Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 44 (2022) 121-137 EISSN 2543-5426

Application of a Knowledge-based Decision Support Model for Soil Tilth Assessment

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ABSTRACT

The objective of this article is to apply a developed knowledge-based decision support model for soil tilth assessment, based on the "tilth index", to help to select the suitable implement for conducting tillage operation. A field experiment was conducted using a randomized design with a strip-plot arrangement, and three replications to quantify the effects of four tillage implements (chisel, disc harrow, disc plow, ridging and split ridging, and wide level disc), on soil physical properties, tilth index of seedbed preparation of Sesame crop, in El Seleit Irrigation Scheme in Botana area, during seasons 2018 and 2019. Tillage operation significantly affected soil physical properties showing an increase in soil moisture content, soil porosity, and decrease in soil bulk density and soil penetration resistance. The highest values of moisture content were at wide level disc, and the lowest values were with chisel plow. The highest values of soil bulk density were under disc harrow tillage which was more than chisel strips, and the lowest values were under ridging and wide level disc. The highest values of soil porosity were under chisel plow and at the wide level disc and the lowest values were under disc harrow which was less than chisel strips. The highest values of soil penetration resistance were under the moldboard, and chisel plow and the lowest values were under the moldboard. The tillage methods significantly affected the plant yield. The highest value of Sesame yield was at the disc harrow and the lowest value was at Chisel. It can be concluded that shallow and intermediate tillage treatments along with disc harrow and wide level disc operation were found inferior in improving soil physical properties. Tilth index rank top the non-soil inversion operations.

***Keywords*:** Tillage, Tilth index, Soil physical property, Analytical Hierarchy Process (AHP)

(Received 26 June 2022; Accepted 26 July 2022; Date of Publication 27 July 2022)

1. INTRODUCTION

Soil tillage is usually carried out to change the soil's physical properties to provide a good seedbed and to enable the plants to reach their full productivity potential. Field crops in Sudan are cultivated in vast areas mainly under different types of soils and crops, with millions of hectares in the irrigated sector (Gezira, New Halfa, Rahad, Suki, Blue Nile, White Nile, Sundose, El Select, and Sugar projects), and 10.5 million ha in the rain-fed sector (mechanized rain-fed "7.14 million ha", and traditional agriculture "8.4–10.5 million ha"). They produce sugar, cotton, sorghum, millet, sesame, sunflower, groundnut, and vegetables and fruits. The seedbed for these crops is prepared by different types of implements. It is thus necessary to develop and apply a knowledge-based decision–aid model to help in selecting the most effective implement to tilth each type of soil to maximize the productivity of grown crops. The determination of the performance of tillage implements and their effect on soil physical properties is of vital importance to alleviate the prevailing land deterioration. The analysis of soil before and after tillage might be a useful tool to determine the optimum tillage requirement.

This, however, requires specification of the functional relations of the best soil indicators that can best describe the properties of the soil, the crop, and the capabilities of the implement. [1] indicated that changes in the soil physical properties (aggregate size, moisture content, penetration resistance, and bulk density) resulting from soil tillage treatment influence yield levels of grown crops. [1] observed that different tillage methods produced different yields, which appeared to relate to the soil tilth produced by tillage methods. They showed that there were no significant differences in seed yields Kikuyu due to the tillage system, with an overall mean yield of 1370 kg/ha.

[2] found that water content was not affected by tillage systems in the top 20 cm of soil. A 2-yr field experiment (2006 and 2007) was conducted by [3] in the Marmara Region of Western Turkey to study the effect of two types of conservation or reduced tillage [shallow tillage (ST) with a rototiller and chisel tillage (CT)] and conventional tillage with a moldboard plow (MT) on bulk density, penetration resistance, water content, oxygen diffusion rate and crop yields in a clay loam soil.

The result of [3] study shows that shallow tillage with rototiller (ST) produced grain yield as much as conventional tillage with a moldboard plow (MT) in 2006, while there were no significant differences among tillage systems in 2007. Soil water content was greater under ST than under MT. ST is also No difference was found among tillage treatments in terms of bulk density and penetration resistance at the topsoil. None of the tillage systems did show non-significant differences in terms of maize yield.

[4] showed that. The tillage depth significantly increased grain yield of wheat from 2.86 t/ha in the zero tillage to 5.33 t/ha in the tillage up to 20-25 cm depth. The interaction of tillage depths and cropping systems significantly affected the yield of rice. [5] investigated the effect of three types of tillage implements (chisel, offset disc harrow, and ridger) on bulk density, porosity, aggregate stability, and penetration resistance of sandy clay soils and clay soil at two locations in Khartoum state.

The study reveals that the bulk density of the soil surface layer was reduced by all tillage treatments compared to no-till, and the values were higher for the clay soil. Soil porosity for all treatments decreased with depth. Bulk density and porosity were generally interrelated, and simple regression analysis showed a high correlation between the two parameters in both soils for the different treatments.

A highly significant difference at the 1 % level was observed between the effects of different tillage treatments on average porosity percentages.

The offset disc harrow had the lowest aggregate stability percentages for both soils. Penetration resistance of the upper soil depth, 0-15 cm, was significantly reduced by tillage treatments compared to no-till in both soil types. The highest reduction was with the offset disc harrow as 31 % in sandy clay soil and 52 % in clay soil. In general, soil penetration resistance increased with depth, and the values were higher in clay soil.

[6] indicated that, rototiller markedly increased total weed density, as compared with moldboard plough, by 72% and 58% in maize and vetch, respectively, while total weed density was statistically similar for the three tillage systems in wheat. Maize yield was significantly higher for rototiller and the lowest for chisel compared to moldboard plough, but, there were no significant differences in wheat yield between the two tillage systems. [7] studied at the University of Khartoum Demonstration Farm in, the performance of two tillage implements: (disc and chisel plough) and their effect on some soil physical properties. The study result showed that disc and chisel plough decreased the soil bulk density, while particle size was not affected by both implements. The soil porosity values were also increased for both implements. The soil moisture content recorded in 30 cm soil profile depth was higher for chisel plough as compared to disc plough. The infiltration rate obtained by the disc plough was slightly higher than chisel plough.

Several attempts have been made by many soil scientists and agricultural engineers to quantitatively describe soil tilth by formulating indices, which are sometimes correlated to crop yields. The soil tilth index (TI), originally developed by [8] is the pioneering work which subsequently modified by [9]. They developed the tilth index to quantify soil tilth using coefficients based on five soil physical properties (bulk density, cone index, uniformity coefficient, organic matter content, and plasticity index). The index ranged from 0 for conditions unusable by plants to 1 for non-limiting soil. The field test studies were conducted near Ames, Iowa, and Waseca, Minnesota for continuous corn rotation, and soybean-corn rotation in seasons 1998 and 1999.

The tilth index was reported to be more responsive to tillage and provided better correlations with crop yield as compared to a modified productivity index. The tilth index was found to significantly increase by tillage and planting operations and then decreased with time until harvest. The relations were tested on a limited amount of data and assumed to be used as an initial guideline. [8] concluded that attempts should be made to generalize the relations by extensive data collection over a wide range of soil, climatic, and management conditions.

[10] investigated the effects of different speeds of rotary tillage and a tractor on some soil physical properties (bulk density, cone index, plasticity index, aggregate uniformity coefficient) and organic matter, and they developed and evaluated a soil tilth index based on the model developed by [8] changes in these soil properties in Malaysian paddy fields. The results of the experiment conducted by [10] indicated a significant decrease in bulk density of the soil due to rotary tillage.

The other soil parameters were not significantly affected by the tillage operation. Analysis of variance indicated a significant difference ($p<0.01$) among the rice yield means. Bulk density was identified to have a high positive correlation with the rice yield. A tilth index consequently developed with only three soil property indicators (bulk density, cone index, and plasticity index) which gave better predictability ($r = 0.56$) of rice yield than when individual soil properties were considered. Results of the study suggest that the tilth index may be used as a tool to assist in yield prediction.

[11] calculated tilth index (T1) from a field experiment of two tillage practices, the traditional tillage, using different chisel plowing passes, and the moldboard plow and two crops wheat and faba bean, to determine the optimum tilth index value for maximum yield of crops. Five soil physical properties, i.e. soil bulk density, cone index, aggregate uniformity coefficient, organic matter content, and plasticity index, were determined for each tillage system to quantify T1 according to the model. The results of the experiment indicated the increase of tilth index as plowing passes increased in the range of 0.52 to 0.67, and the index varies with tillage implement, with the highest value obtained with moldboard plow (0.71). The yield of wheat and faba bean also varied according to the tillage practices and to the T1 values.

[12] reported that "Although tilth concept dated back 1920s, for millennia there has been a strong focus both in practice and in research on developing tillage tools that create suitable growing conditions for different crops, soil types, and climatic conditions, and it still needs to be quantified to practically use it to evaluate tillage quality and to select effective implement to reach the goal of improving the productivity of crops by reaching a high tilth index ".

Recently, [13] developed a knowledge-based decision support model to determine a more representative tilth index. The developed model is based on correcting the limitations present in the tilth index procedures made by [8], [10] and [11]. The tilth index adjustment model calculates the tilth index of the soil at a particular time, estimates crop yield, and provides suggestions for sustaining or improving the tilth. The scheme utilizes the analytical hierarchy procedure to develop a tilth adjustment factor which is based on a combined weight to capture the effects of both the implement and the soil properties. The newly developed model is verified using data published by both [8], and [19].

Against this background the objectives of this study are to develop the functional relations of the soil property indicators by investigating the performance, and effects of five tillage methods on some soil physical properties and yield of rain fed Sesame crop; to apply a developed knowledge-based decision support model for soil tilth assessment to aid in ranking and selecting the suitable implement for conducting tillage operation, and finally to predict crop yields from knowledge of the developed adjusted tilth index.

2. MATERIALS AND METHODS

Data Collection and Analysis

The experiment was carried out at El Seleeit Project which is located in northeast Khartoum State, about 40 km distance from the city center. The site is typical of rain-fed cultivation in the Butana area, with the same arid climate, cracking clay soil, and rain-fed cultivation practices (Table 1).

Table 1. Some selected physical and chemical properties of the study soil

Soil property	Mean Value
Na value	15.8
P_2O_5 (ppm)	115

N (ppm)	530
C (%)	0.42
Clay (%)	67
Nitrate (ppm)	3.4
PH glass electrode (1:5)	7.5
Exchangeable Ca (mg/100 gm)	19.5
Salts (%)	0.05

The experiment was laid out as a randomized strip plot design with three replications, and five different tillage implements chisel plow, ridging, and spilt ridging, moldboard plow, disc harrow plow, and wide level disc. A soil depth in the range of 10 cm to 20 cm is maintained using a 72-horse power tractor. The land was divided into three blocks the tillage treatments are arranged in five random strips in each replication block at horizontal direction parallel to a field ditch and s three water moisture regimes (fully-irrigated, one supplemental irrigation, and rain-fed) in the vertical direction, in two seasons 2018 and 2019. Data for four soil properties (Bulk density, Soil moisture content, soil porosity, and Penetration resistance) were measured following each tillage operation in each strip; Bulk density (Mgm^3) is measured by the core method following [14]. Soil moisture content (%) was measured by oven dry method according to [15]. The moisture content in soil was determined by taking a soil sample from 0-20 cm and 20-40 cm, placing fresh soil in an oven at 105Co for 24 hours. Any loss in soil sample weight after drying was considered as moisture content.

$$Moisture\ content\% = \left(\frac{weight\ of\ wet\ soil - weight\ of\ \ oven\ dry\ soil}{weight\ of\ \ oven\ dry\ soil}\right)100 \ldots\ldots. \quad (1)$$

Soil porosity (%) as the ratio of the volume of pores (cm^3) to its total volume of the soil (cm) is calculated from bulk density and particle density measurements. Penetration resistance (KPa) was measured by cone penetrometer with length 13mm, diameter 9 mm, and net weight of 1.134 kg. Sesame (*Sesamum indicum* L.) crop planting was carried out in the third two weeks of July due to delay of onset of effective rainfall; weeding was carried out whenever necessary. The supplementary irrigation water was applied during periods of drought when the soil started to crack. Generally, the provision of irrigation water was applied in the second half of pod-setting. Cultural practices for variety Khidir recommended by Agricultural Research Corporation are followed. At harvest, two rows were harvested each six meters long to determine the seed yield in Mg /ha.

The Tilth Index Model

The Knowledge-based tilth index determination model developed by [13] in a companion paper is adopted to estimate the tilth index for each of the studied tillage operation from the data of seasons 2018 and 2019 and by following the procedure depicted in the general flow chart of Figure 1.0. The steps of determination are as follows:

Step 1: Scooping of indices:

The purpose of scooping step is to propose a set of candidate soil properties need to be maintained by tillage operations for improving crops yield. These candidate soil property indicators are expected to reflect soil functions and purposes of conducting tillage activities. Guided by published literature the raw initial set of proposed soil attributes to express tilth quality and diagnose impacts of tillage operations on quality of seedbed preparation are suggested in this study to include: (1) bulk density, (2) soil depth (3) infiltration, (4) penetration resistance "cone index", (5) soil porosity, (6) plasticity index, (7) soil roughness, (8) clod size "or aggregate uniformity coefficient", (9) organic matter, (10) weeding efficiency, and (11) water holding capacity " or water content", and (12) soil compaction. These soil properties shall be short listed to have amenable size.

Step 2: Screening and pair wise comparison

Following Abbas and Mohammed (2021) tilth index decision support model the initial list of soil properties is to be reduced by a screening scheme depending on five criteria combined in the relation: (A = (∑(S, U, M, I, R)/total) given by [16] Where: A = Acceptance score; S = Sensitivity to soil degradation; U = Ease of understanding of its value. M: measurement cost-effectiveness; I: Influence on soil, and plant productivity; R: Relationship to ecosystem processes, Total basic scores. Each parameter in the equation is given a score (1 to 5) based on the user's knowledge and experience. The sum of the individual scores in relation to sum of basic scores (25) gives the level of acceptance (A) score which can be ranked in comparison to other potential indicator, such that if the values of individual scores are less than 0.5 it will be rejected.

Step 3: The Establishment of Indicators

Indicator Functional Relationships:

In the model the indicator to express each soil attribute can be defined quantitatively from the measured soil data of each parameter by employing a polynomial relationship (tilth coefficient) following the principle of diminishing

$$CF_{(x)} = A_0 + A_1 \times x + A_2 x_2 + \cdots A_n \times x_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where: CF(x) = tilth coefficient for the soil property 3attribute (X), and Ao, A1, ……., An = empirical constants.

The functional polynomial relationship relation for the evaluation indicators of the selected to reflect soil properties are as:

1. Bulk density (BD in Mgm OM):

$$CF(BD) = 1.0 \; for \; BD \leq 1.3 Mg/m^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$CF(BD) = -1.5 + 3.87BD^2 for\ 1.3 \leq BD\ Mg/m^3$ …………………….. (4)

$CF(BD) = 0.0\ \ for\ BD \geq 2.1 Mg/m^3$ ……………………………………. (5)

2. Cone index (CI in MPa) or Penetration resistance:

$CF(BI) = 1.0\ \ for\ CI \leq 1.0MPa$ ……………………………………….. (6)

$CF(CI) = 1.012 - 0.002 \rightarrow CI - 0.01 \times CP$ …………………………… (7)

$For 1.0 \leq CI \leq 10.0MPa$ ………………………………………………...(8)

$CF(CI) = 0.0,\ \ for\ \ CI \geq 10. MPa$ ……………………………………….. (9)

3. Porosity (P in %): The total soil porosity is to be classified as textural proxy-indicator to express soil depth, and water storage capacity. Porosity is measured as relative value depending on actual percentage of pores occupied by air and water in relation to the proportion of soil pores in ideal soil of 40%.
4. Soil moisture (%): This indicator is the relative value of actual soil moisture related to 80% of theoretical soil moisture at field capacity. The soil moisture at field capacity can be taken from the table 2 [17] as below:

Table 2. Typical reality evaporable water (REW_{max}) and maximum total evaporative water (TEW_{max}) for central soil classification).

Soil texture	Mean value of soil water content limits[a]		Soil texture distribution[b]			REW from equ. (5) (mm)	REW from other sources (mm)	Estimated maximum TEW from equ.4)[c] (mm)
	θ_{PC} mm^3mm^{-3}	Θ_{WP} mm^3mm^{-3}	% sand	% silt	% clay			
Sand	0.12	0.04	92	4	4	6	5[d],6[c]	10-15
Loamy sand	0.14	0.06	84	6	10	9		12-17
Sandy loam	0.23	0.10	65	25	10	9	9[d],[e]	14-27
Loam	0.26	0.12	40	40	20	10	9[e]	20-30
Silt loam	0.30	0.15	20	65	15	9	12[d]	23-34
Silt	0.32	0.15	7	88	5	8		25-37

Silty clay loam	0.34	0.19	10	55	35	11	9[d]	25-37
Silty clay	0.36	0.21	8	47	45	12		25-38
Clay	0.36	0.21	22	20	58	8	6[e]	25-38

[a] From ASCE manual 70 (Jensen et. al. 1990), table 2.6

[b] From SCS soil texture triangle (USDA, 1993).

[c] For Z_e = 0.10-0.15m

[d] Hanks and Hill (1980).

[e] Ritchie (197).

Step 4: Development of Combined Relative Weight

This step is based on running the Analytical Hierarchy Process (AHP), which is accomplished by generating entries of alternative tillage operations with respect to the proposed tilth evaluation indicators in a pair-wise comparison matrix where elements are compared to each other. For each pair-wise comparison matrix, the decision-maker typically uses the eigenvector method [18] and [19] to generate a priority vector that gives the estimated, relative weights of the elements at each level of the hierarchy.

Weights across various levels of the hierarchy are then aggregated using the principle of hierarchic composition to produce a final combined weight or adjustment factor for each alternative tillage operation.

To mask the subjectivity nature in giving weights by pair-wise comparison for the alternative tillage operations and the selected evaluation indicators the user must run the consistency and satisfaction tests. If they are positive the adjustment factors will be accepted otherwise weights generated by pair-wise comparisons need be revised to reach acceptable adjustment factors [18] and [19].

Step 5: Development of The Tilth Index:

To arrive to an overall tilth index for each tillage operation a linear multiplicative relation is to be used to express the functional relations for the proposed indices (tilth coefficient) and their sum is to be adjusted with the score developed in step four. However, the overall adjusted tilth index can be expressed as:

$$ATI = (CF(X_1) * CF_{(X2)} * C\,F_{(X3)} * \ldots\ldots CF\,(Xn\text{-}_1) * C\,F\,(Xn)) * Score \ldots\ldots\ldots\ldots \quad (10)$$

where: ATI = overall adjusted tilth index for tillage operation; CF (xi) = tilth coefficients for each of n soil indicator, and Score = the combined relative weight for the soil indicator – implement type determined by AHP.

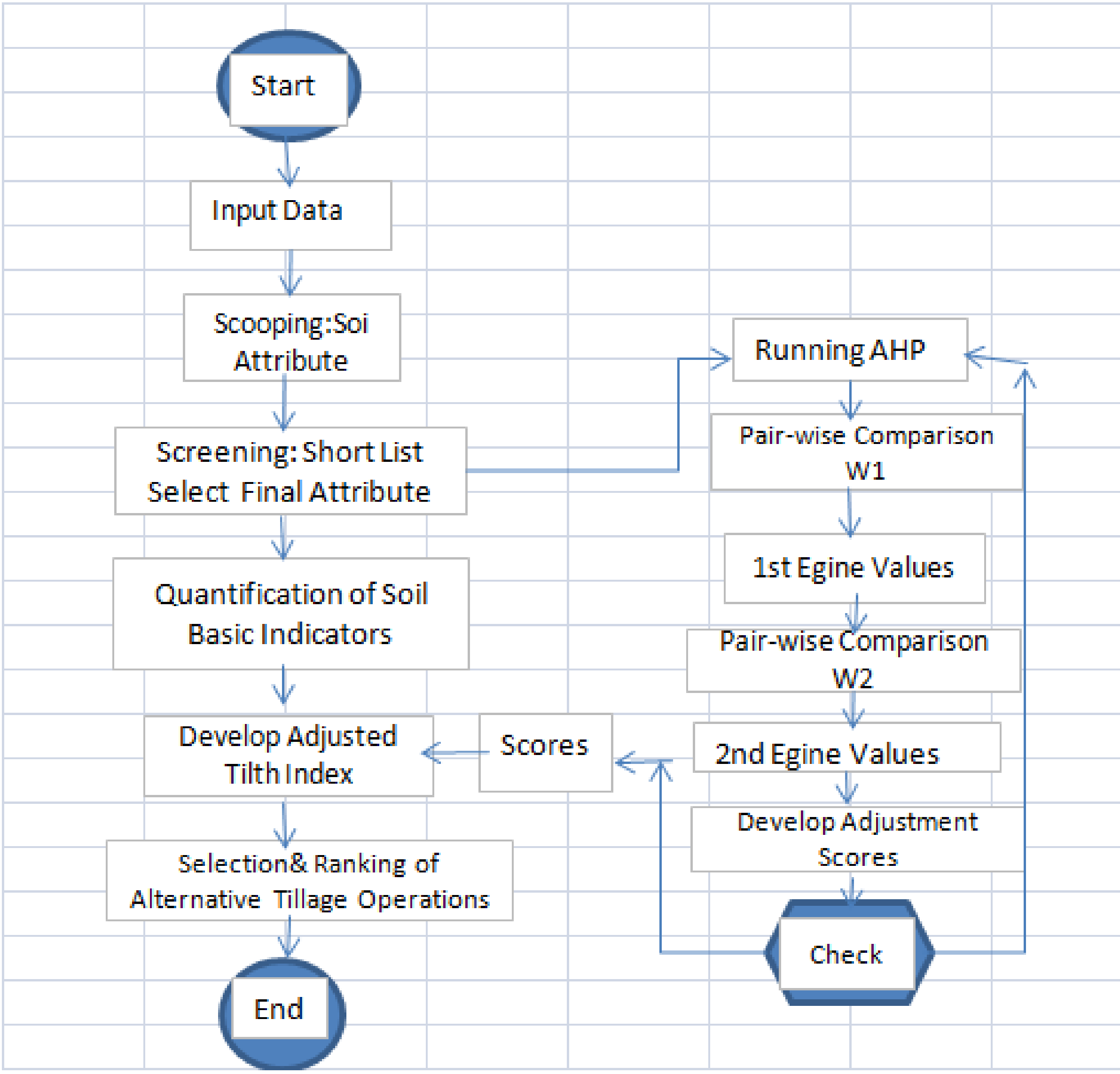


Figure 1. Flow Chart of Tilth index Determination Model

3. RESULTS AND DISCUSSIONS

The Soil Physical Properties after tillage

The effect of different tillage operations on the measured physical properties during seasons 2018 and 2019 is given in Tables 3 and 4 respectively.

Bulk density (Mg m^{-3}): Table 2 shows that in season 2018 different tillage treatments result in a significant decrease in soil bulk density [5], [7], [20] and [21] except the disc harrow which results in higher value, because of inverting of the hard subsoil to the upper layer by the discs [21]. The lowest value was obtained under Double Ridging which does not invert the soil and does not go deep into it as the chisel plow does and does it not invert the soil.

Table 3. The effect of different tillage operations on some physical properties during season 2018.

Tillage Operation	Soil bulk density (Mgm^{-3})	Soil moisture content %	Soil porosity %	Penetration resistance KPa
Chisel Plow	1.302 b*	2.474 e	46.877 d	432.317 a
Double Ridging	1.214 e	2.650 d	50.179 a	247.997 b
Mould board plow	1.233 d	3.434 b	49.478 b	183.36 c
Wide Level Disc	1.295 c	3.597 a	47.117 c	443.203 a
Disc Harrow Plow	1.352 a	2.976 c	44.986 e	445.094 a

Table 4. The effect of different tillage operations on some physical properties during season 2019

Systems of tillage	Soil bulk density (Mgm^{-3})	Soil moisture content %	Soil porosity %	Penetration resistance KPa
Chisel Plow	1.436 b	3.338 e	34.817 d	601.017 a
Double Ridging	1.460 c	3.551 c	33.891 c	295.480 d
Mould board Plow	1.413 e	5.393 a	35.662 a	229.353 e
Wide Level Disc	1.368 d	4.468 b	37.380 b	485.940 c
Disc Harrow Plow	1.467 a	4.931 d	33.651 e	576.720 b

Soil moisture content (%):

Table 2 shows that the different tillage treatments in season 2018 significantly affected the soil moisture content [21]. The highest value was found under wide level disc that may be due to high moisture stored in the soil deep layer not affected by the shallow discs, and the lowest value was for chisel plow [7]. As given in table 3 data of soil moisture content is affected significantly by all tillage treatments compared with the wide level disc (Control as traditional practice in rain fed areas). As shown in Table 3 there are no significant differences between disc harrow plow, moldboard plow, and wide level disc and they recorded higher values of soil moisture content. Similarly, there were no significant differences between chisel plow and double ridging and they recorded the lowest values of soil moisture content.

Soil porosity (%):

Table 3 shows that different tillage treatments significantly affected soil porosity at all treatments in season 2018. The highest value is found by double ridging followed by moldboard plow and chisel tillage, while the lowest values are given by disc harrow plow and then wide level disc. The low level of moisture content with those operations using disc may be attributed to the dryness of inverted pulverized soil by the disc. However, with wide level disc moisture stored in the deeper layers is less affected. Table 3 shows soil porosity data for season 2019 where moldboard and wide level disc significantly affected soil porosity [5], [7] and [21], and disc harrow and ridging are affected negatively due to their high bulk density, the highest value was found under wide level and the lowest value was under disc harrow tillage.

Penetration resistance (kPa):

The data record for penetration resistance measured in season 2018 is depicted in Table 3, which shows a significantly high effect of disc harrow plow, wide level disc, and chisel plow as one group compared to the group of double ridging and moldboard plow, but there is no significant effect within each group. The highest value was under disc harrow tillage, and the lowest value was under moldboard operation. Table 3 shows the results of penetration resistance measured in season 2019. The table indicates that the tillage treatments affected significantly the soil penetration resistance at all treatments. The highest value was found for the chisel operation, and the lowest value was under the moldboard [5] and [21].

The Sesame yields (Mg/ha)

Table 5 shows sesame (*Sesamum indicum* L.), for seasons 2018 and 2019 for the studied tillage treatments. It indicates a significant difference in Sesame yield with tillage treatments compared with wide level disc. Higher values were recorded for season 2018. The yield shows a similar trend with tillage treatments in the two seasons with the highest yield obtained with the chisel plow operations and the lowest yield with wide level disc operations in the two seasons [10].

Table 5. Crop yield data for seasons 2018 and 2019

Tillage operation	Rain fed yield (Mg/ha)	
	Season 2018	Season 2019
Chisel plough	0.700	0.294
Double Ridging	0.621	0.266
Moldboard plough	0.570	0.264
Disc Harrow plough	0.528	0.269
Wide Level Disc	0.533	0.268

Determination of the Tilth Index

Model Application:

The measured data for the impacts of tillage operations on the tested soil properties for season 2018 and 2019 shall be used as input data to run the tilth development model. The sequence of calculations is as follows:

1. **Scooping:** As given in previously (Material and Methods-Tilth Index Model) eleven soil attributes are suggested to evaluate performance of each tillage operation.
2. **Screening:** The screening criteria proposed in the model are used to reach a short list of practical indicators as shown in Table 6:

Table 6. Results of Application of Screening approach

Soil Property	S	U	M	L	R	Score	Decision
(1) bulk density	4	4	5	3	2	72	Accepted
(2) soil depth	3	2	1	3	2	44	Rejected
(3) infiltration	2	2	3	2	2	44	Rejected
(4) penetration resistance "cone index"	4	5	4	3	5	84	Accepted
(5) soil porosity	4	4	5	3	2	72	Accepted
(6) plasticity index	2	2	1	3	2	40	Rejected
(7) soil roughness	2	2	3	2	2	44	Rejected
(8) Particle size "or aggregate uniformity coefficient"	2	2	1	2	2	36	Rejected
(9) organic matter	2	1	1	2	2	32	Rejected
(10) weeding efficiency	2	2	3	2	3	48	Rejected
(11) moisture content	3	5	3	5	4	80	Accepted
S = Sensitivity to degradation	U = Ease of understanding					M = cost-effectiveness	
L = property influence on soil	R = Relation to Ecosystem					A = ∑(S, U, M, I, R)	

It is evident from table 5 the most relevant soil properties to be included s short list are: (1) bulk density (2) penetration resistance "cone index" (3) soil porosity, and (4) soil water content.

3. **Functional Relations:** The application of the polynomial functional relations for the selected soil attributes to generate the respective indicators is given for season 2018 and 2019 in Table 7 and 8, respectively.

Table 7. Functional Relations of Indicators of Soil Attributes for Season 2018

Systems of tillage	Soil Indicators				Adjustment of Tilth Index			
	Soil bulk density (Mgm^{-3})	Soil moisture content %	Soil porosity 40 base %	Penetration resistance kPa	Indicators Tilth Index	Score (CI = 0.2482)	Adj Tilth Index	Rain fed Yield Mg/ha
Chisel plough	1.000	0.089	1.172	1.000	0.105	0.459	0.048	0.700
Double Ridging	1.000	0.089	1.254	1.000	0.112	0.255	0.029	0.621
Mouldboard plough	1.000	0.089	1.237	1.000	0.111	0.194	0.021	0.570
Disc Harrow plough	1.000	0.089	1.178	1.000	0.105	0.187	0.020	0.528
Wide Level Disc	0.990	0.089	1.125	1.000	0.100	0.244	0.024	0.533

Table 8. Functional relations of indicators of soil attributes for season 2019

Systems of tillage	Soil Indicators				Adjustment of Tilth Index			Rain fed Yield Mg/ha
	Soil bulk density (Mgm^{-3})	Soil moisture content %	Soil porosity 40 base %	Penetration resistance KPa	Indicators Tilth Index	Score (CI = 0.2482)	Adjusted Tilth Index	
Chisel plough	1.000	0.089	0.978	1.000	0.088	0.459	0.040	0.294
Double Ridging	1.000	0.089	0.952	1.000	0.085	0.255	0.022	0.266
Mouldboard plough	1.000	0.089	1.002	1.000	0.090	0.194	0.017	0.264
Wide Level Disc	1.000	0.089	1.050	1.000	0.094	0.187	0.018	0.269
Disc Harrow plough	0.804	0.089	0.945	1.000	0.068	0.244	0.017	0.268

Note that for development of the functional relations in table 5 and 6 the Base Soil moisture is 0.8 of Field capacity of 36% =28.8% and Porosity is Based on 40% pore space for ideal agricultural soils. For bulk fensity and penetration resistance the equations given by the tilth model are adopted.

Analytical Hierarchy Process (AHP).

The adopted process is typical to the flow chart of Figure 1. The calculation steps are:

1. Develop a pair-wise comparison matrix for each decision alternative for each criteria, using scale of comparison (1 = Equal importance, 3 = Moderate importance of one factor over, 5 = Strong or essential importance, 7 = Very strong importance, 8 = Extreme importance, 2,4,6,8 Values for inverse comparison.

2. Synthesization
   a) Sum each column value of the pair-wise comparison matrices
   b) Divide each value in each column by its column sum.
   c) Average the values in each row of the normalized matrices.
   d) Combine the vectors of preferences for each criterion.

3. Develop a pair-wise comparison matrix for the criteria.

4. Compute the normalized matrix. Combine these two sets of preferences using egine values to mathematically derive a composite score for each site. Select the site with the highest score.

5. Develop the preference vector.

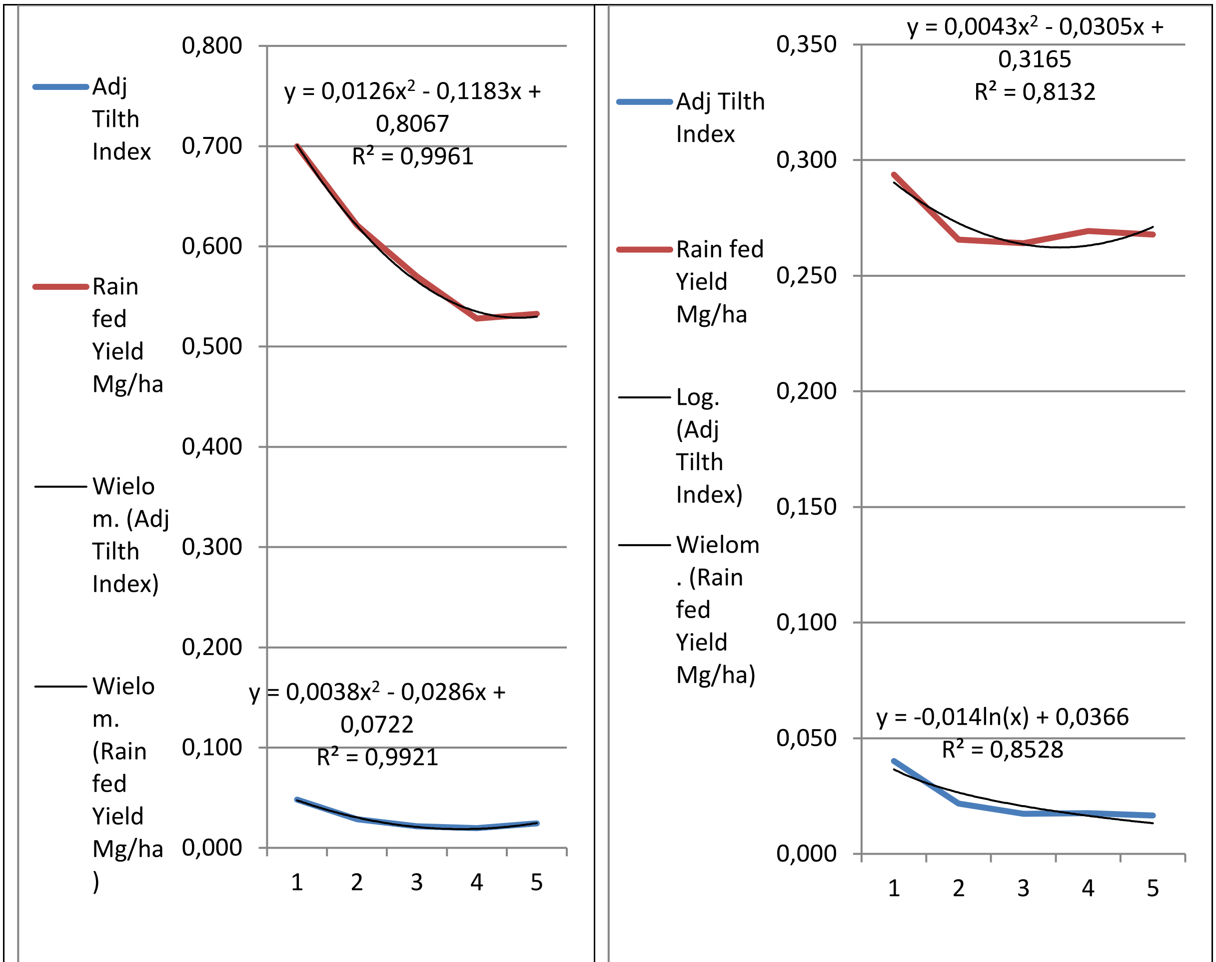
6. Check consistency and satisfaction level using random index value table [18]. If result is negative re-adjust the pair-wise comparison matrices (go to step 1 & 3), otherwise go to step 5. There are 3 steps to arrive at the consistency ratio:
   a). Calculate the consistency measure. $CI = (\lambda max - n)/ (n - 1)$;
   b). Calculate the consistency index (CI).;
   c). Calculate the consistency ratio (CI/RI where (RI) is a random index ($CR = CI / RI$).

The Overall Adjusted Tilth Quality Index

To determine the Overall Adjusted Tilth Quality Index the indicator tillage index (measured from functional relations of attributes) is multiplied with score values (adjustment factors measured by AHP) for each tillage operation in each season (vide Table 5 and 6). The Overall Adjusted Tilth Quality Index is compared to the values of Sesame yield (Mg/ha) in each of the two seasons. The data is shown graphically in Figure 2(a and b).

Comparison of The Overall Adjusted Tilth Quality Index with crop yields for seasons 2018, and 2019 shown in Figure 2 reveals that although crop yield values are higher than the adjusted tilth index, but they almost follow same trend of polynomial relation with Correlation coefficient (R2) of 0.996 for yield and 0.992 for tilth index in season 2018, while the values of the correlation coefficient (R2) for season 2019 are 0.813 for yield and 0.852 for tilth index.

The results of the two seasons indicate a similar ranking order for tillage operations, and confirm the preference of those of non-soil inversion action (chisel followed by double ridging).



Season 2018 **(a)**	Season 2019 **(b)**

Figure 2(a,b). Comparison of The Overall Adjusted Tilth Quality Index with crop yields for seasons 2018, and season 2019.

4. CONCLUSIONS

Tillage operation significantly affected soil physical properties showing an increase in soil moisture content, soil porosity, and decrease in soil bulk density and soil penetration resistance. The highest values of moisture content were at wide level disc, and the lowest values were with chisel. The highest values of soil bulk density were under disc Harrow tillage which was more than chisel strips, and the lowest values were under ridging and wide level disc.

The highest values of soil porosity were under chisel plow and at the wide level disc and the lowest values were under disc harrow which was less than chisel strips. The highest values of soil penetration resistance were under the moldboard, and chisel plow and the lowest values were under the moldboard. The tillage methods significantly affected the plant yield. The highest value of Sesame yield was at the disc harrow and the lowest value was at chisel.

The results of the two seasons indicate a similar ranking order for tillage operation and confirm the preference of those of non-soil inversion action (chisel followed by double ridging). The tillage operations almost follow same trend of polynomial relation operation with crop yields.

Acknowledgements

This study was supported by a research grant awarded from Ministry of Higher Education (Grant Number: 140.1360-1383.01.29). We express our thanks for providing the financial support.

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