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TILLAGE MACHINERY SELECTION MODEL FOR COMBINED NON-CONTIGUOUS FARMS

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Abstract
Small capital and fragmented scattered holdings hinder farm mechanization. These bottlenecks abound in small-scale farms and in developing countries.Machinery transport considerations were incorporated into the Hunt-Wilson least-cost tillage machinery selection model. The model was adapted to tillage implement capacity selection for non-contiguous small farms.The prior width-dependent machine capacity input requirement of the Hunt-Wilson model was circumvented, making the selection process less subjective and not susceptible to the user's experience. The model was validated with parameters from ploughing operations of the machinery hiring unit of the Anambra State Ministry of Agriculture Awka, Nigeria. A 3.3651 m plough width adjusted from the width predicted for the 675 ha with the developed model was considered adequate when compared with the adjusted required basal 2.1909 m size. It was thus chosen for processing the farms. 4 units of 0.9 m working width (ie 0.3100 ha/hr) tractor-powered disc plough which is locally readily available was chosen to provide the desired capacity. The 4 ploughs with 1.240 ha/hr total capacity (ie 3.599 m width) will each be powered by a 48.5 kW tractor. The chosen set of machinery will incur an annual plough machinery and transport cost per hectare of ₦12,866.95. The developed models will assist in selecting cost-effective tillage implements including comparison of machinery alternatives within and across various power sources.

Keywords: Non-contiguous pool farms, Small farms mechanization impediments, Field machinery cost models, Minimum-cost tillage machinery selection

1. Introduction

The lack of economic feasibility in the engine-powered mechanization for small farms and adequate capital had left such farms with hand tool mechanization option. Suitable amalgamation of small farms for engine-powered mechanization (Lai *et al*, 2015 and Adama*et al*, 2009) or availability of appropriate machine for small farms can reverse the trend (Mehta and Pajnoo, 2013). Mechanization increases cropped area and crop output while reducing farm drudgery (Nwuba, 2009 and Oluka, 2014). The removal of drudgery and undignified image from farming will make the enterprise attractive to the younger generation. They presently hate farming with anachronism because of these phenomena (Odigboh, 2000).
Good machinery management which includes proper selection of a machine system is necessary for profitable farm mechanization. Simple mathematical models and economic analysis can enhance the economic appropriateness of machinery selection and other machinery management decisions. The cost of the farm machinery alternatives must be clearly captured for such decision processes.
Machinery depreciation, shelter cost, interest on investment, insurance costs and taxes and duties make up machinery fixed costs. These overhead costs are incurred whether a machine is used or not. Variable costs vary with machine usage and are composed of: fuel, oil and lubricants, labour and repair and maintenance costs. Timeliness cost is an indirect cost penalty levied on the proposed machine for it capacity limitations. Value of crop losses

resulting from the machine's inability to carry out the required farm operations within the suitable period gives its estimate. Since the future cannot be perfectly predicted approximates of these costs are employed (Hunt, 2001).
For mathematical ease, the fixed cost is expressed as a product of the annual machine fixed cost factor -(denoted here as γ for implements andβ for tractors)- and machine purchase price (P). The annual fixed cost factor is the percentage of the purchase price represented by the total fixed cost (Hunt, 1999b and Amaefule*et al*, 2018). The annual variable cost is evaluated as the product of annual machine use hours and the sum of the hourly value of the involved cost components.
For economic management of farm power and machinery, researchers (Oluka, 2000, Hunt, 1999b, etc) have studied farm power and machinery ownership cost and come up with different models to predict costs, size of machines, etc. Oluka (2000) studied cost of owning tractors in Nigeria and came up with models for repairs and maintenance of tractors under different management systems in Nigeria.Sogaard and Sorensen (2004) used a nonlinear programming model for annual costs minimization of individual Danish farms.
Hunt (1999b) studied farm tractor and machinery cost and developed general models to predict annual farm machinery cost, and optimum-cost machinery width for single- and 2-crop situations. This model developed via differential calculus has been popularin farm machinery size selection (Dash and Sirohi, 2008,Akinnuli*et al*, 2014 and others). Zaied*et al*, (2014) selected optimum-cost machinery size based on optimum-cost capacity instead of width.
Such optimum-cost capacity model (Srivastava*et al*, 2006) can be used for machinery selection across power sources. Ismail and Abdel-Mageed (2010) compared the energy and labour requirements of wheat combine, reaper-thresher and manual harvest-thresher systems in Egypt, based on machine capacity. The machine purchase price is expressed as a product of machine width and incremental price per incremental width/incremental capacity for easier differentiation and for machine selection from different machine sizes alternatives.
Very little studies have been conducted on machinery selection for small farms which abound in developing countries including Nigeria. Available farm machinery selection models are not economically suitable for small non-contiguous farms situations. Developing machinery selection models that will also suit fragmented scattered farm is a necessity. This study has the objective of developing models for predicting matching size and number of farm machinery using minimum-cost approach for multi-crop pool farm operations. Such a model will assist farm machinery managers in sound economic machinery selection. It will specially enhance the adoption of mechanical-powered mechanization for small farms in a profitable way.

2.0 Material and Methods

2.1 Theoretical considerations

Hunt and Wilson (2015) noted that the tractor price being far higher than the tillage implement price should influence the least-cost tillage machinery width selection more. By extension, the optimum-cost capacity model which was developed on similar principles could also give likewise erroneous result.They prescribed different models for predicting theleast-cost tillage implement width Eq. (1) and the annual cost Eq. (6). The models were based on tractor fixed costs, implement fixed costs, and tillage fuel cost.

$$w = \sqrt[3]{\frac{\Omega}{\mu}\alpha} \quad (1)$$

The definitions of the variables and notations are listed after the references list. The block variables Ω, α, κ, η and μ are evaluated as in Eqs. (2, 3, 4, 5 and 7) respectively.

$$\Omega = \frac{C_2 d}{e^3} \quad (2)$$

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

$$\kappa = \frac{\pi}{\delta} \quad (4)$$

$$\eta = \frac{\sigma}{H} \quad (5)$$

$$AC_g = \mu w + flT \qquad (6)$$

where the machinery fixed cost per incremental width (μ) and the combined fuel and tractor costs (flT) are given as:

$$\mu = \frac{\gamma}{100} \times \frac{(P_2 - P_1)}{(w_2 - w_1)} \qquad (7)$$

$$flT = \frac{Ad}{2.66e}\eta\Theta + \frac{C_e d\kappa}{2.66e}\Theta \qquad (8)$$

Equation (8) gives the tillage fuel cost (the first part) and the annual tractor fixed cost of the tillage operation (the second part).Θrepresents the specific draught for the tillage operation; evaluated as:

$$\Theta = C_1 + C_2 \frac{100 C_e{}^2}{w^2 e^2} \qquad (9),$$

whereC_1andC_1care draught-related factors that can be found from tables for some known soil types(Hunt-Wilson, 2015).Evaluating Eq. (1) requires a prior choice of implement field capacity, along with the other concerned variables. The computed implement width is eventually compared with implement sizes available in the market, and a suitable size or a combination of sizes of available machine chosen.

Amaefule*et al* (2018) developed a tillage machinery cost, minimum-cost width and minimum-cost capacity models as in Eqs. (10, 11 and 12 respectively), following this Hunt and Wilson (2015) tillage machinery cost and width selection models.

$$AC_g = \mu w + \frac{A}{C_e} L + flT \qquad (10)$$

$$w = \sqrt[3]{\frac{\Omega}{\mu + \mathrm{K}\rho}\left[\frac{100AC_e e}{C_2 S^2 d} L + \alpha\right]} \qquad (11)$$

$$C_e = \frac{0.075A\eta\tau + \sqrt{(-0.075A\eta\tau)^2 + 0.4\big(\mu_c + \mathrm{K}(\rho - 2\tau)\big)SAeL}}{2\mu_c + 2\mathrm{K}(\rho - 2\tau)} \qquad (12)$$

where:

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

$$\tau = C_2 S^3 d \qquad (14)$$

$$\rho = C_1 S d \qquad (15)$$

Eqs. (14) and (15) represents the static and dynamic draught functions. The quadratic root function of machinery capacity $C_e$shown in Eq. (13)was represented in the simpler format in Eq. (16)(Amaefule*et al*, 2018).

$$C_e = \frac{-b' + \sqrt{b'^2 - 4a'c'}}{2a'} \qquad (16)$$

where:

$$a' = \mu_c + \mathrm{K}(\rho - 2\tau) \qquad (17)$$

$$b' = -0.075A\eta\tau \tag{18}$$

$$c' = -0.1SAeL \tag{19}$$

The use of a prior width-dependent machine capacity value in evaluating Eq. (1) was circumvented. This makes the machine selection process less subjective and susceptible to the the user's experience or lack of it. The implement fixed cost per width (μ) in Eqs. (1 and 4) was replaced with the cost per capacity (μ_c).

2.2 Tillage machinery cost and size modelling for pool farm holdings

Farm machinery selection with the general least-cost model gives uneconomic bigger machinery sizes for small scale farms. For example 11 kW tractor size was selected for even sub hectare-sized farms with the model (Dash and Sirohi, 2008). The tillage machinery selection model developed by Hunt-Wilson (2015) on similar basis could be expected to yield likewise uneconomic machinery sizes for small farms. Consolidating small farms into a large enough size has been shown as a possible approach to economic deployment of engine-powered mechanization for small farms (Adama*et al*, 2009; Mehta and Pajnoo, 2013 and Lai *et al*, 2013). This was limited to farms having common boundaries. For a farm having 2 crops (crops 1 and 2 for example), Hunt (2001) gave the annual general machinery cost (AC_c) and optimum-cost machinery width (w_c) models as shown in Eqs. (20 and 22).Variables subscripted 1 refers to crop 1 values of the variable and those with subscript 2, the values of the variables for crop 2.

$$AC_c = \left(\frac{\gamma}{100}\right)P + \begin{Bmatrix} \frac{A_1}{C_{e1}}\left[\frac{\Delta P}{100} + LOfT_1\right] \\ \frac{A_2}{C_{e2}}\left[\frac{\Delta P}{100} + LOfT_2\right] \end{Bmatrix} \tag{20}$$

$$LOfT = L + O + fl + T + \psi \tag{21}$$

$$w_c = \sqrt{\frac{c}{\mu}\begin{Bmatrix} \frac{A_1}{S_1 e_1}[L_1 + T_1 + \psi_1] + \\ \frac{A_2}{S_2 e_2}[L_2 + T_2 + \psi_2] \end{Bmatrix}} \tag{22}$$

This annual machinery cost and the least-cost width models for 2 crops can be adapted to multi-crop multi-farmer case for tillage operation. The farm scenario could be such that the cropped areas serviced by a set of machinery are owned by farmers 1 to m (see Figure 1), whose crops vary from 1 to n. The combined farm machinery cost and selection models developed by Hunt (2001) for the general case (Eqs. 20 and 22) can also be applied to the tillage machinery case.

For such pool farm machinery sharing modeling these further assumptions made were:

- ✓ The soil texture is considered to be of immense effect on annual machinery cost.

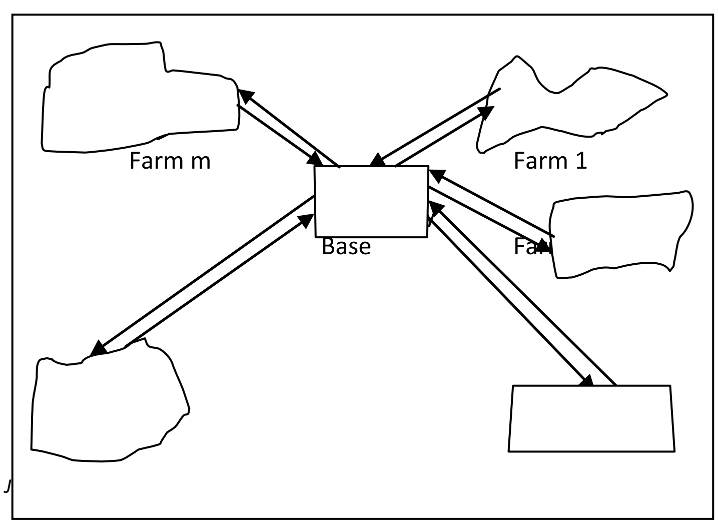

Figure 1: Scattered pool m farms serviced from a single machinery base

- ✓ The effect of field geometry, topography and other inter-field variation are not considered.
- ✓ The farms within any given town/local government area are taken as a lump farm so as to simplify the model evaluation.
- ✓ The variables in the annual cost are considered same for same operations in closely related crops or farm locations. They may differ for the different crops or different areas plots, so as to cater for the possible occurrence of such scenario.
- ✓ The sequence (ie order) of processing the plots was not considered.
- ✓ The machinery transport distance considered is consequently limited to that needed to bring the machinery from its base to a concerned town/area where the farms are located. Whereas the total machinery transport distance to the farms is actual distance traversed, this assumption was adopted to simplify the model development.

Tillage speed (S) and depth (d), field efficiency (e) and labour rate (L) were assumed to be constant for ease of the problem solving. Percentage tractor loading (δ) and the emanating fuel efficiency (H) will actually vary with differing field topography and geometry, soil types and vegetative cover and were treated as so.
The tillage machinery width (w_P) selection and annual cost (AC_{gP}) models for such pool farms were obtained as in Eqs. (23 and 24) respectively.

$$w_P = \sqrt[3]{\left[\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\Omega_{ij}\left(\frac{100A_{ij}C_e e}{\varphi_{ij}}L+\alpha_{ij}\right)}{\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\mathrm{K}_{ij}\rho_{ij}}\right]} \qquad (23)$$

$$AC_{gP} = \mu w + \sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{A_{ij}}{C_{eij}}L + flT_{ij}\right) \qquad (24)$$

Here, variables subscripted i are for crop i and those subscripted j for farmer / farm j.
The minimum-cost tillage machinery capacity selection model for the multi-crop multi-farm machinery sharing case was obtained as:

$$C_{eP} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left(-b'_{ij}\right)+\sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(b'_{ij}\right)^2+4a'_{ij}c'_{ij}\right]}}{\sum_{j=1}^{m}\sum_{i=1}^{n}2a'_{ij}} \qquad (25)$$

Such models can also be useful when machinery hiring is intended instead of outright ownership by farmers. The estimated total farm size summed from all the client farmers plots will then become the farm size for sizing the machine.

2.3 Incorporating transport cost into tillage machinery size selection and annual cost models for pool farm

The time lost to inter-farm machinery transportation need to be considered in choosing an adequate machine size for processing far-flung pool farms. With the inter farm machinery transport cost incorporated, the annual machinery cost equations transforms into Eq. (26).

$$AC_{TP} = \mu w + \sum_{j=1}^{m}\sum_{i=1}^{n}\frac{A_{ij}}{C_e}L + \sum_{j=1}^{m}\sum_{i=1}^{n}\left[flT_{ij} + CT_{ij}\right] \qquad (26)$$

where:

$$CT = \pi_t \Pi_x + h_t L + h_t f l_t \qquad (27)$$

The first term in Eq. (27) is the tractor fixed cost for inter-field machinery transport, and is given as a function of the tractor's maximum PTO power (Π_x). The machinery hourly transport fuel cost is given as

$$fl_t = \eta_t \Pi_x \tag{28}$$

The subscript *t*in thevariables denotes the concerned variables as themachinery transport version of the variables, while the tillage operation variables are without subscripts.

Fully-mounted farm machinery is transported in a lifted position and the required transport power was evaluated like that of drawbar-pulled non soil-engaging implements. The required (tractive) drawbar power for such implements according to Kepner*et al* (2003) is as in Eq. (29).

$$\Pi_t = \frac{F_N \times R_R \times S}{3.6 \times 0.9 \times E} \tag{29}$$

The tractive efficiency E is affected by soil type and condition). For traction on firm road Ehas a value of 0.72 for 2WD and and 0.77 for 4WD tractors. The minimum-cost machinery width and capacity model derived for this transport cost-incorporated case was same as for the no transport cost-incorporation case. See Eqs. (23 and 25).

2.4 Transport time loss correction for the pool farm machinery size model

The minimum-cost machinery width and capacity selection models derived for the machinery-sharing multi-farm with transport cost-incorporated did not reflect any contribution from the machinery transport. However, some time that could have been used for field processing would be lost to the inter-field machinery transportation. The previously selected tillage machinery capacityC_e was thus adjusted to a new valueC_{eR}that will adequately process the given farm size while accommodating the machinery transport time loss h_t. See Eqs. (30 and 31).The derived machinery capacity was also verified if it would adequately process the pool farm within the suitable available working time as in Amaefule*et al*, (2018).

$$C_{eR} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} A_{ij}}{\left(\frac{\sum_{j=1}^{m}\sum_{i=1}^{n} A_{ij}}{C_e} - h_t\right)} \tag{30}$$

$$h_t = \frac{0.27 m_t \sum_{j=1}^{m}\sum_{i=1}^{n} D_{ij}}{\Pi_t} \tag{31}$$

2.5 Model Validation

The model was validated using data gathered from field studies conducted in the small farms serviced by the tractor and equipment hiring unit of the Engineering Department of the Anambra State Ministry of Agriculture Awka, south east Nigeria. The serviced farms were located within latitudes 5º 20″ and 6º 40″ north and longitudes 6º 40″ and 7º 20″ east and varied from 0.5 to 22 hectares in size.

Consolidation of the small farms to into a big enough size for engine-powered ploughing operation was employed in the model evaluation. Values of the models' parameters collected from the studied farms were employed in evaluating the 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 Hunt-Wilson least-cost width was also selected based on the same farm parameters. The plough capacity required on the basis of the available working time and the time reduction by the machinery transport time h_t was obtained, and was converted to the equivalent required minimum (basal) machine width. The 2 models' widths were compared with the basal implement width. Suitable ploughing operation period for rice and cassava farming zones in Anambra State Nigeria was obtained from the operations record of the tractor and machinery hiring unit of the Anambra State Ministry of Agriculture Awka Nigeria.

ANOVA of these widths was done with Excel Software. The computer models were coded on Excel software for the models solution. For the models behaviour under farm size changes, 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.

Experimental Procedures: Ploughing operation was carried out in selected farms at the various locations of the studied.

- ✓ The tillage depth was measured with improvised depth-guaging instrument as was done by Amaefuleet al (2018).
- ✓ The implement working width also was measured with a 5 m tape rule.
- ✓ The farm size was obtained from the machinery hiring outfit records.
- ✓ 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 available days for processing the field was estimated from the period of the year the local farmers in the studied area requested for tractor and ploughing machinery for processing their fields from the agricultural ministry hiring outfit.

The tractor and implement parameters employed in the model simulation are listed in Tables 1 and 2. All collected data was collated and analyzed.

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 β (%)		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 γ (%)	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. Tractor-powered tillage period for rice cropping was carried out within April to June. These amounted to 87 working days for rice and early cassava, and 65 days for late cassava. 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 (1,064 hrs). 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 disc plough widths obtained with the developed model and the Hunt-Wilson model and the required basal width for varying farm sizes are presented in Figure 1. When the pool farms were 45 ha, 145 ha, 420 ha and 675 ha, plough widths (w) of 0.5481 m, 0.9740 m, 2.1009 m and 2.5997 m respectively, were needed for their processing based on the developed model. Basal plough widths of 0.1187 m, 0.3941 m, 1.1442 m and 1.8385 m were required for processing the listed farm sizes in that order. The Hunt-Wilsons model selected least-cost plough widths of 0.8186 m, 1.0201 m, 1.5896 m and 1.7587 m for the same listed farm sizes in that order.

The annual machinery costs per hectare corresponding to the obtained plough widths are plotted against varying farm sizes in Figure 2. Although higher plough widths were obtained for increasing farm sizes by the required basalplough size and the 2 models sizes, their corresponding machinery cost per hectare were continually decreasing. The 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. The plough machinery cost per hectare incurred for the needed basal size width is plotted in Figure 2 for varying farm sizes. The costs incurred was ₦23,820.02,

₦10,464.30, ₦7,639.94 and ₦6,620.47 for the same listed farm sizes in that order. For the Hunt-Wilson model the incurred cost was ₦12,378.38, ₦8,471.28, ₦7,708.13 and ₦7,010.44 for the same farm sizes in that same order.

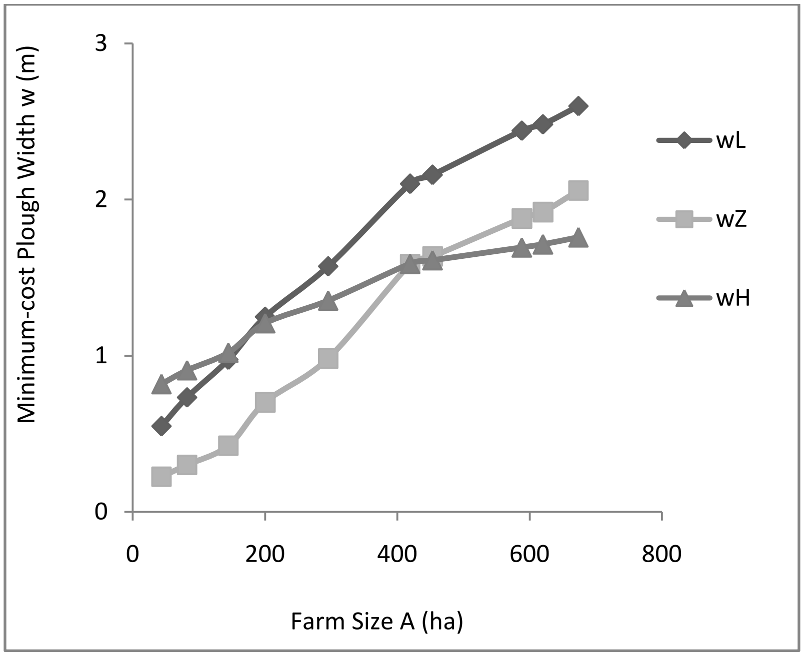

Figure 1: Unadjusted minimum-cost plough width for farm sizes variation

The incurred plough machinery and transport cost per hectare at the serviced-field distances also is plotted against varying farm sizes as also shown in Figure 2.

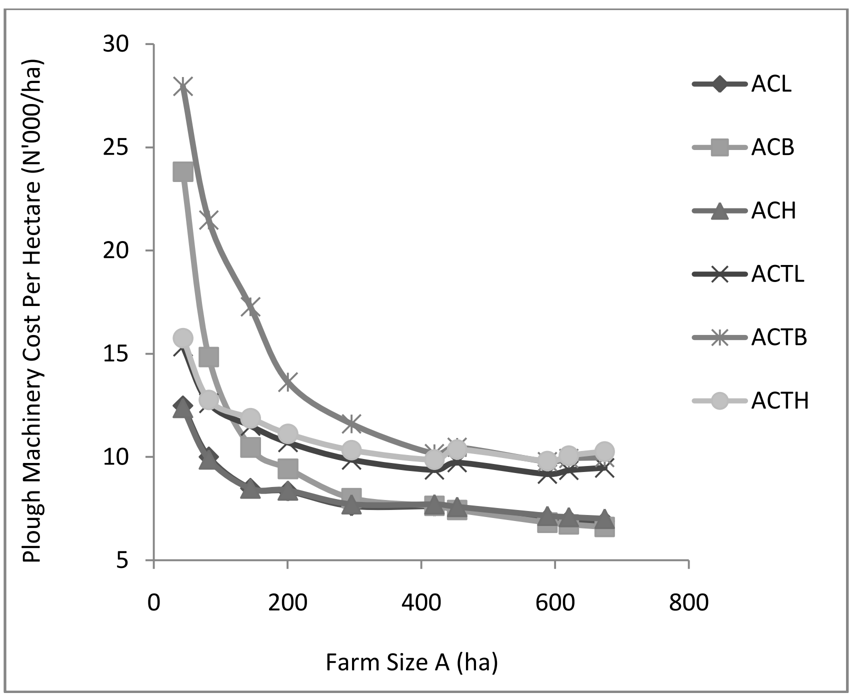

Figure 2: Unadjusted plough machinery cost per hectare for varying farm sizes

The annual plough machinery and transport cost as is expected was higher than the ordinary annual plough machinery cost. It was ₦12,485.44, ₦8,480.44, ₦7,611.25 and ₦6,892.56 for farm sizes of 45 ha, 145 ha, 420 ha and 675 ha respectively with the developed model width. For the required basal width it was ₦23,820.02, ₦10,464.30, ₦7,639.94 and ₦6,620.48 for the same listed farm sizes in that same order. The cost was ₦12,378.38, ₦8,471.28, ₦7,708.13 and ₦7,010.44 for the same listed farm sizes, in that same order with the Hunt-Wilson model.

Table 3: Variation of adjusted plough sizes and corresponding costs from the unadjusted ones[a]

Farm Area A (ha)	Cum. Trnspt. Dist.Dkm)	Minimum-cost Plough width Difference (%)			Plough Machinery cost per hectareDifference (%)		
		w%$_L$	w%$_B$	w%$_H$	AC%$_L$	AC%$_B$	AC%$_H$
45	32	3.99	0.86	5.96	0.43	0.66	0.54
82	56	4.96	1.51	6.13	0.51	1.19	0.02
145	122	8.14	3.29	8.52	0.69	1.46	0.53
200	148	9.12	3.99	8.82	0.35	1.89	0.41
295	208	10.96	5.61	9.43	0.20	2.43	0.59
420	268	13.28	7.23	10.05	0.26	2.84	0.55
453	358	16.86	9.66	12.59	0.41	2.72	0.71
588	434	17.81	11.71	12.36	0.46	3.32	0.86
620	506	20.03	13.66	13.82	0.60	3.36	0.96
675	596	22.74	16.08	15.39	0.85	3.51	1.05

[a]adjusted values were always higher than the unadjusted

In comparison, the adjusted plough widths obtained for the models and the basal required size were higher in value as can be deduced from Table 3. The percentage differences between the adjusted and unadjusted widths obtained are shown in the table for the models and basal required size. The percentage variation is listed for the developed model, Hunt-Wilson model and basal required size in that order. They were 3.99 %, 0.86 % and 5.96 % for the 45 ha farm size, 8.14 %, 3.29 % and 8.52 % for the 145 ha, 13.28 %, 7.23 % and 10.05 % for the 420 ha farm size and 22.74 %, 16.08 % and 15.39 % for the 675 ha farm size. For each model or basal width, the percentage difference was consistently increasing for increasing farm size. This showed that the models for adjusting the predicted widths were sensitive to the transport time loss.

The machinery cost per hectare corresponding to the adjusted plough width obtained for the models and the basal required size were slightly higher in value than the unadjusted widths cost as can be deduced from Table 3. The percentage difference between the costs for the adjusted and unadjusted widths is shown in Table 3. The percentage variation was 0.43 %, 0.66 % and 0.54 % respectively for the developed model, Hunt-Wilson model and basal required size at 45 ha farm. The variation was 0.69 %, 1.46 % and 0.53 % same models in the same order at 145 ha. At 420 ha the variation was 0.26 %, 2.84 % and 0.55 % for models in the same order. For 675 ha the variation was 0.85 %, 3.51 % and 1.05 % for the models in the same order.

For each model or basal width, the percentage difference was highest for the highest farm size simulated. This showed that the annual cost models were sensitive to the predicted widths adjustment for the transport time losses. The percentage change in the widths was generally higher than that for the cost per hectare for each farm size. The percentage change in the plough machinery cost per hectare was smallest at 420 ha with the developed model. For this model, the adjusted plough machinery cost per hectare was lower than that for the unadjusted cost for farm sizes lower than the 420 ha. It became higher at farm sizes of 420 ha and above. 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 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). Onwualu*et al* (2006) andRasouli*et al* (2009) 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. Pooling small farms into large enough size can enhance mechanizing them economically.

For the 675 ha maximum farm size simulated the 3.3651 m predicted with the developed model was considered adequate and chosen for processing the farm when compared with the adjusted basal 2.1909 m required size. This translates to a 1.1592 ha/hr plough field capacity. The adjusted 2.0785 m plough width predicted by the Hunt-Wilson model was seen as inadequate when compared with the basal width required. 4 units of the smallest-capacity tractor-powered disc plough available readily in the local market (a 0.3100 ha/hr plough) was chosen to provide the desired field capacity.

The chosen small-sized plough will suit the small, irregular-shaped and scattered pool farms better than larger ones (Hunt, 2001 and Amaefule*et al*, 2018). Zoz (1973) concurred with this preference of small-sized machines. Larger implements he argued present with flexibility and maneuverability problems and more transportation difficulties in accessing geographically spread out fields.

3 pieces of the 3-bottom (70 cm disc diameter) plough of 0.3100 ha/hr capacity and 0.9 m working width was chosen. The 4 ploughs with 1.240 ha/hr total capacity (ie 3.599 m) is expected to adequately process the 675 ha farm size. Each plough will be powered by a 48.5 kW tractor. A total of 4 tractors will be required. The chosen machinery will incur an annual plough machinery and transport cost per hectare of ₦12,866.95.

4.0. Conclusion

The models employed in this study predict the machinery cost and minimum-cost capacity for field machines under varying farm size, and need tractor power, and the prices of tractor, implement and fuel as other input variables. Individual farms were amalgamated into big enough size so as to derive the benefit of reduced machinery cost per hectare under increased farm size for the economic mechanization of small farms. With the adjustment for inter-field transport time loss incorporated, the machinery selection model was adopted for machinery size prediction for fragmented non-contiguous pool farms.

The adjusted 3.3651 m predicted for the 675 ha pool farms with the developed model was considered adequate when compared with the adjusted required basal 2.1909 m size and was chosen for processing the farm. 4 units of the smallest-capacity tractor-powered disc plough available readily in the local market (a 0.3100 ha/hr plough) was chosen to provide the desired field capacity. The 4 ploughs with 1.240 ha/hr total capacity (ie 3.599 m) will eac be powered by a 48.5 kW tractor. The chosen machinery will incur an annual plough machinery and transport cost per hectare of ₦12,866.95.

5.0 Recommendation

Appropriate machinery selection and cost-effective mechanization of agriculture with engine-powered technologywillbe expectedlyenhanced in Nigeria and other locations through the deployment of the developed models.Socio-cultural factors should be carefully considered in theagglomeration of the smaller farms to facilitate its acceptability to the small farmers. Determining the suitable 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 for given units: c = 10)

e = field efficiency of operation, decimal
Γ = machine life, yrs
r =rate of interest, %
ts = combined taxes, shelter and insurancecosts as percentage purchase price, %
Π = equivalent PTO power needed for anoperation, kW
γ = annual implement FC percentage, %
FC = annual fixed cost of machinery, ₦
A =area cultivated by the farmer, ha
T = machine's hourly tractor fixed cost, ₦/hr
L = labour cost per hour, ₦/ hr
ψ_c =timeliness cost per hour, ₦/hr
Δ =machine repair and maintenance cost as a % machine purchase price, %
AD = available working days annually, days
D = annual transport distance, km
μ= annual implement fixed cost per machine width, ₦/m
μ_c= annual implement fixed cost permachine capacity, ₦/ha
L_c = labour cost per hectare, ₦/ha
T_c = implement's tractor (fixed) cost per hectare, ₦/ha
ψ_c = timeliness cost per hectare, ₦/ha
P = machine purchase price, ₦
δ =percentage PTO power loading on tractor, %
flT= combined tillage fuel and tractorcost, ₦
fl_T =hourly transport fuel cost, ₦/hr
AC_g = annual tillage machinery cost, ₦
$LOfT$ = combined labour, lubricant, fuel, tractor and timeliness cost per hour, ₦/hr
π = annual tractor fixed cost per PTOpower for the tillage operation, ₦/kW
σ =fuel price, ₦/l
H =fuel efficiency at given % of maximum loading, kW.hr/l
Π= the equivalent PTO power employedin the tillage operation, kW
C_1 ,C_2= soil-dependent static and dynamicdraught constants
β = tractor annual fixed cost percentage, %
κ= tractor fixed cost-to-percentage power loading for the operation, ₦/kW
d = depth of tillage operation, cm
w_L = developed model-predicted width, m
w_H = Hunt-Wilsons model-predicted width, m
w_B = required basal tillage machinerywidth, m
$w\%_L$ = adjusted and unadjusted developed model's width difference, %
$w\%_H$ = Hunt-Wilsons model width difference, %
$w\%_B$ = adjusted and unadjusted required basal width difference, %
$AC\%_L$ = adjusted and unadjusted machinery cost per hectare difference incurred for the developed model-predicted width, %
$AC\%_H$ = adjusted and unadjusted machinery cost per hectare difference incurred for the Hunt-Wilsons model-predicted width, %
$AC\%_B$ = adjusted and unadjusted machinery cost per hectare difference incurred for therequired basal size, %
C_{eP} = minimum-cost tillage machinery capacity for multi-crop multi-farm scenario, ha/hr
AC_{gP} =combined annual tillage machinery cost for multi-farm multi-crop farm, ₦
AC_L = machinery cost per hectare predictedfor the developed model width,
₦/haAC_{TP} = machinery transport cost incorporated annual machinery cost,
₦/ha
CT = annual machinery transport cost, ₦
AC_H = machinery cost per hectare predictedfor the Hunt-Wilson model width, ₦/ha
AC_B = machinery cost per hectare for therequired basal machinery size width, ₦/ha
AC_{TL} = machinery and transport cost per hectare predicted for the Hunt-Wilson model width, ₦/ha
AC_{TB} = machinery and transport cost per hectare predicted for the required basal size width, ₦/ha

AC_{TH} = machinery and transport cost per hectare predicted for the Hunt-Wilson model width, ₦/ha
C_{eR}= Field machinery capacity adjusted for machinery transport time losses, ha/hr
F_N = static vertical force on the tractor drive wheels, kN
R_R = coefficient of rolling resistance on the tractor drive wheels, dimensionless
E = tractive efficiency (ratio of draw bar power to axial power, dimensionless