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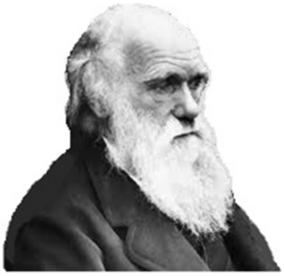

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Diagnosis of Performance of Four Tillage Methods by Analytical Hierarchy Procedure (AHP) and Overall Tilth Index in Clay Vertisols

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ABSTRACT

This study was carried out during seasons 2018/2019, and 2019/2020, in Tayba Block-the Sudan - Gezira central clay plains, to evaluate the field performance of four land preparation methods using three tillage equipment: chisel plow "intensive tillage", disc harrow "medium tillage", ridger "minimum or reduced tillage" and no tillage machine. An overall tilth index to reflect field performance of tillage methods was determined from four measured soil tilth indicators (bulk density, porosity, aggregate uniformity, and penetration resistance). Diagnosis of land preparation methods was made using analytical hierarchy procedure (AHP) for ranking tilth indicators by weight assignment and determination of overall tilth index using a linear relation. The results show that Bulk density of the soil surface layer was reduced by tillage implements compared to no till. High significant difference at 1 % level was observed between reduced or no tillage and intensive tillage by chisel or disc harrow on average percentage Soil porosity. Bulk density and Soil porosity are inter-related with similar trend. Aggregate stability showed highest value with no till treatment followed by chisel plow, while those obtained by harrow or ridger implements do not differ significantly. Penetration resistance was significantly lowered by tillage implement compared with using no tillage machine. The highest reduction is achieved by disc harrow followed by ridger and the least reduction is made by chisel plow. Penetration resistance is interrelated to Bulk density. Using analytical hierarchy procedure ranked the tillage indicators in descending order by weight values of 1.01, 0.62, 0.29 and 0.12 for Penetration resistance, Bulk density, Porosity, and Aggregate particle stability respectively. The diagnosis of tillage

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alternatives by development of the overall tillage index resulted in ranking tillage methods in descending order of preference as: ridger, disc harrow, chisel plow, and no tillage machine. It is thus recommended to use reduced tillage "ridging only" as the most technically feasible tillage method achieve an optimal seedbed with minimum energy input.

***Keywords*:** Tilth Index, Tillage methods, Vertisols, Analytical Hierarchy Procedure (AHP), Penetration resistance, Bulk density, Porosity, Aggregate particle stability

1. INTRODUCTION

Vertisols of the central Sudan during summer time offers difficult physical environments to crop production (Bashir et al, 2015). Therefore, tillage is necessary to modify these environments to create optimum conditions for increasing production of field crops. Tillage practices have often been considered as limiting factor to crop production in heavy clay soil [1]. Different tillage methods are employed to maximize crops yield by manipulating the soil to improve its physical properties and to prepare fine seedbed for plant germination and growth, incorporation of agricultural chemicals and crop residues by burying weeds, or construction of certain land structures for wind erosion control. These tillage methods vary by their cost, which is function of tillage intensity, and by the quality of tilth they produce according to type of implement used. There are different types of tillage systems ranging from intensive tillage using chisel plow to medium tillage using disc harrow to minimum or reduced tillage using ridger. However, due to the frequently reported high cost of tillage practice some farmer tends to go for using no tillage machine at all [2] and [3]. Crop producer are usually confronted by the questions of the selection of the relevant land preparation method to employ; how to quantify the overall tillage index by which to judge tilth quality and select the machine to employ.

Many researchers [4], [5], [6], [7] and [8] reported that the main objectives of using tillage implement are to reduce soil bulk density, increase soil porosity, favor water infiltration, and have more soil aggregate stability. To evaluate these tillage indicators, it is necessary first to quantify them and then to judge their values against standard or threshold levels (maximum, mid, and minimum levels) to assess attainment of good soil tilth [9]. Due to variability of tilth quality evaluation indicators there is a need to develop one overall index that can capture the all variable indicators to help in the selection of the optimum tillage method.

Using tillage systems in crop production are criticized by some scholars to result in negative impacts on soil such as soil compaction, and erosion, dust emission, and degradation of the environment [2], [10] [11] and [12]. Consequently, they recommend to use reduced or even no tillage [13], [14], [15] and [16] claim that improper selection and unjustified use of tillage implements may destroy the crop root zone in the soil and waste fuel and energy inputs. This calls for developing a procedure to select the optimum tillage method with low intensity, and results in minimum cost and good tilth. Development of such procedure require as pre-requisite setting performance diagnostic scheme for various tillage implement.

Attempts have been made to create evaluation tools or methods to quantify seedbed conditions following tillage [9], [17] [18] [19] and [20]. The quality of seedbed preparation is traditionally evaluated arbitrary by visual assessment and subjective classification by "good tilth" or "poor tilth" [20]. This method cannot be used reliably to make management decisions regarding selection of tillage method. This calls for developing more predictable quantitative evaluation methods. Some of the methods that were proposed used techniques that measured soil physical properties and scaled them by relating them to the expected yield [9] [20]. [21] stated that these approaches provided some useful guidelines, but were neither adequate nor consistent because soil quality cannot be measured directly, but must be inferred or estimated by key indicators and development of quantitative methods are highly required. Quantitative seedbed evaluation methods can generally be classified into two categories. The first is to directly measure soil physical or mechanical properties (bulk density, penetration resistance, mean weight diameter, clod size and porosity [17], [18], [22], [23], [24] and [25], and rate them according to how much yield is produced [17]. The second includes methods that combine several soil physical properties into mathematical expressions, pseudo-transfer functions, multi-criteria analysis or process models [26], to give a more global evaluation of the soil. The first category is criticized by [27] who warns that measuring and reporting an individual soil parameter is no longer sufficient since some properties such as bulk density may be confounded by several other factors. Confounding factors include e soil moisture and organic matter content [25] and [28].

Methods that are classified in the second category include the soil tilth index [29] and [20], the index of physical condition, scoring functions [30], and the least limiting water range index [37]. They are developed from empirical data measuring soil physical properties and crop yield. The yield is predicted from the soil properties to develop a quantitative relationship that can be used to predict future production levels. The second category is criticized by its empirical nature and ignorance of the complex soil environment consisting not only of physical but also biological, chemical and external factors (e.g. rain fall) that affect yield [26].

Previous attempts to quantify the seedbed conditions following tillage have been made, but it has been difficult to determine which soil physical properties should be used to measure tilth.

Researchers often use porosity, bulk density, structure, compaction, particle size distribution, and clod size distribution [18], [23], [24], [25] and [32]. Among these properties, bulk density remains the most popular and widely measured. Bulk density changes are most evident following tillage, when compared to other physical soil condition indicators. [33] however, warned that the field method for determining bulk density is not very accurate and gives only an approximate idea of soil make up. [28] further state that since several factors (such as moisture and organic matter content) can confound bulk density measurements, it should not be the only soil physical factor used as a soil quality indicator.

The degree of compactness, relative compaction and resistance to penetration indices, use a single soil property to model a complex environment. [34] Found that using the degree of compaction (relative density) instead of bulk density improved the applicability of the model by diminishing differences in values of LLWR between different soil types. Similar results were obtained by [35]. Combining several soil physical factors to account for the complexity of the soil environment was a common goal among researchers in the 1990s [9], [34], [35], [36], and [37]. Regression procedures were used by [36] to model tilth. They selected only those soil variables that made a significant contribution toward yield, [37] characterized the structural quality of the soil using the least limiting water range index (LLWR). The LLWR was a range in soil water content after rapid drainage had ceased and where water potential, aeration, and mechanical resistance to root penetration had minimal effect on plant growth [9], [29] and [34] used tilth coefficients to model the relationship between soil variables and yield. The "Tilth Index" was a quantitative value ranging from 0.0 for worst to 1.0 for best conditions used to describe soil conditions relating to plant growth. [20] found that determining the tilth coefficients was iterative and arbitrary. They modified. [29]'s linear correlation model to a new quadratic relationship. However, neither model could consistently distinguish which tillage method produced better tilth. This confirmed that their methods needed further refinement and investigation. Soil condition can be examined holistically by considering the chemical, biological, and physical factors affected by tillage. This approach is consistent with the concept of soil quality that has been extensively researched by [21]. They simply defined soil quality as its capacity of the soil to function. Each soil indicator supporting a given function is related quantitatively to the function it supports [38]. Using scoring functions requires no simulation modeling to estimate the functional relationships between soil properties and soil quality, and the method is easy to use.

The main objective of this study is to Diagnosis the field performance of four tillage methods (chisel plow, disc harrow, ridger and no tillage machine), using four measured soil tilth indicators (bulk density, porosity, aggregate uniformity, and penetration resistance).

As such, in this study evaluation of different land preparation methods was planned to be made by combining the defined soil physical properties through a method to quantify tillage indices for each soil character, and make pair-wise comparisons between them using AHP and then obtain the resulting overall tillage index using a linear relation from four different long-term crop seedbed tillage practices (no-till, reduced tillage, medium and conventional tillage).

2. MATERIALS AND METHODS

The experiment was conducted during seasons 2018/2019, and 2019/2020, at El Suni Minor Canal in Tyba Block of Gezira Scheme Sudan. The soil is clay Vertisol, with a high CEC, and characterized by alkaline reaction with a pH of 7.5, and low permeability [39]. Some of its physical and chemical characteristics are shown in the table (1.0). The study area is characterized by a semi-arid climate. Annual mean air temperatures is 28.0 °C, and monthly mean solar radiation ranges between approximately 20 and 26 MJ/m^2, with the minimum occurring in July and December. Total precipitation is 280 mm (20year average), almost all of which falls between July and October. Dry spells occur during the rainy season, resulting in delaying crop growth.

Table 1. Study site some soil physical and chemical characteristics

Depth (cm)	EC (µS/cm)	CEC (m Mc/kg)	Organic-C (g/kg)	Total N (g/kg)	pH	Clay %	MC %	Ece ds/m	SAR	BD g/cm^3
0-25	406	573	6	0.36	8	50	6.7	2.92	4.6	1.29
25-45	363	573	5	0.23	9	52	6.3	3.07	4.7	1.31

45-70	596	589	4	0.21	9	53	6.7	3.42	5.2	1.33
70-90	1189	648	7	0.19	8	55	6.7	3.47	6.1	1.37
90-110	1397	664	7	0.21	8	57	6.8	3.72	6.4	1.39
110-150	2260	592	5	0.18	8	52	6.87	3.92	6.9	1.42

This study was carried out to evaluate the field performance of four land preparation methods using three tillage equipment: chisel plow, disc harrow, ridger and no tillage machine was used. An overall index of field performance was determined from four measured soil tilth indicators (bulk density, porosity, aggregate uniformity, and penetration resistance) and three estimated operating parameters (theoretical and effective field capacity, field efficiency and fuel consumption).

Massey Ferguson 165 tractor (54.8 Kw PTO power), and three tillage implements were used chisel plough (With 5-units with 180 cm width of cut, and 3-point hitching), offset disc harrow (With 9 × 2 units with 225 cm width of cut, and 3-point hitching), and ridger (With 3 units with 210 cm width of cut, and 3-point hitching). Materials and equipment used include a stop watch, measuring tape 50 m), steel pegs, some chalk, a barrel and a one liter graduated measuring cylinder for fuel refilling and measurement. Complete randomized block design with three replications was used in which a total treatments area (1600 m^2) was divided into blocks of (25×64 m^2 size separated by two-meter buffer margins and head lands for machine turning) and treatments were randomly distributed over these blocks.

2. 1. Measurement of soil characteristics after tillage operation

These include: bulk density, porosity, aggregate particle stability, penetration resistance and soil moisture storage) (Table 2).

a. **Bulk density** (gm/cm^3) was made using the clod method as described by [3] and [40].

b. **Soil porosity** (SP which soil voids to soil total volume) was estimated by initially determining soil particle density (PD) using Archimedes principle and [41] relation:

$$PD = \frac{(W_s - W_a)}{[(Ws-Wa)-(Wsw-Ww)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

where: Pw = density of water at temperature of determination (gm/cm^3); Ws = weight of pycnometer plus oven dry soil sample with water; Wa = weight of pycnometer filled with air; (Wsw = weight of pycnometer filled with air and water; Ww = weight of pycnometer filled with water.

A volumetric flask (100 ml) was used in place of a pycnometer, because the sample was large enough to compensate the decrease in precision of measuring fluid volume.

Then from bulk density (BD), and by using [42] the Soil porosity (SP) is given as:

$$SP = \left[1 - \left(\frac{BD}{PD}\right) \times 100\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

c. **Soil aggregation stability (SA)** was identified by using (Aggregation particles less than 50 microns) method described by Richard (1954) [43], and by applying the formula:

$$SA = \left[\frac{(W_2 - 0.06)}{(W_2 - S) + W_1}\right] \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

where: W_1 = Weight of soil sample in water, W_2 = Weight of soil sample in (Calgon), and S = Weight of calgon (= 0.06).

d. **Penetration resistance determination** (kg/cm^2) was made according to the method described by [44] using hand operated soil test pentrometer [Dynamic cone pentrometer (DCP)]. Penetration resistance of soil was measured according to [45] in (Kg/cm^2) by calculating the pressure exerted by an 8 kg falling hammer on a base of 50 mm diameter through a number of blows, depending on the strength of the soil. The falling hammer exerts (0.408 Kg/cm^2) through one blow and the soil resistance to penetration for certain depth was calculated by gathering all blows needed to reach that depth, multiplied by the pressure of one blow (0.408 kg/cm^2).

e. **The soil moisture storage** after tillage operation was determined directly using gravimetric sampling technique, in which the weights of wet samples were measured, and then soil samples were dried in an oven at temperature of 105-110 c؛ for 24 hours. Soil moisture content percentage on weight basis is calculated as follows [46]:

$$\%\, MC(wet\ basis) = \left[\frac{\text{wet sample weight} - \text{dried sample weight}}{\text{Dried sample weight}}\right] \times 100 \ldots\ldots\ldots \ (4)$$

$$\%\, MC(volume\ basis) = [MC\ on\ wet\ basis \times Bulk\ density \times 100] \ldots\ldots \ (5)$$

Table 2. Collected average field data

Tillage Methods	ridger	harrow	No Till	chisel
Bulk Density (gm/cm^3)	1.325 a	1.305 a	1.350 a	1.320 a
Porosity (%)	50.00 a	50.85 b	51.35 b	50.25 a
Aggregate Particle Stability (%)	42.85 a	39.9 b	37.85 c	38.8 c
Penetration Resistance (MPa)	8.35 b	8.25 c	8.975 a	8.025 d
The moisture storage (%)	27.21 c	38.00 a	36.53 b	13.75 d

Means followed by same letters row wise are not significantly different using Duncan Multiple Range Test

2. 2. Diagnosis of Field Performance

Step 1: Scooping and screening of indices of soil properties

Guided by published literature the raw and initial set of proposed soil attributes assumed to express tilth quality and diagnose impacts of tillage operations on quality of seedbed preparation are suggested 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. From this set of candidate soil properties select those measurable soil properties to be considered as indicator capable to reflect soil properties that need to be achieved by tillage operations for improving crops yield. Following [47] the criteria of selection may include: sensitivity to ecosystem processes and soil degradation, ease of understanding of its value, low measurement cost, influences on soil, and plant productivity. However, the selected number should be a mean able to calculations.

In this study bulk density (gm/cm^3), porosity (%), aggregate particle stability (%), penetration resistance (MPa), and the after tillage moisture storage (%) were selected as soil properties expected to be altered by tillage operations.

Step 2: Establishment of coefficient of each Indicator

This step is to be directed to define tilth coefficients quantitatively from the measured data of each soil property by defining its functional Relationships by setting the three crop growth threshold limits for each indicator (sufficiency, critical and limiting point) by employing a general format of polynomial relationship [29]:

$$CF(X) = [A_0 + (A_1 \times X) + A_2 \times X^2] \times 0.01 \ldots\ldots\ldots\ldots \quad (6)$$

where: CF(x) = tilth coefficient for the soil property attribute (X), and Ao, A1, A2 = empirical constants to express the growth threshold limits, (sufficiency, critical and limiting level), and o.o1 is scaling factor to normalize values in the range of (1.0 or less). The coefficient of each Indicator at the threshold levels and their respective functional two degree polynomial relationship for the evaluation indicators selected in this study are as depicted in Table (3).

Table 3. Determination of the coefficient of each soil evaluation Indicator

Soil Indicator (A)	**Threshold Limits**		
	Sufficiency FC = 1.0	**Critical FC = Eqn**	**Limiting FC = 0.0**
Bulk Density (gm/cm^3)	BD < = 1.3	FCBD (1.3 to 2.1) = ((-1.5) + (3.8*A) + (3.878*A^2))*0.01	BD > = 2.1
Porosity (%)	P = >45.%	FC P (0.0 to 45%) = 0.1*P	P< = 45.0

Aggregate Particle Stability (%)	AP > = 50	FCAP(2 to 5) = ((0.348) + (0.245*A) + (0.023*A^2))*0.01	AP < 20
Penetration Resistance (MPa)	PR< = 1.0	FCPR(1.0 to 10.0) = ((1.012) + (-0.002*A) + (0.01*A^2))*0.01	PR > = 10

<u>Step 3:</u> Development of evaluation Indicator 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 [48] 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 an acceptable adjustment factors.

Development of Combined Relative Weights is made by ranking the indicators with pair wise comparison using of Analytical Hierarchy Procedure (AHP). The main objective of using the AHP is the development of relative weight for each indicator. The process of the AHP can be accomplished by generating entries of alternative tillage operations with respect to the proposed tilth or operating parameters 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 [48] to generate a priority vector that gives the estimated, relative weights of the indicator 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 and iterated to reach an acceptable adjustment factors [48].

<u>Step 4:</u> Development of the overall 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:

$$OTI = CF(X_1)W_1 + CF(X_2) \times W_2 + CF(X_3) \times W_3 + \cdots . CF(X_{n-1}) \times W_{n-1} + CF(X_n)W_n. \qquad (7)$$

where: OTI = overall adjusted tilth index for tillage operation; CF (Xi) = tilth coefficients for each of n soil indicator, and Wi = the relative weight for the Xi soil indicator determined by AHP.

3. RESULTS AND DISCUSSIONS

3. 1. Determination of soil characters

a. For Soil Bulk Density (gm/cm^3): Table 2 shows that from statistical analysis there were no significant differences ($P<0.05$) in the effect of tillage on this parameter. Results also indicated that, soil bulk density decreased after tillage methods compared with that before tillage. Recall that average soil bulk density values measured before tillage found to be around 1.35 g /cm^3. These bulk density values increase as the season progresses. This could be due to drying and wetting of the soil caused by irrigation cycles. This is in agreement with Gezira soils given by [1]. The results show that Bulk density of the soil surface layer was reduced by tillage implements compared to no till.

b. For porosity (%): As given in table 2 high significant difference at 1 % level was observed between reduced or no tillage and intensive tillage by chisel or disc harrow on average percentage Soil porosity. Bulk density and Soil porosity are inter-related with similar trend. There is no significant difference within intensive tillage treatments (chisel and harrow) and also no significant difference within ridger as reduced treatment or with no till treatment.

c. Aggregate stability (%), showed highest value with ridger treatment followed by harrow plow, while those obtained by no till or chisel implements do not differ significantly.

Penetration resistance (MPa): Table 2 shows that Penetration resistance was significantly lowered by tillage implement compared with using no tillage machine [49]. The highest reduction in comparison to no tillage is achieved by chisel plow followed by disc harrow and the least reduction is made by ridger. Penetration resistance is interrelated to Bulk density [1].

3. 2. Determination of Tilth Indicators

Using tillage indicators coefficients shown in Table (3) the measured soil tillage characteristics given in table (2) are transformed to tilth indicators by following the steps and functional relations given in the procedure stated for determination of tillage index and depicted and in Table (4).

Table 4. The coefficients of each tilth indices with respective soil tillage characteristics

Tilth Methods	No Till	chisel	harrow	ridger
Tilth Indicators				
Bulk Density (gm/cm^3)	0.09	0.09	0.09	0.09
Porosity (%)	1.00	1.00	1.00	1.00

Aggregate Particle Stability (%)	0.53	0.47	0.43	0.44
Penetration Resistance (MPa)	1.00	1.00	1.00	1.00

3. 3. Determination of weighting values

Step 3 was followed for estimation of evaluation Indicator Relative Weights. Pair-wise comparison of indicators is based on using the Scaling factor given in Table (5).

Table 5. Scaling factor for pair-wise comparison

Preference level	Definition	Explanation
1	Equally preferred	Two activities contribute equally to the objective
2	Equally to moderately preferred	Interpolate a compromise judgment numerically between 1 and 3 for no good word to describe it
3	Moderately preferred	Experience and judgment slightly favor (i) activity over the other (J)
4	Moderately to strongly preferred	Interpolate a compromise judgment numerically between 3 and 5 for no good word to describe it
5	Strongly preferred	Experience and judgment strongly favor (i) activity over the other (J)
6	Strongly to very Strongly preferred	Interpolate a compromise judgment numerically between 5 and 7 for no good word to describe it
7	Very Strongly preferred	The strongly favored activity (i) by experience and judgment demonstrated dominance in practice over the other (J)
8	Very Strongly to extremely preferred	Interpolate a compromise judgment numerically between 7 and 9 for no good word to describe it
9	Extremely preferred	The evidence favoring one activity (i) over the other (J) is highest possible order of affirmation
Reciprocals of the above	If activity (i) has one of the above nonzero numbers assigned to it when compared with activity (j), then j has the reciprocal value when compared with (i)	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit

This result on generating the indicators Pair wise Comparison Matrix (Table 6).

Table 6. Indicators Pair wise Comparison Matrix

Tilth Indicators	Bulk Density (gm/cm^3)	Porosity (%)	Aggregate Particle Stability (%)	Penetration Resistance(MPa)
No Till				
Bulk Density (gm/cm^3)	1.00	2.00	5.00	9.00
Porosity (%)	0.50	1.00	4.00	3.00
Aggregate Particle Stability (%)	0.20	0.25	1.00	4.00
Penetration Resistance(MPa)	0.11	0.33	0.25	1.00
chisel				
Bulk Density (gm/cm^3)	1.00	6.00	7.00	4.00
Porosity (%)	0.17	1.00	7.00	3.00
Aggregate Particle Stability (%)	0.14	0.14	1.00	2.00
Penetration Resistance(MPa)	0.25	0.33	0.50	1.00
harrow				
Bulk Density (gm/cm^3)	1.00	5.00	6.00	3.00
Porosity (%)	0.20	1.00	6.00	3.00
Aggregate Particle Stability (%)	0.17	0.17	1.00	4.00
Penetration Resistance (MPa)	0.33	0.33	0.25	1.00
ridger				
Bulk Density (gm/cm^3)	1.00	8.00	6.00	3.00
Porosity (%)	0.13	1.00	7.00	4.00
Aggregate Particle Stability (%)	0.17	0.14	1.00	6.00
Penetration Resistance (MPa)	0.33	0.25	0.17	1.00

This matrix is utilized by AHP to rank the evaluation indicators and the scores are taken as the relative weight and given in Table (7).

Table 7. Overall Ranking (Scores)

Tilth Indicators	Score	Rank
Bulk Density (gm/cm^3)	0.62	2
Porosity (%)	0.29	3
Aggregate Particle Stability (%)	0.12	4
Penetration Resistance (MPa)	1.01	1

3. 4. Determination overall index and Ranking of tillage alternative methods

Table 8 shows the evaluation scores obtained for each tillage method and their respective overall tillage index. Table 8 is determined for each tillage indicator by multiplication of each tilth coefficient (Table 4) with its relative weights obtained using pair-wise comparison and given in Table (7) and equation 3 to arrive to their overall indices as detailed in step 4. Determination of the overall tilth index reveals that selection of reduced tillage for seedbed preparation is most effective method in clay Vertisols.

Table 8. Tillage methods scores and overall index

Tilth Indicators	Tilth Methods			
	ridger	harrow	No Till	chisel
Bulk Density (gm/cm^3)	0.053	0.053	0.054	0.053
Porosity (%)	0.289	0.289	0.289	0.289
Aggregate Particle Stability (%)	0.061	0.054	0.049	0.051
Penetration Resistance (MPa)	1.009	1.009	1.009	1.009
OTI (SUM)	1.412	1.404	1.401	1.402
Ranking	1.0	2.0	4.0	3.0

4. CONCLUSIONS

From this research the main conclusions are: Disc implements (ridger and disc harrow) were found to be slightly more effective in terms of tilth index than no tillage machine or chisel plow. It is recommended to employ minimum tillage method (ridging only) for it was always the most effective tillage tool for heavy clay soils. All tillage methods resulted in similar effects on soil bulk density and penetration resistance. Chiseling has more pronounced effect on porosity. Chisel plow requires higher draft and higher drawbar power compared to disc harrow. However, minimum tillage (ridging only) was less expensive and could be recommended for seed bed preparation of clay soil.

The developed seedbed evaluation procedure in this study could be used as a useful tool to select the type of tillage implement to use for optimal seedbed preparation with minimum possible energy input (reduced intensity) under given soil conditions. However, more studies are needed in future to use of this evaluation tool in conjunction with impact of machine operating parameters on system performance, spatial analysis and yield mapping, to provide a better assessment of how tillage management can be improved. The aim should be to balance the benefits of soil conservation against a desired tilth condition.

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