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Studies of Tractor and Crop Parameters combinations for optimal Selection of Machinery Sizes: A- Review

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Abstract: *Globally Agricultural equipment's and machineries are one of the major investment costs in today's modern Agro industries for foremost land holders. However; wrong decisions on farm machinery investment and machinery selection process will have a negative effect on the profitability of the companies, whereas scientific selection and proper utilization of agricultural machinery will enhance profitability by reducing downtime caused by machinery breakdowns, power losses and implement-tractor mismatching, which can be achieved by performance and cost of farm machinery utilized. A review of tractor, implement selection and its utilization for improved farm operations was done from the available published literature. Mainly; several literature focus on tractor, implement variables and cost parameters by giving less attention on crop parameters. Crop parameters, like;* start date, hectare coverage, hours and *soil properties, need further study to get additional valuable data for the selection of optimum size tractor and implement in order to enhance production efficiency at lower costs. Collection of information (data) and quantitative analysis of the results were considered for the present analysis, forwarding conclusion, and recommendations for the appropriate selection of machine sizes. It was found that crop parameters like Soil types, soil physical properties and field conditions vary from one agro-ecological area to the other. It is therefore highly recommended to conduct the studies at specific agro-ecological areas, if comprehensive and genuine performance data for farm machinery selection is required.*

Key words: *Crop parameter, Machinery selection, Optimum capacity, Performance.*

Introduction

Agricultural implements refer to those machines basically used in the farm for field operations; such as land clearing, tillage or seed bed preparation, seed planting, fertilizer application, mechanical weeding, weed and pest control, harvesting and transporting. These machines are powered by tractor and are used in the farm for agricultural field operations. Most of these machines are fully mounted, semi-mounted, self-propelled or trailed implements. Modern agricultural operation demands, application of these field machinery and implements in various farm operations; from field clearing to harvesting. And also today's competitive agricultural market demands better utilization of resources and minimization of operating costs, so as to optimize production and increase profits. The major costs of any modern agricultural production system are machinery cost. Increasing the performance efficiency of farm machinery may lead to a serious cost reduction, hence, the optimum farm power machinery components achieved through combination of required tractor power for single operation, the machine size and number of tractor needed to complete field operation at optimum time [1-2]. Identifying critical field operations that will require an implement with the highest draft force, estimating available time to complete the prioritized task, determining the work rate (ha/hr), determining the width of the implement required, determining the soil resistance, estimating required power at the draw bar and determining PTO power are the key parameters to select optimum tractor capacity [3]. Crop details and sound implement selection criteria should be considered, as the input for the development of computer system, which allows the user to choose specific crops and required field operation suitable for the selected crop. The designed may be possible for various combinations of crops in the computer system. The selected designed options of computer system for four crop combinations considered were sorghum, sesame, sunflower and cotton. The system deals with three operations; seedbed, seeding, and weed control; via six implements namely; chisel plow, disk harrow, wide level disk, row-crop - planter, inter-row-cultivator and sprayer. [4]. The computer system consisting of "C" programming language; an input information, like; list of desired field operations and crop parameters, like start date, hectare coverage, and hours per day for each operation and other input of the program includes crop yields, penalty dates for planting and harvesting, availability and cost of labor, and certain economic data were provided to the computer system. Additionally, stored data files contain machine prices list and productivity values, work day profitability, and equation constants for computing machine costs. For different machinery sets or a specified set of machinery, the program schedules the field operations and computes the total machinery-related costs including costs for the machines, labor, and timeliness [5]. Also; there are many developed systems model to support the process of choosing the optimal level of farm mechanization in terms of technical capability. The optimization model is a non-linear programming model implemented by using the programming software like; suite General Algebraic Modeling System (GAMS), which is based upon a least-cost concept involving all expected fixed and variable costs (including timeliness costs) for a particular farm size and crop plan [6]. The farm machinery economic evaluation, selection criteria, optimum tractor and implement sizes depending on tractor-plough properties. The connection between draft and fuel consumption relative to the operation cost and a machine selection is identified as a present idea to evaluate the tractor-plough operation. Used tractor tire specifications and the chisel plough properties are analyzed by the visual basic program to calculate the fuel cost/fed at different tractor power, forward speed and plough width [7]. A machinery size selection model and annual cost model for heavy tillage implements based on differential calculus as in Hunt-Wilson's least-cost tillage width model, considering field processing labor cost. Hunt-Wilson model's need for prior arbitrary width-dependent machinery capacity input for width selection circumvented. The capacity based machinery size selection helps to assist in decision making on tillage implement selection model; including comparison of machinery alternatives within and across various power sources [8].

Performance Indicators of Farm Machinery Selection

Performance indicators of farm machinery like: machine field efficiency, time efficiency, theoretical field capacity, effective field capacity, material capacity, energy consumption and power requirements of the machine should be considered in machine selection. These performance indicators are decisive factors for determining the machine capacities and adopting important management policies. They are used to ascertain, how effective a machine would carry out its function and ensure timeliness of operation [9, 23, 24]. The various Indicators of Field Machinery Selection are as discuss below;

Theoretical Field Capacity

Theoretical field capacity of a field machine is the rate of field coverage that would be obtained if the machine performing its function 100 % of the time at rated forward speed and always covered 100 % of its rated width [9]

$$Ct = \frac{C_e}{e} ----(1)$$ Where:

C_t = theoretical field capacity, ha/hr; C_e = effective field capacity, ha/hr; e = field efficiency, decimal

Field Efficiency

Field efficiency is expressed as *per cent* of a machine's actually achieved under real conditions. It accounts for failure to utilize the full operating width of the machine (overlapping) and many other time delays. These may include turning, filling with seed, fertilizer or pesticide, emptying grain, traveling to a supply tender or grain cart, cleaning a plugged machine, checking a machine's performance and making adjustments, waiting for trucks, and operator rest stops [10].

$$e = \frac{C_e}{C_t} ---(2)$$

Effective field capacity

The effective field capacity as the actual average rate of coverage by the machine, based upon the total field time.

Published literature reported that it is impossible to operate machines continuously at their rate width of action; therefore their actual capacity is substantially less than the theoretical capacity [11].

$$C_e = \frac{Swe}{c} ------------------------------$$

Where

C_e = effective field capacity, ha/hr, c = constant; w = machine size - rated width, m; S = field speed (km/hr)

e = field efficiency, decimal

Material capacity

Machine material capacity is estimated by considering the speed of operation, implement working width, the field efficiency of the machine and the weight of soil scooped (for tillage implements) for the planter, the quantity of seeds loaded in the hopper; and for harvester the quantity of seed handled in a given time is obtained from the equation as below;[11].

$$M = \frac{swey}{c} ----4$$

Where: M = material capacity, km/h; y = yield/mass of material handled, kg/m2; s = implement/machine speed, km/hr; w = implement working width, cm; e = implement field efficiency, %; c = constant = 10.

Tractor Performance

Tractor is a prime device used now days in advanced farming for getting the optimum production of agricultural produce. Tractor as a machine designed to generate a high tractive force at slow speeds, for the purpose of hauling a trailer or farm implements used in agricultural land preparation, cultivation, chemical application, harvesting etc. Consideration of effectiveness of tractors in converting power to drawbar is vital in selecting field efficiency for tillage activities. Energy is mainly lost to generate traction force applied to the parts which enable the implements to move through the soil. The energy losses are dependent on the type and weight of the tractor, field conditions and the load pulled [12-13]. The magnitude of drawbar power available depends on many factors, namely, soil condition, speed of operation, tire size, ballasting, etc. Furthermore, it is reported that effect of soil variations on performance of tractor as soil resistance varies in different soil conditions. It is concluded that a tractor capable of performing all operations in time for a specified size of field in lighter soil may not able to do them in heavier soil for the same size of field. Moreover, the tilt for heavier soil is achieved later than the lighter soil, which means in any season total number of working hours available for heavier soil will be less than the lighter soil [14-15]. The typical speed and the draft requirement for various implements for different field operations **in** different soil conditions are given in table 2. The necessary activities for optimal selection and matching of tractor and implements are: (i) predict the draft and power requirement of the implement taking into consideration factors such as depth and speed of operation, implement width and soil condition. And (ii) Predict the tractive capability and the drawbar power that can available on the tractor by considering factors such as vehicle configuration, weight distribution, ballasting, tractive device type, and terrain conditions [16].

Measurement of draft: Draft is the power in relation to pull-type or mounted implements, actually required to pull or move the implement at uniform speed. Unit draft is draft per unit width, usually, expressed as newton per centimeter (N/cm). Draft is calculated due to drawbar power using Equation 5 [11]

$$D = \frac{c * DBP}{S} \text{ ------ (5)}$$

Where,

D= Draft, Kn, C= Constant=3.6, DBP= Drawbar power, kw, S= travel speed km/hr

Drawbar: It is the power required to pull or move the implement at a uniform speed, in relation to either a pull – type or a mounted implements, and can be expressed by the following equation [11]

$$DBP = \frac{D * S}{C} \text{ ----- (6)}$$

Fuel consumption

Fuel costs vary with the use of the machine; the fuel consumption is measured or estimated and multiplied by its respective price to determine its cost. Fuel costs will depend on the type of work done and tractor power and load. The overall fuel consumption of tractors as follows: 1.89 L/h for 40 hp tractors, 3.78L/h for 65 hp tractors and 7.57L/h for 90 hp tractors [11, 17]. The most accurate method for estimation of these costs is the actual records on similar machines, and operations. In case where such records are not available, it's relatively simple to estimate these costs because fuel consumption is directly related to the amount of energy extended. The specific fuel consumption of a diesel engine to the power utilization ratio X, [18] as follows:

Diesel fuel consumption = $0.52X + 0.77 - 0.04(73.8X + 173)^{1/2}$ …. (7)

Where:

X = the ratio of equivalent PTO power required by an operation to that maximum available power from PTO

Table 2 Draft, recommended speed and field efficiency for various implements /equipment [19]

Implement/equipment	**Draft per meter width, kN**	**Typical speed km/hr**	**Field efficiency, %**
MB Plough (200mm depth			
Heavy clay soil	15.7	4.5	80
Heavy soil	13.73	5.0	80
Medium soil	10.30	5.0	80
Light soil	6.87	6.0	80
One way disc plough			
Heavy clay soil	5.90	6.0	80
Medium soil	4.41	6.0	80
Light soil	2.94	6.0	80
Offset or heavy tandem disc harrow			
Heavy clay soil	5.90	6.0	80
Medium soil	4.91	6.0	80
Light soil	3.73	6.0	80
Duck foot cultivator			
Heavy clay soil	4.41	6.0	80
Medium soil	2.94	6.0	80
Light soil	1.47	6.0	80
Seed Drill			
Heavy clay soil	1.47	5.0	70
Medium soil	0.88	5.0	70
Light soil	0.49	5.0	70
Planter			
Heavy clay soil	1.47	5.0	70
Medium soil	1.72	5.0	70
Light soil	1.77	5.0	70

Role of Crop Parameters on Machinery selection

The crops parameters like**,** sowing schedule, coverage hectors, cropping pattern, Soil types, soil physical properties and field conditions etc have a great influence on the selection of machine for agricultural production. Also soil physical properties have a significant influence on the performance and efficiency of farm machinery especially on tillage implements. It would be necessary to study the type and characteristics of a soil for specific field conditions before deciding to engage farm machines for any field operation. The system developed offers the user three choices for changing soil conditions; which are: firm, tilled and sandy or soft soils, and then the system computes the required drawbar power for the selected implements [4,27]. Data collected by on actual farms indicated that machinery used on the farms was not always properly matched to the available power, and in several cases machinery was oversized with respect to the area farmed. To make an accurate comparison, it was evident that a properly sized machinery complement was needed for the different tillage systems on different soils under various cropping sequences [20].

Results and Discussion

The power requirements in Kilowatts increased as soil factor changed from firm to tilled and sandy or soft soils as shown in figure 1 below. In all cases chisel plow requires higher kilowatt of power, whereas inter row cultivator with less, that might be due to differences in depth of operation.

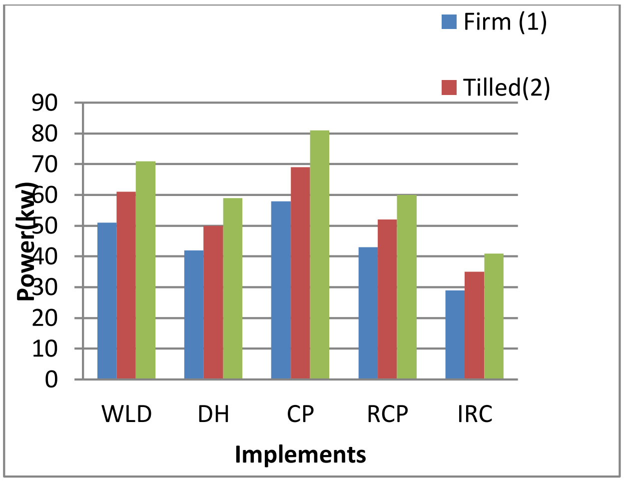

Figure1 Variation of power required for different implements for changing soil factors [4], in which, WLD = Wide Level Disc, DH =Disc Harrow, CP =Chisel Plow, RCP =Row Crop Planter, IRC =Inter Row Cultivator

The computer system results also showed insignificant differences between the predicted and actual data for effective capacity (ha/hr), implements width (m) and fuel consumption (L/h) for three field operations (seedbed preparation, seeding, and weeding operations) and 3 farming systems (zero-tillage, conventional, and heavy machines farming systems). The system estimates the size and number of machine, power requirement and fuel consumption for the implements and operations. Figure 2 below presents the comparisons of actual and predicted field capacity, fuel consumption and implement width of some implements.

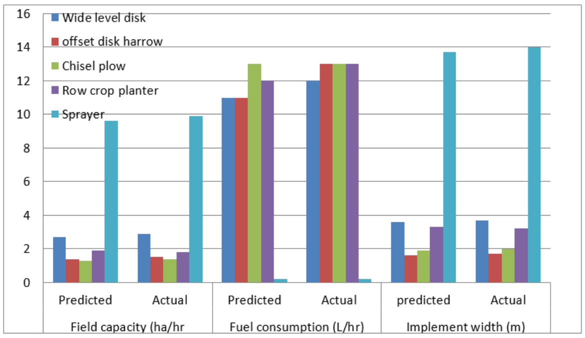

Figure 2 Comparisons of actual and predicted field capacity, fuel consumption and implement width of some implements [4]

From figure 2 above, it is observed that there is no significant differences between predicted and actual results for all parameters namely; field capacity (ha/hr), fuel consumption (L/hr) and implement width (m) for implements. Therefore, the result indicates a validity of the developed system as consistency between actual data and the system predictions are higher.

From figure 3, it is observed that, the increasing cultivated area for example from 420 to 3780 ha, the number of machines changed from machine one to 3, 6, 9, 9, 5, and 3 machines for wide level disk, disk harrow, chisel plow, row crop planter, inter-row cultivator and sprayer, respectively. The results indicate that, chisel plow and row crop planter are highly sensitive to the changes in area. It is also concluded that this may be due to their effective width, working speed or available working hours per day. On the other hand, WLD and sprayer are less sensitive to the changes in cultivated area [4,25,26].

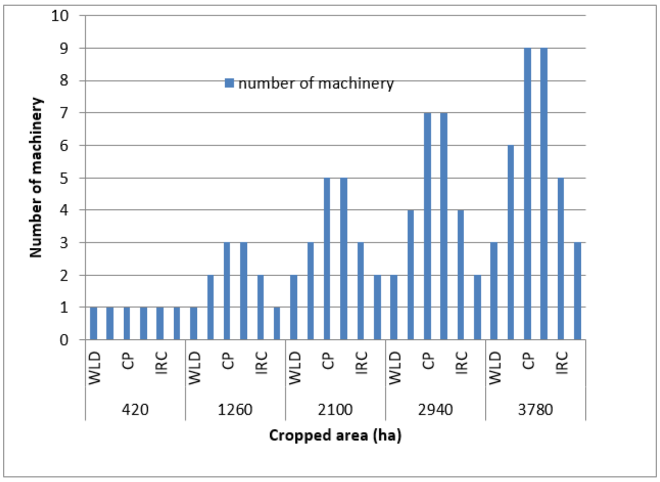

Figure 3 Effect of changing cropped area on number of machines for deferent operations[4]

Figure 4 indicates the system's estimation of the optimum machine working width when annual working days are changed. It helps the farmers to select the appropriate width of a machine according to the available working days and farm size. The results also indicated that, the predicted working width for all studied machines decreased significantly as annual working days increase because farmers get relatively enough time to perform their farm activities with smaller implements. This practice is good only where agronomic window is large, otherwise timeliness cost is incurred.

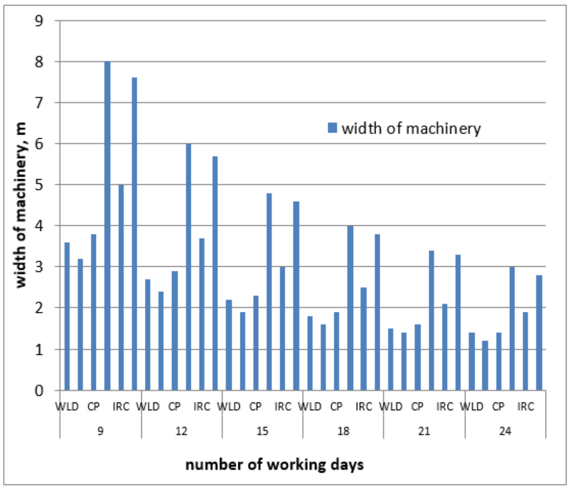

Figure 4 Effect of changing working days on machine width [4]

Figure 5 depicts improved the sizing of a single machine as well as machinery sets on a specific farm by allowing for a structuring of the input data, which coincides with the type of data and amount of data already present on the farm. The model was developed to estimate the optimal least-cost sizes of the whole-farm machinery complement, taking into account constraints such as workability, timeliness, sequence of operations, labor availability, etc. Some results of their findings were presented bellow based on units of capacity category.

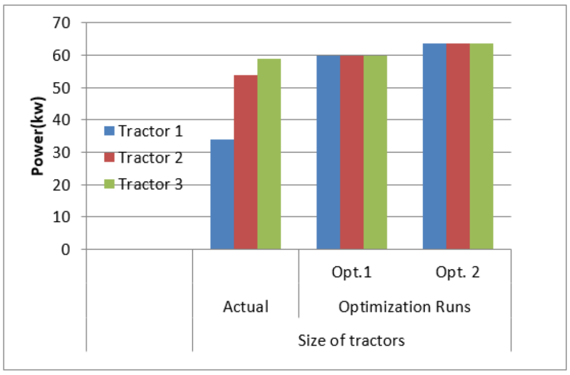

Figure 5 Comparison of actual and optimized farm tractor power.

It is known that there are different land preparations activities like; sub soiling, ploughing, harrowing, land leveling and cultivation. The optimum tractor size selection should be determined by the activity which requires more tractor power. In optimization run 2 as depicts in figure 5, a larger tractor is optimal, due to the introduction of an exact chopper, which requires more tractor power. Therefore; an increase in tractor power will enable the use of bigger implement which can utilize the increased tractor power.

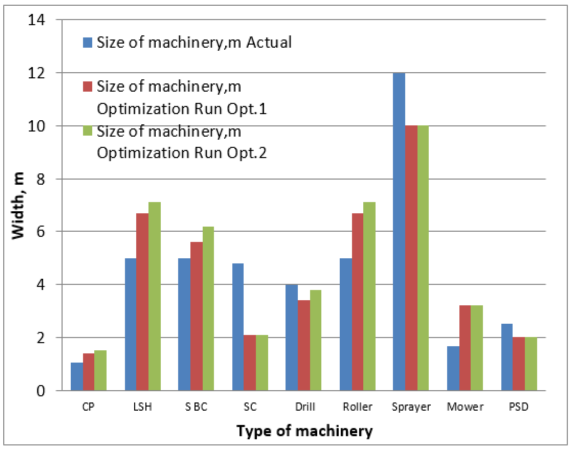

Figure 6 Comparison of actual and optimized power requirements of some implements [6]

Timeliness, cropping plan, available tractor size and workability associated with the operations to be performed are important factors in selecting the optimum size of farm implements. Figure 6 shows comparisons of optimized machinery requirements to actual machinery present on a case-study farm. It showed good similarity except for some significant differences, which suggest that some of the actual machines are not sized optimally

Conclusions

Form the above studies the following conclusions were made**;**

Changing soil factor changes the power requirement for different farm operations; changing implements also require different kilowatts of power. For example chisel plow requires higher kilowatts of power, whereas inter row cultivators consumes less power. Different systems estimate the size, number of machine, power requirement and fuel consumption for the implements and farm operations.

The systems also made comparisons of actual and predicted field capacity, fuel consumption and implement width of implements and reported no significant differences between predicted and actual values for the parameters namely; field capacity (ha/hr), fuel consumption (L/hr) and implement width (m) for implements. Furthermore, computer systems also estimated the optimum machine working width when annual working days are changed. It is also indicated that, the predicted working width for all studied machines decreased significantly as annual working days increase because farmers get relatively enough time to perform their farm activities with smaller implements.

According to findings, optimum tractor size selection should be determined by the activity which requires more tractor power that means an increase in tractor power will enable the use of bigger implement which can utilize the increased tractor power.

Findings also added that timeliness, cropping plan, available tractor size and workability associated with the operations to be performed are important factors in selecting the optimum size of farm implements.

Annual working days (crop calendar) affect machine working width, however, other crop parameters; like soil conditions and coverage of hectares also affect farm machinery selection and differences in field operations and farming systems require different implement type and size with difference capacity (ha/hr) and fuel consumption for tractors (L/hr)

Recommendations

Crop parameters like field conditions, soil types, soil physical properties and crop calendar vary from one agro-ecological area. Therefore it is recommended that more studies should be conducted at specific agro-ecological area if comprehensive performance data for farm machinery selection is required for selection of optimum size farm machinery.

Conflict of Interests

The authors declare that they have no competing interests; honest efforts are to transfer the technology to the farmer's community and agro industries for the better improvement of agro-production.

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