JEAS

JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

Journal of Engineering and Applied Sciences 14 (2018), 1-12

# A FIELD MACHINERY CAPACITY SELECTION MODEL FOR TILLAGE OPERATIONS IN NIGERIA

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**Abstract**
A machinery size selection model and annual cost model were developed for heavy tillage implements. The model development was based on differential calculus as in Hunt-Wilson's least-cost tillage width model. Field processing labour cost was considered and the Hunt-Wilson model's need for prior arbitrary width-dependent machinery capacity input for width selection circumvented. The model was validated with data from tillage operations of the machinery hiring unit of Anambra State Ministry of Agriculture Awka, Nigeria. The capacity based machinery size selection will assist in decision making on tillage implement selection model; including comparison of machinery alternatives within and across various power sources. A plough capacity of 0.8956 hectare per hour which translates to 2.5997 m was predicted for processing the 675 ha farm simulated by the developed model. This capacity was considered adequate when compared with the lower 1.8385 m width required on the basis of available suitable field operation period. The smallest plough width of 1.7587 m predicted by the Hunt-Wilson model was seen as less than adequate. Finally based on the pieces of equipment available readily in the local market, 3 pieces of 0.310 hectare per hour was chosen to provide the needed plough capacity. Their combined capacity of 0.930 hectare per hour translates to a width of 2.999 m. The corresponding annual machinery cost per hectare was predicted as ₦5,542.72.

**Keywords:**Farm mechanization, Field machinery cost models, Minimum-cost tillage machinery selection, Field machine capacity.

## 1. Introduction

Mechanization of agriculture increases cropped area and crop output while reducing farm drudgery (Nwuba, 2009 and Oluka, 2014). Based on the 3 main power sources the technological levels of mechanization are categorized into hand-tool, draught-animal and mechanical-power technologies (Sims and Kienzle, 2006). Because farming like any other business is engaged in for economic benefits, farm mechanization must be done in a way that yields desirable economic and other benefits. Diverse factors (like technologies, equipment types, size and combinations) affect farm mechanization equipment performance (Rijk, 1999), making the equipment selection a management decision issue in any proposed agricultural project.

Power and machinery has been reported to amount up to 60 % of the overall (non-land) investment on a farm (Dash and Sirohi, 2008). Moreover, reversal of the machinery selection decisions once the machine is procured is very costly. The selection of the mechanization level and equipment types, deserve adequate attention since they significantly affect profitable farm mechanization. The Hunt-Wilson (2015) cost-based tillage machinery selection model has some short-comings. It predicts the least-cost width with a prior width-dependent variable input. Machinery labour cost which affects the least-cost machinery width for any given farm size (Srivastava *et al*, 2006) was neglected in the model's development.The objective of this study was to develop a minimum-cost tillage machinery size selection model that needs no prior arbitrary machine size variable. Equally, the machinery labour cost effect will be considered in developing the model. Avoiding the need of a prior machine size input for machine width prediction will make the machinery selection process less subject to the user experience or otherwise. The developed model will assist farm machinery managers and tractor and equipment hiring companies in sound economic machinery selection.

Different models exist for mechanization management decision support. Conditions that were not considered during a model development process or that vary from the basis of the model formulation may be taken care of with correction factors. Takeshima *et al* (2013) simulated Nigerian farm households' in farm size choice and mechanization adoption for land preparation with a linear programming (LP) model. Awulu*etal* (2016) developed a graphical user interface driven mathematical program for matching tillage implement to tractor size.

Sogaard and Sorensen (2004) used a non-linear programming model for annual costs minimization of individual Danish farms. Sequence of operation and other machine and farm parameters were utilized in addition to the machinery costs for achieving cost minimization. Economic or physical variables based single objective quantitative models are traditionally used by researchers in machinery selection (Dash and Sirohi, 2008). The optimum-cost machinery width model developed by Hunt (1999b) via differentiation for selecting the optimum-cost machine width is shown in Eq. (1).The definition of the variables and notations is listed after the references list.

$$w = \sqrt{\frac{10A}{\mu Se}(L + T + \psi)} \tag{1}$$

Akinnuli*et al* (2014) adapted the model for tractor and implement selection in Nigeria. Srivastava *et al* (2006) gave the optimum-cost machine size in the form of machine capacity ($C_e$) as shown in Eq. (2).The incremental price per incremental width or per incremental capacity was used to estimate price per unit size for evaluating the fixed cost function.

$$C_e = \sqrt{\frac{A}{\mu_c}(L_c + T_c + \psi_c)} \tag{2}$$

Dash and Sirohi (2008) used the optimum-cost width model (Eq. 1) for selecting farm power and machinery size for Indian paddy-wheat farming system.Akinnuli*et al* (2014) used the model for farm machinery selection in Nigeria. Zaied*et al* (2014) selected machinery size based on the optimum-cost field capacity instead of the optimum-cost width. The optimum-cost capacity (Eq. 2), can be adopted for machinery selection across power sources. Ismail and Abdel-Mageed (2010) compared the energy and labour requirements of Combine, reaper-thresher and manual wheat harvest-thresher systems in Egypt based on machine capacity.

For heavy-draught tillage implements like ploughs, harrows, etc,Hunt and Wilson (2015) reported that Eq. (1) will lead to very large erroneous optimum width selection. This they say results from the assumption that tractor cost $T$ is independent of implement size. By extension, Eq. (2) could also give similar result. The purchase price of the required tractor is much higher than thetillage implement price, and should affect the optimum-cost tillage implement size selection more. They recommended the use of a different annual cost model based on tractor fixed costs, implement fixed costs, and tillage fuel cost as follows

$$AC_g = \mu w + \frac{A}{C_e} fl + \pi\Pi \tag{3}$$

The third part of the annual tillage cost equation is the annual tractor fixed cost ($T$) allocated to the tillage operation. The annual tillage cost equation is evaluated as

$$AC_g = \mu w + \frac{Ad\sigma}{2.66He}\Theta + \frac{\kappa d C_e}{2.66e}\Theta \tag{4}$$

where:

$$\kappa = \frac{\pi}{\delta} \tag{5}$$

$$\Theta = C_1 + C_2\frac{100{C_e}^2}{w^2e^2} \tag{6}$$

$C_1$ and $C_2$ are obtainable from table for known soil types, (Hunt and Wilson, 2015).Eq. (6) evaluates the specific draught ($\Theta$) for the tillage operation.

Following the example of the general machinery cost model, $AC_g$ can be differentiated with respect to implement width to get the tillage machine width that minimizes the annual tillage machine cost. The least-cost width developed by Hunt and Wilson (2015) from the solution of the derivative is shown in Eq. (7).

$$w = \sqrt[3]{\frac{C_2 d}{\mu e^3}\alpha} \quad (7)$$

where $$\alpha = 75A\eta {C_e}^2 + 75\kappa {C_e}^3 \quad (8).$$

Eq (9) expresses the ratio of fuel price to the tractor engine's fuel efficiency at the given percentage power loading.

$$\eta = \frac{\sigma}{H} \quad (9)$$

The method for evaluating Eq. (7) involves imputing a prior implement field capacity value the user desires, along with the other concerned variables (Hunt and Wilson, 2015). Finally the computed implement width is compared with implement sizes available in the market, and a suitable size or a combination of sizes of available machine chosen.

## 2.0 Material and Methods

### 2.1 Theoretical considerations

For cost or profit optimization, machinery costing must be properly addressed. Farm machinery cost is composed of fixed costs and variable costs. Fixed costs are made up of machinery depreciation, shelter cost, interest on investment, insurance costs and taxes and duties. Variable costs on the other hand are made up of: fuel, oil and lubricants, labour and repair and maintenance costs (Kepner*et al*, 2003). Variable costs vary with machine use while fixed costs are independent of machine use. Timeliness cost is an indirect cost introduced so as to ensure that the minimized cost can be practicable. It is a penalty levied on the proposed machine for possible losses in crop value resulting from its failure to carry out the given operations within the optimum period.

Costs approximation is considered adequate for future costs estimation since the future cannot be perfectly predicted (Hunt, 2001). For the ease of mathematical manipulation, fixed cost (*FC*) is given as a product of annual machine fixed cost factor percentage ($\gamma$) function and purchase price (*P*). The machine fixed cost is the sum of the annual fixed cost components. The annual fixed cost is expressed as a percentage of the purchase price as in Eq. (10)(Hunt, 2001).To obtain the fixed cost factor percentage ($\gamma$) the unknown machine salvage value was estimated as ten percent of the purchase (Hunt, 1999).In annual machinery cost estimation variable costs are evaluated as a product of the annual machine use hours and the hourly total variable cost estimate.

$$\gamma = 100\left[\frac{0.9}{\Gamma} + 0.55r + ts\right] \quad (10)$$

### 2.2The model development

Field processing labour cost was included as one of the essential machinery cost components in the minimum-cost tillage machine size determination. The model developed in this study was based on the assumptions that hourly repair and maintenance, and lubricant costs depend on field size processed and not machine size (Hunt and Wilson, 2015). It was also assumed that farm and crop parameters; like farm size, required operations and time windows,etc are known.The developed annual tillage cost equation was obtained as in Eq. (11) by including operation labour cost to Eq. (4).

$$AC_g = \mu w + \frac{A}{C_e}L + \frac{Ad}{2.66e}\eta\Theta + \frac{C_e d\kappa}{2.66e}\Theta \quad (11)$$

Usingdifferential calculus as done by Hunt and Wilson (2015), the minimum-cost width was gotten as in Eq. (12).

$$w = \sqrt[3]{\frac{C_2 d}{[\mu + \mathrm{K}\rho]e^3}\left[\frac{100AC_e e}{C_2 S^2 d}L + \alpha\right]} \quad (12)$$

where:

$$\mathrm{K} = \frac{0.0375\pi}{\delta} \quad (13)$$

$$\rho = C_1 S d \quad (14)$$

**2.3 A Minimum-cost tillage machinery capacity model**

The Hunt-Wilson least-cost width model requires a desired machine capacity as input. This makes the machine selection process subjective, and susceptible to the user's experience or lack of it. The machine width chosen will in that case change with the desired capacity used. Equally machine capacity is a function of machine width as can be seen in Eq. (15). Consequently this study sought to eliminate the approach of using an arbitrary prior machine capacity for evaluating machine width. The model developed in this study selected the tillage machine size on machine capacity basis as was done by Srivastava*et al* (2006) for the general machine case. The implement fixed cost per width ($\mu$) in Eq. (12) was thus replaced with fixed cost per capacity ($\mu_c$). Effective field machine capacity was given by Field and Solie (2007) in terms of working width and speed, and field efficiency as

$$C_e = \frac{Swe}{10} \quad (15)$$

The cube of Eq. (12) was obtained and the output multiplied by $\left(\frac{Se}{10}\right)^3$based on the definition of the field machine capacity given in Eq. (15). This converts the obtained $w^3$to ${C_e}^3$. A quadratic equation in machinery capacity ($C_e$) was obtained as in Eq. (16)

$$(\mu_c + \mathrm{K}\rho - 2\mathrm{K}\tau){C_e}^2 - 0.075A\eta\tau C_e - 0.1SAeL = 0 \quad (16)$$

where $$\tau = C_2 S^3 d \quad (17)$$

Eq. (15) was simplified by representing the block variables with simpler terms defined in Eqs. (18) to (20).

$$\mu_c + \mathrm{K}(\rho - 2\tau) = a' \quad (18)$$

$$-0.075A\eta\tau = b' \quad (19)$$

$$-0.1SAeL = c' \quad (20)$$

Eq. (16) was thus simplified as

$$a'{C_e}^2 + b'C_e + c' = 0 \quad (21)$$

This quadratic function of $C_e$was solved using the formula method and has the feasible solution shown in Eq. (22).

$$C_e = \frac{-b' + \sqrt{b'^2 - 4a'c'}}{2a'} \quad (22)$$

**2.4 Model validation**

The model was validated using data gathered from field studies conducted in the farms serviced by the tractor and equipment hiring unit of the Engineering Department, Ministry of Agriculture, Mechanization, Processing and Export of Anambra State, Nigeria. The studied farm was located around latitude and 6º 20′′ north and longitude 7º

8″ east and cropped cassava. For evaluation of the field machine size with the developed model, combination of the studied farms sizes was employed in order to achieve sizes considered big enough for economic mechanization. Ploughing operation in the location was studied. Values of the models variables collected from the studied farms were employed in evaluating the minimum-cost implement machinery capacity selected by the model. Speed ($S$) of 5.3 km/hr, tillage depth ($d$) of 18.5 cm and field efficiency ($e$) of 0.65 based on the observed operations parameters were employed. The least-cost width was equally selected with the Hunt-Wilson model based on the same farm parameters input.
The value of the required basal field capacity based on the available hours for the tillage operations in the studied location, see Eq. (23) were also compared with those evaluated with the selection models based on the input parameters collected. Suitable time for ploughing operation in the non-flooded cassava zones of Anambra State Nigeria was obtained from the operations record of the Anambra State Agricultural Development Programme (ASADAP) Awka.

$$C_{eQ} = \frac{A}{AD \times G} \qquad (23)$$

The required basal field capacity and the one obtained with the developed model were converted to the equivalent machine width. The widths obtained with the model developed in the study and the Hunt-Wilson model widths were compared with the basal capacity's equivalent width for validation of the model. ANOVA of these widths was done with Excel Software. The computer models were coded on Excel software for the models solution. The ratio of the width-to-farm size and cost per hectare were employed in the ANOVA so as to have a common basis for comparing their means.

**2.5 Experimental procedure:**

Ploughing operation was carried out in selected farms at the various study locations.

- ✓ The tillage depth was measured with improvised depth-guaging instrument, see Figure (1). One limb of the builder's square was dipped vertically into the tilled portion close by an untilled area. A magnetic sticking plum was placed on top of the horizontal limb of the square to show when it was balanced horizontally. The vertical distance from the square top to the surface of the untilled portion was measured with a 5 m tape rule. The tillage depth was evaluated as the difference between the length of the vertical square limb and this measured distance.
- ✓ The implement working width also was measured with a 5 m tape rule.
- ✓ The farm size was obtained from the hiring outfit records.

**Figure 1: Tillage depth measuring instrument**

- ✓ The time spent to process the field was measured with stop watch.
- ✓ Forward speed of the field operations were obtained by measuring the distance traversed with a 30 m tape rule and the time taken to cover the distance with a stop watch. The ratio of the travelled distance to the time taken was obtained.
- ✓ The equipment purchase prices and cost items were gotten from dealers and hiring outfits. The data collected for input into the models are listed in Tables (1 and 2), and were analyzed.

- ✓ The available days for processing the field was estimated from the period of the year the local farmers in the studied area requested for tractorrizedploughing services from the Anambra State-run tractor and machinery hiring outfit in Awka, Nigeria.

**Table 1: Tractor parameters used**

| **Model** | | **MF 425** |
|---|---|---|
| Drive Option | | 4WD |
| Capacity/ Power Size | Indicated (kW) | 48.50 |
| | PTO (kW) | 46.56 |
| Weight | (kg) | 2870 |
| Total $\beta$ (%) | | 19.61 |

**Table 2: Implement parameters used**

| Model | | Baldan AF 3 3-Bottom Disc Plough | Baldan AF 4 4-Bottom Disc Plough |
|---|---|---|---|
| Disc Diameter | (m) | 0.71 | 0.71 |
| *Speed* $S$ | *(km/hr)* | 5.3 | 5.3 |
| Working Width $w$ | (m) | 0.9 | 1.2 |
| Tillage Depth $d$ | (cm) | 18.5 | 18.5 |
| Field Capacity $C_e$ | (ha/hr) | 0.3100 | 0.4133 |
| Field Efficiency $e$ | | 0.65 | 0.65 |
| Fixed Cost Factor $\gamma$ | (%) | 24.61 | 24.61 |

**3.0 Results and Discussions**

The effect of farm size variations on the selected size of plough and their corresponding annual tillage machinery costs for a given soil-type pool farms were studied. The period of the year the farmers came for tractor and plough hiring was mid-March to mid-July for early cassava. Implement and machinery hiring for late cassava tillage operations was requested in September through November. These amounted to 87 working days and 65 days for early and late cassava respectively. This gave a total of 152 days. With the hiring outfit's seven working hours in a day, the available period amounted to One Thousand and Sixty Four hours. The farm area was divided by these available hours to estimate the required basal plough capacity.

**3.1 Plough size and cost under farm size variations**

The minimum-cost disc plough widths obtained with the model developed in the study and the Hunt-Wilson model for varying farm sizes are presented in Figure 2. The plough width derived from the basic plough capacity requiredto process the given farm sizes within the available tillage period is also shown in Figure (2). Plough widths ($w$) of 0.5481 m, 0.9740 m, 2.1009 m and 2.5997 m were obtained from the minimum-cost plough capacity selected with the developed model for farm sizes ($A$) of 45, 145, 420 and 675 hectares respectively. The basal plough widths computed on the basis of available operation time for completing farm sizes were 0.1187 m, 0.3941 m, 1.1442 m and 1.8385 m for the listed farm sizes in that order. The Hunt-Wilsons least-cost plough widths selected were 0.8186 m, 1.0201 m, 1.5896 m and 1.7587 m for the same listed farm sizes in that order.

The prediction of the plough width obtained for the 2 models with the farm size followed a 2nd order polynomial trend. The L- model trendline equation was as shown in Eq. (24), and had an $R^2$ value of 0.998.

$$w_L = -3 \times 10^{-6} A^2 + 0.0054A + 0.2985 \quad (24)$$

The trendline equation for H- model was as shown in Eq. (25), with an $R^2$ value of 0.996.

$$w_H = -2 \times 10^{-6} A^2 + 0.003A + 0.6755 \quad (25)$$

For the required basal machinery size prediction from the farm size, it was a linear equation as shown in Eq. (26), and had an $R^2$ value of 1.

$$w_B = 0.0027A + 4 \times 10^{-15} \quad (26)$$

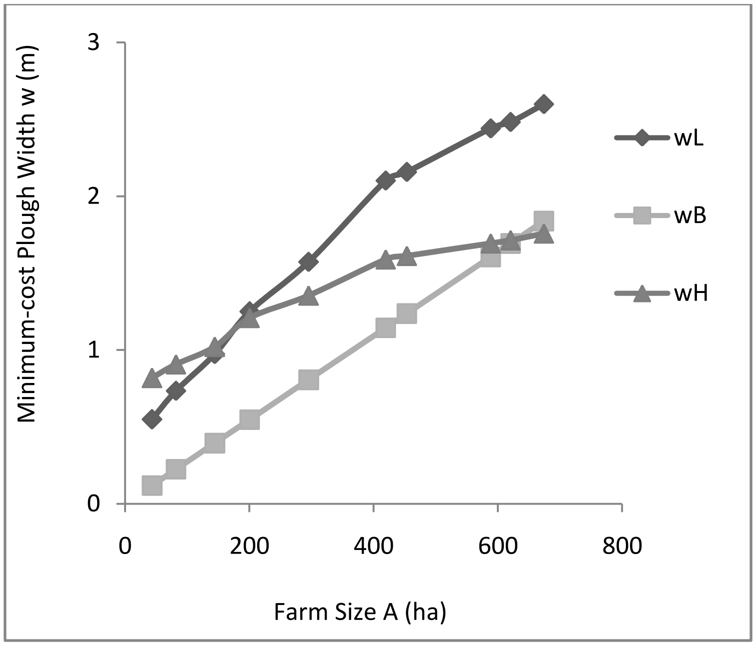


**Figure 2: Minimum-cost plough width for farm sizes variation**

Higher plough widths were selected for increasing farm sizes by the 2 models and basal plough sizing. It can be seen that the least-cost plough width selected by the Hunt-Wilson model was higher than the widths obtained from the developed model for all the farm sizes simulated. A singular prior capacity (0.301 ha/hr) was chosen for the Hunt-Wilson model width evaluation for all the farm sizes simulations. This could have resulted in the sustained increasingly lower values of the Hunt-Wilson model width in comparison to the developed model width.

The arbitrary choice of the prior capacity has been noted as subject to the users experience or otherwise. The width selected by the Hunt-Wilson model could not suffice the basal capacity required at 675 ha farm size. There was probably a need to increase this desired prior capacity for higher farm size. The need for the avoidance of this subjective approach has been highlighted earlier-on and the solution is proffered in the model developed in this study.

Table 2 shows the ANOVA F- and p-values for each of the 2 models width per hectare comparison with the basal width per hectare at the 0.05 level of significance. The test F value of 15.7047 obtained in the developed model's width comparison with the basic width was higher than the F-critical of 4.4138. Also the 0.00091 p-value obtained in the ANOVA test is less than the 0.05 p-value for 95 % confidence level. This shows that the widths predicted by the developed model differed significantly from the basic size widths for the studied farm sizes.

For the Hunt-Wilsons model width comparison with the basal width, the 4.9344 F-test obtained was higher than the F-critical of 4.4138. Also the 0.03636 p-value was less than the 0.05 p-value for 95 % confidence level. This showed

**Table 2: ANOVA F- and p values of the basal and model widths**

| ANOVA Result (F-crit = 4.4138, P = 0.05) | | |
|---|---|---|
| **Group Pairs Compared** | $wR_L : wR_B$ | $wR_H : wR_B$ |
| F-test | 15.70479 | 4.93447 |
| p-value | 0.00091 | 0.03939 |

that the widths predicted by the Hunt- Wilson model were significantly different from the basic size widths for the studied farm sizes. This implies that a dependable attendant lower fixed cost can be expected for the reduced plough sizes predicted at lower farm sizes by the developed model. Small-scale farmers have the problem of small capital and will find the application of the model a suitable solution.

The annual plough machinery costs per hectare for the 2 models are plotted against varying farm sizes in Figure 3. The annual plough machinery cost was ₦16,578.54, ₦10,670.67, ₦9,238.50 and ₦8,145.70 for the same sizes (*A*) of 45 ha, 145 ha, 420 ha and 675 ha, respectively for the developed model width. For the Hunt-Wilson model it was ₦12,378.38, ₦8,471.28, ₦7,708.13 and₦7,010.44 for the same listed farm sizes in that same order. The plough machinery cost per hectare corresponding to the basal size width is also listed in Table 2 and plotted inFigure 3. Itwas ₦23,820.02, ₦10,464.30, ₦7,639.94 and ₦6,620.47 for the same listed farm sizes in that order.

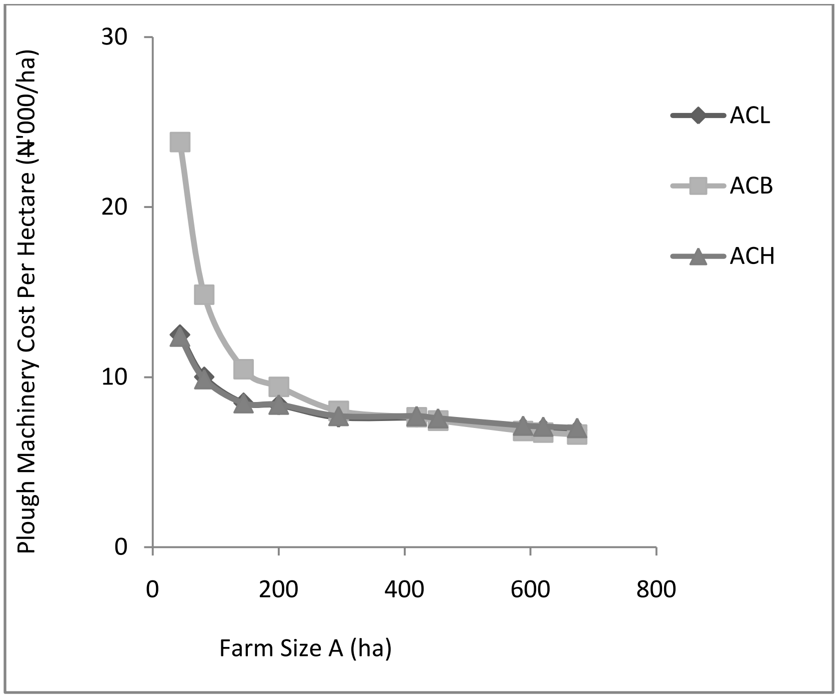


**Figure 3: Annual plough machinery cost per hectare for varying farm sizes**

The plough machinery cost per hectare incurred for the selected width can be predicted with a power function of the farm size. The L- model trendline equation was as shown in Eq. 27, and had an $R^2$ value of 0.9482.

$$AC_L = 24232A^{-0.196} \tag{27}$$

For the H- model trendline was as shown in Eq. 28, and had an $R^2$ value of 0.9389.

$$AC_H = 22916A^{-0.185} \tag{28}$$

The basal size cost trendline was as shown in Eq. (29), and had an $R^2$ value of 0.9504.

$$AC_B = 103298A^{-0.433} \tag{29}$$

It was observed that the plough machinery cost per hectare for the Hunt-Wilson model width was lower than that of the developed model's widths for the studied farm sizes of 145 ha and less. Thereafter, it was higher than the developed model cost. The cost for the basal size width was the highest at farm sizes below 420 ha. As from farm sizes of 420 ha and above, it became lower than the Hunt-Wilson model cost. The basal width cost was less than the developed model's cost for farm sizes above 420 ha.

The F-test for each of the 2 models plough machinery cost per hectare and the basal size cost ANOVA at a 0.05 level of significance is also shown in Table 3. The test F value of 1.1082 for thedeveloped model's comparison with the basal size cost was lower than the 4.4138 F-critical value. Also the p-value of 0.3063 obtained in the ANOVA test is greater than the 0.05 p-value for 95 % confidence level. This showed that the annual plough machinery costs incurred per hectare for both models widths are not significantly different. For the Hunt-Wilson model's cost comparison with the basal size cost, the test F was 1.0651 and was lower than the 4.4138 F-critical value. Their ANOVA p-value of 0.3157 is greater than the 0.05 p-value for 95% confidence level. This shows no significant difference between the plough machinery costs per hectare incurred with the Hunt-Wilson model width and the basal size width.

**Table 3: ANOVA F- and p values of the corresponding cost per hectare**

| Group Pairs Compared | $AC_L : AC_B$ | $AC_H : AC_B$ |
|---|---|---|
| ANOVA Result (F-crit = 4.4138, P = 0.05) | | |
| F-test | 1.10826 | 1.06518 |
| p-value | 0.30638 | 0.31570 |

The foregoing shows that the annual plough machinery cost ($AC_g$) and the minimum-cost tillage capacity ($C_e$) models are sensitive to farm size variation. The annual tillage machinery cost per hectare decreased generally with increasing farm size. The decrease was sharp at smaller farm sizes up to 145 ha farm, and thereafter was gradual. The plough machinery costs for the 2 models widths and the basal plough size tended towards close values for each studied farm size for farm sizes of 420 ha and above.

The machinery costs per hectare were continually decreasing with increasing farm size, showing that the mechanization of large farms is more economical than that of small farms. The mechanization of larger farms has been reported as more economical than that of the smaller ones (Najafi and TorabiDastgerduei, 2015). Rasouli*et al* (2009) and Onwualu*et al* (2006) have reported fragmented and scattered holdings as some of the constraints to agricultural mechanization. Mehta and Pajnoo (2013) asserted that without the availability of machine appropriate for small farm holdings or substantial farm amalgamation there will be little mechanization. This may be explained by the fact that farm mechanization like any other business venture is economics-driven.

For the 675 ha maximum farm size simulated the 2.5997 m predicted with the developed model was considered adequate for processing the farm when compared with the basal 1.8385 m required size. The 1.7587 m plough width predicted by the Hunt-Wilson model was seen as inadequate when compared with the basal width required. The 2.5997 m predicted by the developed model was therefore chosen for processing the 675 ha farm. This translates to a 0.8956 ha/hr plough field capacity. The smallest capacity tractor-powered disc plough available readily in the local market (a 0.9 m *ie* a 0.310 ha/hr disc plough) was considered for deployment in combinations that will make up the desired field capacity.

The chosen small-sized plough will suit the small, irregular-shaped and scattered pool farms better than larger ones. The increased machine maneuverability problems and inter-farm transport costs that would result if larger-sized machinery should be used, will also be reduced. The claim is supported by Zoz (1973) who reported additionally that larger implements present with more transportation difficulties in accessing geographically spread out fields, and flexibility and maneuverability problems. 3 pieces of the 3-bottom (70cm disc diameter) plough of 0.3100 ha/hr capacity and 0.9 m working width was chosen. With these 3 ploughs capacity totaling 0.930 ha/hr (ie 2.999 m) the 675 ha farm size will be adequately processed. This selected size will incur an annual plough machinery cost per hectare of ₦5,542.72.

Effect of changing labour cost on plough machine size and machinery cost: The predicted annual plough machinery cost per hectare and the minimum-cost width for the labour rate changes in a 420 ha farm is shown in Table 4. A plough width of 1.6663 m was derived from the capacity selected by the L- model for ₦550.00 wages per hectare.

**Table 4: Predicted plough widths and incurred machinery costs for varyinglabourrates[a]**

| Labour Rate $L$ (₦/ha) | Selected Plough Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_B$ | $w_H$ | $AC_L$ | $AC_B$ | $AC_H$ |
| 550.00 | 1.6663 | 1.1442 | 1.2738 | 6165.73 | 6073.82 | 6292.70 |
| 700.00 | 1.8059 | 1.1442 | 1.2738 | 6392.60 | 10972.40 | 6634.52 |
| 850.00 | 1.9327 | 1.1442 | 1.2738 | 6598.44 | 15870.99 | 6976.34 |
| 1000.00 | 2.0495 | 1.1442 | 1.2738 | 6788.20 | 20769.57 | 7318.16 |

[a]Simulation of labour cost variations fora 420 ha farm

The basal size was1.1442 m, and the H- model selected 1.2738 m for the same labour rate. For ₦700.00, ₦850.00 and ₦1,000.00, labour rates the plough widths were 1.8059 m, 1.9327 m and 2.0495 m respectively with the with the L- model. The H-models widths and basal sizes remained unchanged for labour rate changes.

The incurred plough machinery cost per hectare was ₦6,165.73 for ₦550.00labour rate based on L- model cost. It was ₦6,073.82 based on the basal size and ₦6,292.70 with the H- model for the same labour rate. The ₦700.00labour rate gave annual machinery cost per hectare of ₦6,392.60, ₦10,972.40 and ₦6,634.52 with the L- model, basal and H- model sizes, respectively. For the ₦850.00labour rate, the corresponding annual plough machinery cost was ₦6,598.44, ₦15,870.99 and ₦6,976.34for the L- modelsize, basal size and H- model size respectively. For the ₦1,000.00labour rate, the corresponding annual plough machinery cost was ₦6,788.20, ₦20,769.57.07 and ₦7,318.16 with the L- model, basal and H- model sizes respectively. The obtained results showed that labourrate affected the annual plough machinery cost predicted by the tillage machinery models and the plough sizes predicted by the L- model.

## 4.0. Conclusion

The models employed in this study employs farm size, tractor power, and the prices of tractor, implement and fuel as input variables. The soil draught coefficient and tillage depth, speed and field efficiency are also needed as input. The annual cost of the tillage machinery and minimum-cost tillage machinery width are predicted as output for any given farm size. As the farm size increased the predicted width increased while the costs per hectare decreased continually. This showed that mechanization of large farms is more economical than that of small farms. Theselected size for the developed model varied with varying labour, while the H- model selected size and the basal size remained unchanged with varying labour rate.

The cost obtained for both models predicted widths and the basal width computed on the basis of available operation time were very close for farm sizes above 420 ha. The 2.5997 m plough width predicted by the developed model, which translates to 0.8956 ha/hr capacity was selected for processing the 675 ha farm simulated. When crosschecked with the pieces of equipment available in the local market, 3 pieces of plough having 0.9 m working width *ie* 0.310 ha/hr field capacity were chosen. This translated to a total width of 2.7 m. They will be powered by three 48.5 kW matching tractors.

The machinery sizes predicted by the L- and H- models were higher than the size calculated on the basis of the available hoursfor processing the given farm size. Increasing labourrate led to increase in plough machine size selected with the L- model. However the plough size selected with the H-model and that for the basal size remained unchanged withchanging labour rate.On the other hand, annual plough machinery cost predicted by the tillage machinery models generally increased with increasing labourrate.

## 5.0 Recommendation

The deployment of the developed model in Nigeria and other locations, it is expected will enhance appropriate machinery selection and cost-effective mechanization of agriculture with engine-powered technology. Smaller farms (of less than 200 ha) will enjoy lower machinery costs with the application of the developed L- model than with the deployment of the existing Hunt-Wilson model.For reduced machinery cost,agglomeration of smaller farms and developing models that will handle machinery selection for such scenario is recommendedsincelarge farmsmechanization is more economical than that of small farms. Determining thesuitable field work days will make the basal capacity estimation more dependable for comparing the selected machinery sizes.Appropriate and relevant farm record keeping will enhance the models deployment and help in mechanization studies and tractor and equipment management in the country.

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**List of Symbols**

| | | |
|---|---|---|
| $C_e$ = | effective field capacity, | ha/hr |
| $S$ = | operation forward speed, | km/hr |
| $w$ = | working width of machine / minimum-cost width selected, | m |
| $c$ = a constant; (for evaluating field capacity: $c = 10$) | | |
| $e$ = field efficiency of operation, | | decimal |
| $\Gamma$ = machine life, | | yrs |
| $r$ =rate of interest, | | % |
| $ts$ = combined taxes, shelter and insurance costs as percentage of purchase price, | | % |
| γ = annual implement $FC$ percentage, | | % |
| $FC$ = annual fixed cost of machinery, | | ₦ |
| $A$ =area cultivated by the farmer, | | ha |
| $T$ =fixed cost of tractor used by machine per hour, | | ₦/hr |
| $L$ = labour cost per hour, | | ₦/hr |
| ψ = timeliness cost per hour, | | ₦/hr |
| $AD$ = available working days annually, | | days |
| $D$ = working hours per day, | | hr/day |

| | |
|---|---|
| $\mu$= annual implement fixed cost per machine width, | ₦/m |
| $\mu_c$= annual implement fixed cost per machine capacity, | ₦/ha |
| $L_c$ = labour cost per hectare, | ₦/ha |
| $T_c$ = implement's tractor (fixed) cost per hectare, | ₦/ha |
| $\psi_c$ = timeliness cost per hectare, | ₦/ha |
| $p_c$ =purchase price per machine width, | ₦/m |
| $\delta$ =percentage power loading on tractor, | % |
| $fl$ =hourly fuel cost, | ₦/hr |
| $AC_g$ = annual tillage machinery cost, | ₦ |
| $\pi$ = annual tractor fixed cost per PTOpower for the tillage operation, | ₦/kW |
| $\sigma$ =fuel price, | ₦/l |
| $H$ =fuel efficiency at given % of maximum loading, | kW.hr/l |
| $\Pi$ = the equivalent PTO power employedin the tillage operation, | kW |
| $C_1$ ,$C_2$= soil-dependent draught constants | |
| $\gamma$ = implement annual fixed cost percentage, | % |
| $\beta$ = tractor annual fixed cost percentage, | % |
| $\kappa$ = ratio of incurred tractor fixed cost-to-thepercentage power loading for theoperation, | ₦/kW |
| $d$ = depth of tillage operation, | cm |
| $\emptyset$ = fraction of annual tractor use hoursdeployed in the tillage operation | |
| $w_L$= developed model predicted machinerywidth, | m |
| $w_B$= required basal size tillage machinerywidth, | m |
| $w_H$= Hunt-Wilsons model predictedmachinery width, | m |
| $wR_L$= developed model width-to-farmsize ratio | |
| $wR_H$= Hunt-Wilsons model width-to-farmsize ratio | |
| $wR_B$= required basal size machinery width-to-farm size ratio | |
| $AC_L$= machinery cost per hectare predictedfor the developed model width, | ₦/ha |
| $AC_H$= machinery cost per hectare predictedfor the Hunt-Wilson model width, | ₦/ha |
| $AC_B$= machinery cost per hectare predictedfor the basal machinery width, | ₦/ha |