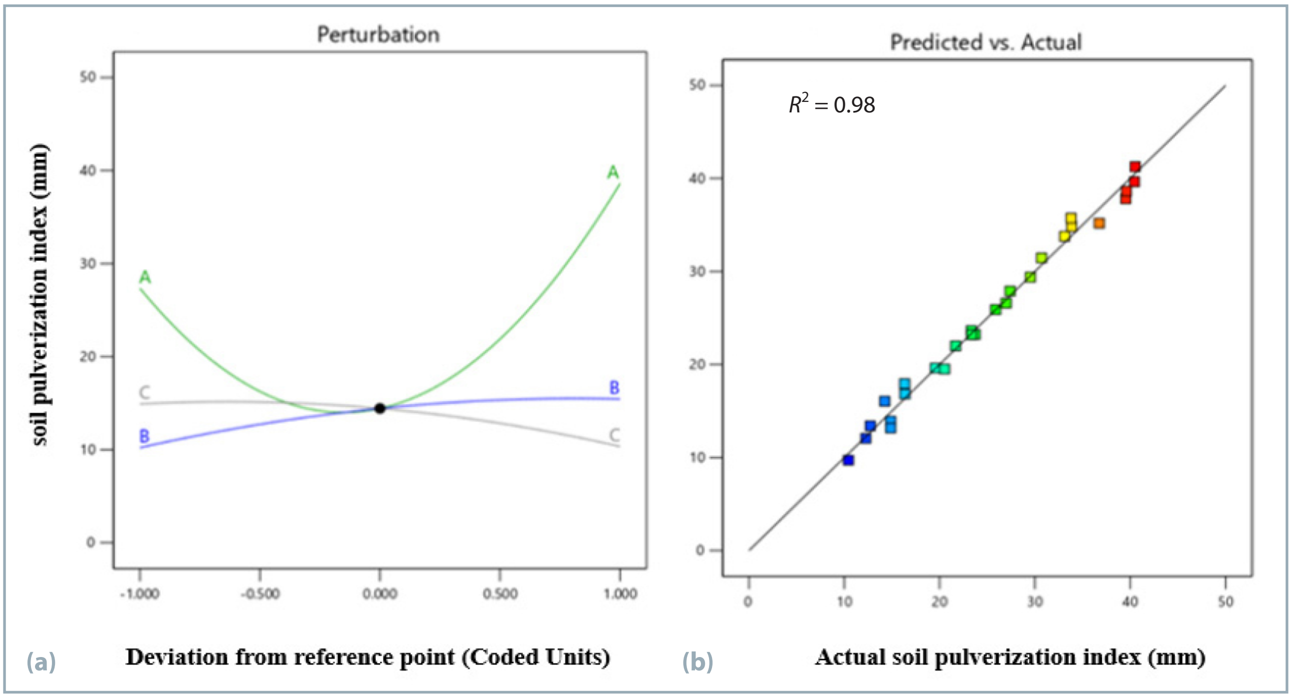

Fig. 2 Perturbation plot (a). Actual vs. predicted soil pulverisation index (b)

Table 6 A three-level, three-factor randomised design arrangement utilising actual, predicted, and residual values of the soil pulverisation index (disk harrow application)

Run	Coded factors			Actual factors			Pulverisation index of soil (mm)		
	A	B	C	soil moisture content	operating depth	forward speed	actual values	predicted values	residual
1	-1	-1	1	9.25	10	5.47	19.57	19.62	-0.05
2	-1	-1	-1	9.25	10	3.17	23.36	23.21	0.15
3	1	0	-1	17.56	15	3.17	16.33	17.94	-1.61
4	-1	0	0	9.25	15	4.85	25.89	25.9	-0.01
5	-1	0	-1	9.25	15	3.17	27.39	27.89	-0.50
6	1	-1	-1	22.32	10	3.17	33.85	34.83	-0.98
7	0	1	0	17.56	20	4.85	16.36	16.84	-0.48
8	0	1	-1	17.56	20	3.17	20.53	19.51	1.02
9	-1	0	1	9.25	15	5.47	23.74	23.23	0.51
10	-1	1	1	9.25	20	5.47	23.33	23.64	-0.31
11	1	-1	1	22.32	10	5.47	30.7	31.46	-0.76
12	1	0	0	22.32	15	4.85	39.53	37.8	1.73
13	0	-1	-1	17.56	10	3.17	14.87	13.18	1.69
14	0	-1	0	17.56	10	4.85	12.26	12.07	0.19
15	0	-1	0	22.32	10	4.85	33.12	33.78	-0.66
16	1	1	-1	22.32	20	3.17	40.53	41.25	-0.72
17	0	-1	1	17.56	10	5.47	10.44	9.73	0.71
18	1	1	1	22.32	20	5.47	33.79	35.73	-1.94
19	0	1	1	17.56	20	5.47	14.87	13.91	0.96
20	-1	1	-1	9.25	20	3.17	29.53	29.39	0.14
21	0	0	1	17.56	15	5.47	12.73	13.42	-0.69
22	1	0	1	22.32	15	5.47	36.75	35.19	1.56
23	-1	-1	0	9.25	10	4.85	21.69	22	-0.31
24	1	1	0	22.32	20	4.85	39.6	38.63	0.97
25	1	-1	0	22.32	10	4.85	33.12	33.78	-0.66
26	0	0	0	17.56	15	4.85	14.25	16.05	-1.80
27	1	0	-1	22.32	15	3.17	40.45	39.64	0.81
Mean	–			–			25.50	25.54	-0.04

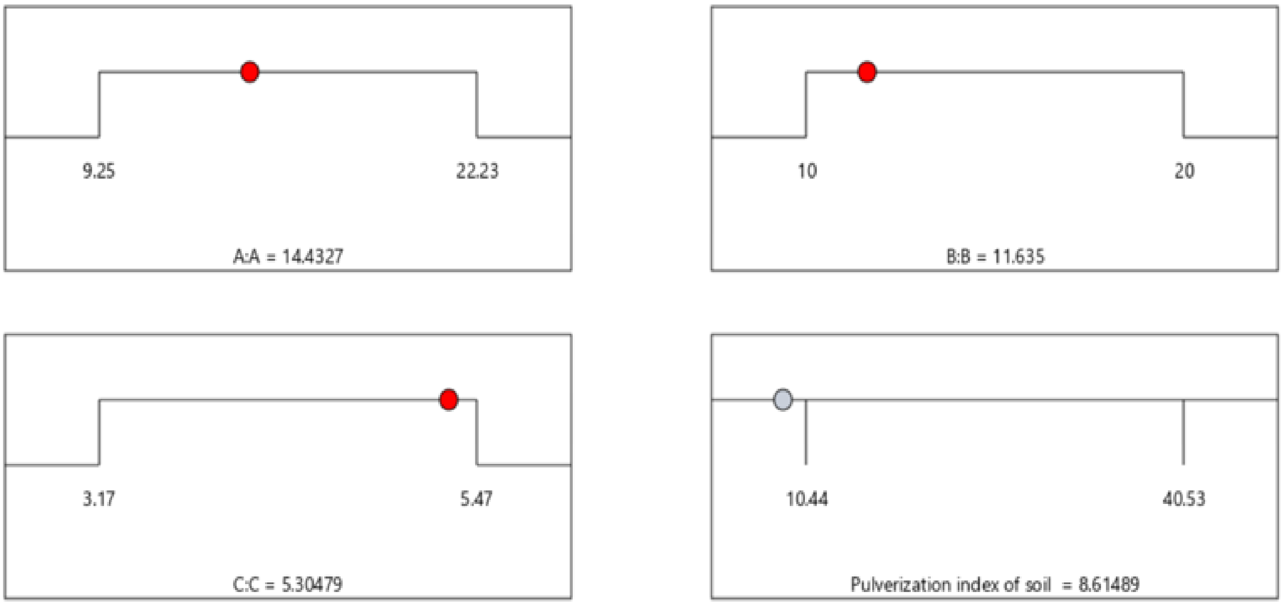

Fig. 3 Optimisation plot of soil moisture content, operating depth, and forward speed and soil pulverisation index for disk harrow

Conversely, forward speed has the least significant influence among the components considered. The scatter plot in Fig. 2b illustrates the relationship between the actual values of the pulverisation index and the corresponding projected values obtained from the final model.

Optimisation of the soil pulverisation index

The response graph of the optimisation procedure with the ideal functional parameters of forward speed, operating depth, and soil moisture content is shown in Figure 3. A response surface technique by design expert was used to optimise the disk harrow's soil pulverisation index. The optimum soil pulverisation index of 8.61 mm was obtained at the soil moisture content, operating depth, and forward speed of 14.43%, 11.64 cm, and 5.30 km·h^{-1}, respectively, and the response's desirability of 1.00 was attained. The optimum values of moisture, depth, and speed which gave the optimum value of the soil pulverisation indexing. The values found in this investigation are within the range that Usaborisut et al. (2020) attained.

Conclusion

It can be concluded from this study that the multiple regression models proposed by the Design Expert program for the soil pulverisation index were highly accurate. There was a definite consistency between the predicted R^2 and adjusted R^2. Consequently, the trial values indicated good correlations between the independent variables, supporting the coefficient of determination (R^2 = 0.989). Moreover, there were no statistical differences between actual and predicted data according to the t-test at a significant level of 0.05. Higher pulverisation for soil of 40.53 mm (low soil pulverisation) was recorded at the highest soil moisture content of 22.23% and 20 cm operating depth, respectively, and the least forward speed of 3.17 km·h^{-1}. The lowest soil pulverisation index of 10.44 mm (high soil pulverisation) was recorded at the medium soil moisture content of 17.56%, 10 cm operating depth, and speed of 3.17 km·h^{-1}. The results of current research suggest that the pulverisation indexes broadly influenced by soil moisture content, followed by operating depth being the secondary factor, while forward speed has the least substantial impact among the components under consideration. It can be strongly recommended to use a disk harrow to pulverise soil based on soil moisture content, tillage depth, and forward speed.

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References

ABBASPOUR-GILANDEH, Y. – SEDGHI, R. 2015. Predicting soil fragmentation during tillage operation using fuzzy logic approach. Journal of Terramechanics. vol. 57, pp. 61–69. DOI: https://doi.org/10.1016/j.jterra.2014.12.002

ABRAHÁM, R. – ZUBČÁK, T. – MAJDAN, R. – KOLLÁROVÁ, K. – MATEJKOVÁ, E. – MASAROVIČOVÁ, S. – DRLIČKA, R. 2022. Drawbar performance of tractor tyres with steel spikes at 100%-wheel slip. In Acta Technologica Agriculturae, vol. 25, no. 2, pp. 97–104. DOI: https://doi.org/10.2478/ata-2022-0016

AL-HAMED, S. – WAHBY, M. – ABOUKARIMA, A. – AHMED, K. 2014. Development of a computer program using visual basic for predicting performance parameters of tillage implements. In MISR Journal of Agricultural Engineering, vol. 31, no. 3, pp. 1157–1190. DOI: https:/doi.org/10.21608/mjae.2014.99147

AL-JANOBI, A. – AL-HAMED, S. – ABOUKARIMA, A. – ALMAJHADI, Y. 2020. Modelling of draft and energy requirements of a mouldboard plough using artificial neural networks based on two novel variables. In Engenharia Agrícola, vol. 40, no. 3, pp. 363–373. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v40n3p363-373/2020

ALMALIKI, S. A. – HIMOUD, M. S. – MUHSIN, S. J. 2021. Mathematical model for evaluating slippage of tractor under various field conditions. In Basrah Journal of Agricultural Sciences, vol. 34, no. 1, pp. 49–59. DOI: https://doi.org/10.37077/25200860.2021.34.1.05

ALMALIKI, S. A. 2018. Simulation of draft force for three types of plow using response surface method under various field conditions. In Iraqi Journal of Agricultural Sciences, vol. 49, no. 6, pp. 1123–1131. DOI: https://doi.org/10.36103/ijas.v49i6.151

ALWAN, A. A. 2019. A field study of soil pulverisation energy by using different mouldboards types under various operating condition. In Basrah Journal of Agricultural Sciences, vol. 32, no. 2, pp. 373–388. DOI: https://doi.org/10.37077/25200860.2019.284

BLACK, C. A. 1965. Methods of Soil Analysis. Part 1 Physical and Mineralogical Properties Including Statistics of Measurement and Sampling. 9.1. Madison, Wisconsin : American Society of Agronomy Inc., 770 pp. ISBN 9780891182030.
DOI: htts://doi.org/10.2134/agronmonogr9.1

CVIKLOVIČ, V. – SRNÁNEK, R. – HRUBÝ, D. – HARNIČÁROVÁ, M. 2021. The control reversing algorithm for autonomous vehicles with PSD-controlled trailers. In Acta Technologica Agriculturae, vol. 24, no. 4, pp. 187–194. DOI: https://doi.org/10.2478/ata-2021-0031

DAHHAM, G. A. – AL-IRHAYIM, M. N. – AL-MISTAWI, K. E. – KHESSRO, M. K. 2023. Performance evaluation of artificial neural network modelling to a ploughing unit in various soil conditions. In Acta Technologica Agriculture, vol. 26, no. 4, pp. 194–200.
DOI: https://doi.org/10.2478/ata-2023-0026

LENTH, R. V. 2009. Response-surface methods in R, using rsm. In Journal of Statistical Software, vol. 32, no. 7, pp.1–17.
DOI: https://www.jstatsoft.org/article/view/v032i07

MUHSIN, S. J. 2017. Performance study of mouldboard plow with two types of disc harrows and their effect on some soil properties under different operating conditions. In Basrah Journal of Agricultural Sciences, vol. 30, no. 2, pp. 1–15.
DOI: https://doi.org/10.37077/25200860.2017.37

NASSIR, A. J. 2018. Effect of mouldboard plow types on soil physical properties under different soil moisture content and tractor speed. In Basrah Journal of Agricultural Sciences, vol. 31, no. 1, pp. 48–58. DOI: https://doi.org/10.37077/25200860.2018.75

NASSIR, A. J. – MUHSIN, S. J. – NDAWI, D. R. 2022. The technical evaluation of three different types of tillage combined machines and compared them with individual tillage machines. In Basrah Journal of Agricultural Sciences, vol. 35, no. 2, pp. 341–361. DOI: https://doi.org/10.37077/25200860.2022.35.2.26

NATSIS, A. – PAPADAKIS, G. – PITSILIS, J. 1999. The influence of soil type, soil water and share sharpness of a mouldboard plough on energy consumption, rate of work and tillage quality. In Journal of Agricultural Engineering Research, vol. 72, no. 2, pp. 171–176. DOI: https://doi.org/10.1006/jaer.1998.0360

ODUMA, O. – EHIOMOGUE, P. – NTUNDE, D. I. 2023. Model development and optimisation of the disk plough efficiency on loamy-sand soil in South-East Nigeria. In Research in Agricultural Engineering, vol. 69, no. 1, pp. 9–17.
DOI: https://doi.org/10.17221/72/2021-RAE

ODUMA, O. – EHIOMOGUE, P. – OKEKE, C. G. – ORJI, N. F. – UGWU, E. C. – UMUNNA, M. F. – NWOSU-OBIEOGU, K. 2022. Modelling and optimization of energy requirements of disc plough operation on loamy-sand soil in South-East Nigeria using response surface methodology. In Scientific African, vol. 17, article no. e01325. DOI: https://doi.org/10.1016/j.sciaf.2022.e01325

ODUMA, O. 2019. Development of empirical regression equations for predicting the performances of disk plough and harrow in clay-loam soil. In Agricultural Engineering International: CIGR Journal, vol. 21, no. 3, pp. 18–25.

UMANI, K. C. – FAKAYODE, O. A. – ITUEN, E. U. U. – OKOKON, F. B. 2019. Development and testing of an automated contact plate unit for a cassava grater. In Computers and Electronics in Agriculture, vol. 157, pp. 530–540.
DOI: https://doi.org/10.1016/j.compag.2019.01.028

USABORISUT, P. – SUKCHAROENVIPHARAT, W. – CHOEDKIATPHON, S. 2020. Tilling tests of rotary tiller and power harrow after subsoiling. In Journal of the Saudi Society of Agricultural Sciences, vol. 19, no. 6, pp. 391–400. DOI: https://doi.org/10.1016/j.jssas.2020.05.002