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Evaluation of Four Tillage Methods Operating parameters by Overall index using Analytical Hierarchy Procedure and Compromise Programming Technique in the Gezira Heavy Clay Soils

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Abstract: This work was excuted during seasons 2018/2019, and 2019/2020, in Tayba Block-the Sudan - Gezira central clay plains, to evaluate the field operation 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 operation index is estimated from four measured machine operating characteristics. Diagnosis of land preparation methods was made using analytical hierarchy method for weight assignment for assignment of relative weights for the operating parameters, and compromise programming technique for ranking of tillage methods. The experiment was conducted as a factorial experiment with RCBD, the LSD test at 1%and 5 % was used to compare between means. Results indicate that no significant differences (P<0.05) in field efficiency between Chisel plow and ridger and harrow showed the least efficiency value. There is significant differences in fuel consumption rate between all treatments with highest consumption is by Chisel plow and lowest is by ridger. The significantly highest rear wheel slippage is attained by ridger while there is no significant differences in that resulted from chisel or disc harrow. The significantly highest field capacity (P<0.05) is attained by ridger followed by harrow and then chisel plow. The analytical hierarchy procedure ranked the machines operation indicators in descending order by weight values of 1.02, 0.62, 0.29 and 0.12 for. Multi-criteria analysis by compromise programming technique results in overall indices of tillage equipments: ridger, chisel plow, disc harrow in descending values of 67.53, 61.00, and 57.29 respectively. The overall performance index (OPI) for the operation of the agricultural equipment could be used to take the tillage decision-making process by selecting the most effective machinery to give optimum seed bed with minimum energy input. However, it is not possible to calculate the overall index for no tillage method because without using a machine there is no fuel consumption, no field efficiency, no field capacity, and no wheel slippage. This imply that for heavy clay soils of Gezira Scheme and in other similar environments it is recommended to use reduced tillage "ridging only" as the most technically feasible tillage method, other wise use chisel plowing if funds are available.

Keywords: Tilth Index, Tillage Methods, Heavy Clay, Analytical Hierarchy Procedure (AHP), Compromise Programming Technique, Field Efficiency, Rear Wheel Slippage, Fuel Consumption Rate

1. Introduction

The Vertisols of the central Sudan during summer time is characterized by hard particle when dry and sticky one upon wetting. This results in difficult physical environments and limiting factor in heavy clay soil for crop production [1]. Hence, tillage operations are is essential to change these environments for optimum seedbed. Different tillage methods are employed to maximize crops yield, improve its physical properties and to prepare seedbed for plant germination and growth [2].

Hussein and Munir, 1986 and Melvin, 2005, Bowrs, 1989; Dahab and Elzain, 2011, Chenu el al., 2000, and Coates and Thacker, 2001 [3-8] criticized using intensive tillage operations in crop production and claim that improper selection and unjustified use of tillage implements in the field may destroy the crop root zone by soil compaction or erosion by wind and water and waste fuel and energy inputs.

Consequently, they recommend to use reduced or even no tillage [4]. They expressed performance of field operations by indicators to express cost and time elements [7-10]. 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. The quality of tilth and cost of tillage operation are function of field capacities, operation efficiencies, tire slippage and fuel consumption [11-14]. There are different types of tillage systems ranging from intensive tillage using chisel or moldboard primary tillage to medium tillage using disc harrow to conservation 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 or zero tillage using a planter machine only [6, 9]. Crop producers are usually confronted by the questions of the selection of the most effective and economical land preparation method to employ due to lack of funds or necessity of timeliness. Then, how to quantify the overall tillage index by which to accept field practice and select the effective machine to employ.

Attempts have been made to create evaluation tools or methods to quantify machinery field performance seedbed conditions Hakansson, 1990 [15-18]. The quality of conducting seedbed preparation is traditionally evaluated arbitrary by visual assessment and subjective classification such as "good or poor" or "acceptable or non-acceptable operation" [18]. Hence, the need a rises of developing quantitative procedure to evaluate the quality of field operation of the tillage equipment. This needs to be made by first quantification of machine field operating parameters, and then to judge their values against standard or threshold levels (maximum, mid, and minimum levels) to assess attainment of good field operation [17]. Due to the need to use multiple field operating parameters the evaluation of operation indicators need to be grouped in one overall index that capture the characteristics of all indicators.

Tillage equipment field operating parameters usually used to express costs and timeliness functions are field capacity, field efficiency, rear wheel slippage, and fuel consumption rate [19]. The field operating parameters includes measurements of implement draft, fuel consumption, real forward velocity, tillage depth wheel slippage, drawbar power and traction effciency and engine speed. Abualgasim and Dahab (2017) Studied the suitable effective use of five tillage treatments (Offset disc harrow + ridging, Disc plough + ridging, Chisel plough + ridging, Ridger plough and Animal drawn plough) on some soil physical properties (soil moisture content, soil bulk density, soil aggregate stability and infiltration rate) at the farming research station (Elrawakeeb) – west of Khartoum – Sudan [20]. The tillage implements were measured by draft force, fuel consumption, theoretical field capacity, effective field capacity and field efficiency, and recommend that the best implement gain the highest effective field capacity and at the same reduced the fuel consumption is the ridger plough. Abbas et al (2016) investigated the effect of different tillage methods on some soil physical properties, effective field capacity and fuel consumption under semi-arid climate of north kordofan state, sudan [21]. Their results suggested that deep tillage practices (chisel plow) performed better than shallow tillage practices (disc plough), and concluded that deep tillage practices (chisel plow) performed better than shallow tillage practices (disc plough). Elzain (2007) investigated the effect of three tillage implements (Chisel plough, offset disc harrow, and ridger) on four field performance parameters: wheel slippage, fuel consumption rate and field efficiency on two types of soils (sand and clay) in Khartoum area [22]. The results indicated that: the disc harrow gave the highest field efficiency of (79.9%) at the clay soil location. The chisel plough demonstrated the highest wheel slippage (19.2%) and fuel consumption rate (15.7L/ha). The lowest slippage (10.4%) and fuel consumption rates (5.97 L/ha -1.06 L/hr) were recorded by the disc harrow. However, field capacity. field efficiency, rear wheel slippage, fuel consumption rate indicators that reflect field operations differ in their nature, importance and relative effect therefore, they need to be expressed by assignment of evaluation weight to help in generating one value to aid in the selection of the optimum tillage method. Determination of weighting function for the indicator of each field operation parameter is difficult undertaking because it is subjective in nature. There are many methods to rank each operating parameter weighting scoring functions such as pair-wise comparison or Delphi or Analytical Hierarchy Procedure (AHP). The AHP) is developed and used by Saaty, (1977) to rank alternatives by a suitable weight scoring functions [23]. It advantage over other weighting methods is its ability to test the consistency of weight judgments statistically. The procedure starts by generating entries of operation performance indicators used for alternative tillage method, and then run pair-wise comparison matrix where elements are compared to each other guided by table equipped with comparison rules. For each pair-wise comparison matrix, the decision-maker typically uses the eigenvector method to generate a priority vector that gives the estimated, relative weights of the elements at each level of the hierarchy [23-25]. 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 machine 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 till it converge in repeated iterations.

The process of determining an overall index to express all operation evaluation indicators generated for each problem is a multi-criteria problem. Karlen et al. (1998) stated that the current approaches to solve such multi-criteria problem is to employ descriptive statistics provided some useful guidelines, but were neither adequate nor consistent because quality of field operation and thereby cost and time elements cannot be measured directly, but must be inferred or estimated by key indicators and development of quantitative methods are highly required [26]. Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria and for decision making the conflicting criteria and objectives are to be considered simultaneously. Typical conflicting criteria in evaluating options are direct cost or price or its pro-indicator (e.g. fuel cost) and other criteria, to measure quality which is in conflict with the cost (e.g. wheel slippage). Multiple-criteria evaluation problems consist of a finite number of alternatives, explicitly known in the beginning of the solution process such as the different tillage method in our case. Each alternative is represented by its field operation performance indicators in multiple criteria. The problem here is thus defined as finding the best alternative for a decision-maker (DM), or "sorting" or "classifying" or "ranking" alternatives. According to Wang et al (2013) there are a number of available MCDM methods including: Analytic hierarchy process (AHP); ELECTRE (Outranking); Goal programming (GP); utility theory, fuzzy theory, and performance-based modeling Evaluation Based on Distance from Average or ideal solution [27-33].

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 Overall Index to express four measured machine operating indicators (theoretical and effective field capacity, field efficiency and fuel consumption) by Analytical Hierarchy Procedure and Compromise Programming Technique in The Gezira Heavy Clay Soils.

Materials and Methods

A. The experimental site and Design

This experiment was conducted during seasons 2018/2019, and 2019/2020, at El Suni Minor Canal in Tayba-Block of Sudan Gezira Scheme (14.4⁽North and 33.5⁽ East and 405m altitude). The soil is clay Vertisol, with a high CEC, and characterized by alkaline reaction. Some of its physical and chemical characteristics are shown in the table (1.0). The climate is semi-arid.

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, & 3-point hitching), offset disc harrow (With 9 X 2 units with 225 cm width of cut, & 3-point hitching), and ridger (With 3 units with 210 cm width of cut, & 3-point hitching). Materials and equipments 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 m2) was divided into blocks of (25×64 m² size separated by two meter buffer margins and head lands for machine turning) and treatments were randomly distributed over these blocks.

Table 1. Study site some soil physical and chemical characteristics

Depth (cm)	EC (µS/cm)	CEC (m Mc/kg)	Organic-Carbon (g/kg)	Total Nitrogen (g/kg)	pH	Clay %	MC %	Ece	SAR	BD (g/cm³)
0-25	406	573	6	0.36	50	50	6.7	2.92	4.6	1.29
25-45	363	573	5	0.23	52	52	6.3	3.07	4.7	1.31
45-70	596	589	4	0.21	53	53	6.7	3.42	5.2	1.33
70-90	1189	648	7	0.19	55	55	6.7	3.47	6.1	1.37
90-110	1397	664	7	0.21	57	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

B. Measurement of machine operating parameters

These include: field efficiency, rear wheel slippage, fuel consumption rate:

1. Field efficiency measurement was determined as follows:
   - Ploughing started and continued at constant speed (8 Km/hr) after finishing the preparation of the experimental area, and the start time was recorded by using the stopwatch in (sec)
   - Time needed to finish one tractor travel (20m distance), which is the plot length, was recorded.
   - Time needed to complete the ploughing of the plot was registered.
   - field efficiency (FE %) was found by the equation:

$$FC\% = \frac{\text{Sum of Times of all executed travels inside the plot}}{\text{Total time to finish the plot}} \times 100 \quad (1)$$

2. The rear wheel slippage (RWS) was determined as follows:
   - First the rear wheel was marked tangent to the ground surface by a piece of chalk
   - The number of revolutions of the wheel when the tractor was unloaded with implement (WL) were marked and counted until the tractor finished travel.
   - The number of revolutions is counted and marked again for the same travel, when the tractor was loaded with the implement (L).
   - The wheel slippage was calculated as:

$$Wheel\ slippage\% = \frac{(L - WL)}{(WL)} \times 100 \quad \text{---------------} \ (2)$$

3. Fuel consumption rate (FCR) measurement:
   - The tractor started working the with its full tank capacity.
   - After finishing the plot, the tank was refilled with the graduate cylinder.
   - The volume of fuel that was needed to refill the fuel tank was determined.
   - The fuel used was calculated as: First;

$$Fuel\ consumption\left(\frac{l}{hr}\right) = \frac{\text{tank fuel amount before work} - \text{tank fuel amount after work}}{\text{Time hour}}. \text{------} \ (3)$$

$$Fuel\ consumption\left(\frac{l}{ha}\right) = \frac{\text{Tank Supplied re-fuel from cylinder reading ml}}{\text{Area of the plot "m}^2} \times 10 \ \text{--------------} \ (4)$$

4. Theoretical Field Capacity: it is calculated for the various tillage implements using a constant speed of 8 Km/hr by the formula:

$$TFC = (W \times S) / C \quad \text{-----------------------------} (5)$$

Where: TFC = Theoretical field capacity (ha/hr); W = Theoretical width (m); S = forward speed (km/hr); C = conversion constant (10).

C. Diagnosis of Field Performance

1. Operating parameters 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 to generate a priority vector that gives the estimated, relative weights of the elements at each level of the hierarchy [23-25]. 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 aim of using AHP is to develop a 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 to generate a priority vector that gives the estimated, relative weights of the indicator elements at each level of the hierarchy [23, 25]. 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 [23, 25].

2. Generating the overall Index of the operating parameters

There does not exist a unique optimal solution for MCDM problems and it is necessary to use decision-makers' preferences to differentiate between solutions. The concept of an optimal solution is often replaced by the set of non-dominated solutions. A solution is called non-dominated if it is not possible to improve it in any criterion without sacrificing it in another. Therefore, it makes sense for the decision-maker to choose a solution from the non-dominated set. In this study the non-dominated set is solved using the ideal point compromise programming technique as described by Yu (1973) [34]. The compromise solution is a feasible solution, which is the closest to the ideal and means an agreement established by mutual concessions. Yu (1973) and Zeleny (1974) define the ideal solution (Yu describes this solution as the "utopia point") as any solution that would simultaneously optimize each individual objective [34]. In objective function space this point has the coordinates Z(x*) = [Z1(x*), ..., Zk(x*)], where x* optimizes every Zh(x). It is an unusual case where there is a single solution which simultaneously optimizes all of the objectives. However, a representation of the unobtainable ideal solution can be obtained for any properly bounded set of alternatives by optimizing each Zh(x) separately. To measure closeness, a distance function is introduced into the analysis, which minimizes the distance between the solution and the ideal points. Depending on the measure of distance used, a set of compromise solutions can be obtained for minimized distance as [35].

For minimization case:

Lp min = D min; ------------------------------ (6)

Subject to:

D min = {Wj * {(Zj(x) - Zj*)/(Zj* - Zj**)}^(1/p)} <dmin , for all j ------------------------------ (7)

X ε F and X, D max > 0; ------------------------ (8)

For maximization case the LP problem is to be solved following [36] as:

Maximize L max = D max; Subject to:

Dmax = Wj * {(Zj*-Zj(x))/(Zj* - Zj**)}^(1/p) for all j -------------------(9)

X ε F and X, D max > 0

Where: (Wj) = indicator relative weight; (Zj*) maximum target indicator value; Zj(x)= actually attained indicator value; (Zj**) minimum target indicator value; p= type of relation (1.0) for linear, (2.0) for quadratic and (∞) for infinity relation. Ultimately, when (P=oo), the largest of the deviations completely dominates the distance measure. In addition to P = 00, the values (P = l.0), and (P = 2.0) are commonly used. (P= 1.0) implies the longest geometric distance between two points in that the deviations are simply summed over all dimensions. When (P = 2.0) we obtain the shortest geometric distance between two points, a straight line. Other values of P are not as easily interpreted. Where F is the feasible set and (X) is the vector of decision variables, (zj*) and (z*j) are the ideal and anti-ideal values for objective(j) (the ideal value was assumed to be the best value from the pay-off matrix and the anti-ideal the worst), (zj(x)) is the jth objective function and (wj) is the weight attached to objective (j).

Results and Discussions

1. Determination of each machine operating parameters

The Operating Parameters for Tillage Methods is depicted in table (2). Rsults showed no significant differences (P<0.05) in field efficiency between Chisel plow and ridger and harrow showed the least efficiency value. There is significant differences in fuel consumption rate between all treatments with highest consumption is by Chisel plow and lowest is by ridger. The significantly highest rear wheel slippage is attained by ridger while there is no significant differences in that resulted from chisel or disc harrow. The significantly highest field capacity (P<0.05) is attained by ridger followed by harrow and then chisel plow.

Table 2. The average Operating Parameters for Tillage Methods

Tilth Methods	no Till	chisel	harrow	ridger
Operating Parameters				
Field Efficiency (%)	0.00	87.5 a	80.9 b	89.3 a
Fuel Consumption Rate (lit/hr)	0.00	7.8 a	5.96 b	2.82 c
Rear Wheel Slippage (%)	0.00	11.2 b	10.5 b	12.99 a
Field Capacity (ha/hr)	0.00	3.08 a	4.06 b	9.6 c

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

2. Using AHP for Developing Relative Weights of indicators

Determination of weighting values scores for each indicator of operating parameter is determined using pair-wise comparison and the rules given in table (3). The rules for determining the relative weights for each indicator of operating parameter are based on setting the preference of the i^{th} indicator in relation to the

j^{th} indicator, and on creating a reciprocal matrix [aij] where (aij) is the expert's initial evaluation. Applying these rules for the relative weight by pair-wise comparison for the operation indicators of Field Efficiency (%) Fuel Consumption Rate (lit/hr), Rear Wheel Slippage (%), and Field Capacity (ha/hr) results in the matrix of table (4). However, data of table (4) is reached after satisfying the consistency and satisfaction tests.

3. Determination overall index by (CP) for Ranking of tillage methods

The determination overall index and Ranking of tillage alternative methods by adopting the eight step Compromise programming procedure and shown in table (5).

Table 3. Rules for setting par-wise comparison between indicators of field operations

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&3
3	Moderately preferred	Experience and judgment slightly favour (i) activity over the other (J)
4	Moderately to strongly preferred	Interpolate a compromise judgment numerically between3 &5
5	Strongly preferred	Experience and judgment strongly favour (i) activity over the other (J)
6	Strongly to very Strongly preferred	Interpolate a compromise judgment numerically between 5 & 7
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 & 9
9	Extremely preferred	The evidence favoring one activity (i) over the other (J) is highest possible order of affirmation

Table 4. Operation indicators weights pair-wise comparison matrix

Overall Ranking (Scores)		
Tilth Indicators	Score	Rank
Field Efficiency (%)	0.62	2
Fuel Consumption Rate (lit/hr)	0.29	3
Rear Wheel Slippage (%)	0.12	4
Field Capacity (ha/hr)	1.02	1
SUM	2.04	

Table 5. The overall index and Ranking of tillage methods

Operating Parameters	Tilth Methods			
	No Till	chisel	harrow	ridger
Field Efficiency (%)	0.00	54.25	50.16	55.37
Fuel Consumption Rate (lit/hr)	0.00	2.26	1.73	0.82
Rear Wheel Slippage (%)	0.00	1.34	1.26	1.56
Field Capacity (ha/hr)	0.00	3.14	4.14	9.79
Overall index	0.00	61.00	57.29	67.53
Rank	0.00	2.00	3.00	1.00

Conclusions

From this research it is evident that: ridging only was the most effective in land preparation of clay soil followed by chisel plow. No significant differences (P<0.05) in field efficiency between chisel plow and ridger and harrow showed the least efficiency value. There is significant differences in fuel consumption rate between all treatments with highest consumption is by Chisel plow and lowest is by ridger. The significantly highest rear wheel slippage is attained by ridger while there is no significant differences in that resulted from chisel or disc harrow. The significantly highest field capacity (P<0.05) is attained by ridger followed by harrow and then chisel plow. Multi-criteria analysis by compromise programming technique results in overall indices of tillage equipment: ridger, chisel plow, disc harrow in descending values of 67.53, 61.00, and 57.29 respectively. The developed seedbed evaluation procedure in this study could be used in future with other additional operating performance indicators (e.g. draft) as a useful tool to select the type of tillage implement to use for optimal seedbed preparation with minimum cost and energy inputs under other soil types.

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Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

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