# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

Food is a major requirement for human survival. Lack of it has pulled down nations. Nations have gone to war because of fertile lands to produce foods for its citizens. It is therefore necessary to ensure food security and mass production of foods and fibre for consumption and use by agro industrial establishment. This has made agricultural mechanization an essential ingredient in national socio-economic development.

Agricultural mechanization which is the efficient, effective and economic deployment of machines or other engineering technologies in agricultural activities with the aim of improving labour productivity, reducing operations drudgery (Oluka, 2014) has given birth to viable commercial agriculture. Improvement of human living conditions (Anazodo, 1986 and Lamidi and Akande, 2013) and increased profitability of farm enterprises are also realized through agricultural mechanization.

For economic management of farm power and machinery, researchers (Oluka, 2000, Oluka and Nwani 2013, Hunt, 1999b, etc) have studied farm power and machinery ownership cost and come up with different models to predict costs, size of machines, etc. Different management system and farm conditions were covered in their studies. 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. Modelling of the costs for repairs and maintenance of rice mills under different management systems in Nigeria has also been undertaken by Oluka and Nwani (2012). Hunt (1999b) studied farm tractor and machinery cost and developed models to predict annual machinery cost, and optimum cost machinery size selection for single crop and 2-crop situation. Hunt and Wilson (2015) studied the annual costs of heavy tillage implements for single crop farms. They reported that the tractor price being far higher than the implement price should influence the minimum cost tillage machinery size selection more the implement price does.

In all the studies and models of previous researchers, a knowledge gap exists in the development of the models which considers the following;

-suitability to small farms,

-avoidance of the use of a prior arbitrary field capacity (which is a function of machine width) for selecting machine width,

-overlapping operation windows situation for the multi-crop multi-farms,

-inclusion of the multi-crop multi-farm with scattered location condition, and operation labour cost consideration in the tillage machinery width selection model.

## 1.2 Statement of Problem

The inability to give mechanization planning the required attention has resulted in failure of mechanization programmes. This has led to the dearth of the desirable impact of mechanization in such affected countries (Sims and Kienzle, 2017). Earnest effort must thus be given farm mechanization planning, including mechanization equipment selection. Economic selection of appropriate equipment is thus required for effective and sustainable agro mechanization ventures.

Models for selecting farm power and machinery have been developed and employed by several researchers (Dash and Sirohi, 2008), but they do not seem to address the needs of very small-sized farms. According to Eurostat (2017) classification, farms of less than 2 hectare are very small-sized farms, 2 ha to less than 20 ha farms are small-sized farms, 20 ha to 100 ha farms are medium-sized farms and over 100 ha farms are large-sized farms. Small and very small small farm holdings abound in the Nigerian farming systems. Mechanizing such farms with power sources greater than their required capacities will be uneconomical and wasteful. Majority of the global food output is provided by small farms (Sims and Kienzle, 2017). The paradox however is that such farms have received little studies on mechanization planning. A suitable farm machinery selection model for developing countries should allow a cost-effective machinery selection for big and small-sized farms alike. Developing countries as used above refers to developing economies countries (Gbadamosi, 2018).

## 1.3 Aim and Objectives

The aim of this study is to model farm machinery selection for scattered farms using minimum-cost method. The specific objectives of the study are:

i. To develop a minimum-cost tillage machinery selection model that will suit big and small scattered farms which hitherto has not been considered.

ii. To develop minimum-cost tillage machinery selection models that do not need the
arbitrary variable input encountered in the existing Hunt-Wilson model.

iii. To develop models that incorporate the influence of labour cost on minimum-cost machine sizing in tillage machinery selection.

iv. To develop minimum-cost tillage machinery selection models that are adapted to the possible farm operation window overlap encountered in multi-crop pool farms.

### 1.4 Justification of the Study

The study attempts to solve the constraints posed to the mechanization of agriculture globally by the problems of small farm holdings. It will also ease the hindrances to small farmers' mechanization machinery acquisition; that arise from farmer adequate capital unavailability. The ease of engine-powered farm mechanization adoption will reduce drudgery and attract more youth to farming business. The study also affords farm managers a dependable model for field machinery selection. Local data for agricultural field machinery costing and selection in Nigeria and particularly Anambra State will be made more visible through the study. This will reduce the reliance on foreign ones since such data are location-specific.

### 1.5 Scope and Limitations of the Study

The study was limited to the development of minimum-cost machine selection model following the differentiation approach of the Hunt's least-cost method. The model is cost based and does not consider the returns from the farm operations. Effect of inflation on the cost model can be reckoned by replacing the machine purchase price with an inflation rate-corrected price. Estimation of annual farm machinery cost was done from known farm, crops and machinery parameters. Only the cost items influenced by machine size for the given farm scenario, and not the comprehensive machinery cost were employed for developing the farm's minimum-cost machinery size. This same approach used by Hunt (2001) and Hunt and Wilson (2015). It was adopted since the differentiation of items that are lacking in a width function with respect to will yield a zero derivative.

The farm sizes studied for the model application were limited to the extent that enhances profitable of mechanization of pool small farms. The effect of field geometry on the machinery field capacity was not considered in order to reduce the complexity of the models. The types and ranges of sizes/capacities of tractors and their associated implements available in the market imposed restrictions on the model's capability to implement the exact size of required equipment for a given farm size. Availability of comprehensive data for evaluating the model also posed limitations in the study.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Mechanization and machinery management

Mechanization is an ingredient for realizing the economic benefits of agricultural investments. The need for proper management of this investment component cannot be over emphasized. The serious economic implication of mechanization decisions and diversity of processes and equipment types makes machinery management essential.

### 2.1.1 Overview of machinery management

Poor planning and implementation of mechanization programmes lead to their failure. Proper selection of a machine system and understanding the mechanical principles and limitations of each machine are necessary in good machinery management. Efficient operation of the field machines, appropriate maintenance, timely machine repair and replacement are also important. (Oluka, 2000) Simple mathematical modelling and economic analysis are used to evaluate the economic appropriateness of the proposed machinery management. Farm machinery selection and replacement decisions require good judgment of the economic worth of the machine to the farm enterprise.

The machine's maintainability, availability, reliability, material efficiency and after-sales services' availability must be assessed. Machinery calibration and adjustments are good management practices that reduce errors and provide confidence that the performance standards are being met. However soil-surface conditions, properties of the materials handled, wear in the metering mechanisms, and slackness in the control linkages contribute error even after appropriate adjustments/calibration has been made (Hunt, 1999a). Machine maintenance plan and operations scheduling affect machinery utility and cost effectiveness, and must not be overlooked. Human relations and other organizational management factors no doubt affect cost-effectiveness of machine use.

Overlapping of implement paths is done during field operations in order to ensure the avoidance of skips and this reduces the field operations efficiency. Overlaps and skips are both wasteful in grain seeding, agrochemical application, and other input placement operations. Over-application of agrochemicals means unwarranted increase of pollutants in the environment. Misplacement of rows by planters, leads to the repetition of the misplacement in all subsequent row-cropping operations. Appropriate steering and simultaneous control of the operation processes of the tractor–implement combination or self-propelled machine is more difficult for wider and more complex implements (Hunt, 1999a).

### 2.1.2 Agricultural field machinery capacity concept

The performance of an agricultural field machine can be assessed in terms of the work quality or effectiveness and work rate or quantity accomplished in a given time. Effectiveness of machine planting for example includes properly metering a seed for planting without damaging it, placing it accurately in the desired position and covering the placed seed with soil and right compaction. Compaction of the soil with the machine road wheel passes is another aspect for work quality judgment, since soil aeration and infiltration are consequently affected. Zaied *et al* (2014) reported that rate and quality are the measures of agricultural machine operations performance. According to them timely operation, work quality and avoidance of product waste are important agricultural operations.

Machine work rate can be measured in terms of how much area of the field a machine covers within a given time of the actual work, like in land clearing and tillage operations. The area capacity $C_e$ can be evaluated as:

$$C_e = \frac{S w e}{C} \quad \text{ha/hr} \qquad (2.1)$$

where :

$C_e$ = effective field capacity ha/hr

$S$ = operation forward speed km/hr

$w$ = working width of machine m

$e$ = field efficiency of operation dimensionless decimal

$c$ = a constant; $c$ has a value of 10 (Field and Solie, 2008).

The constant $c$ converts units of the speed and width into field capacity unit.

Using implement operation speed units different from km/hr or the implement width different from m will result in differing values of $c$. The field efficiency ($e$) corrects the theoretical capacity to effective field capacity ($C_e$).

The field efficiency, speed and maintenance factor for some common farm operations from ASAE (2011) standards are listed in Appendix 2A. According to Zaied *et al* (2014) and Hunt (2001), 'field efficiency accounts for failure to utilize the theoretical operating width of the machine, time lost because of operator capability and habits and operating policy and field characteristics. Travel to and from a field, major repairs, preventive maintenance, and daily service activities are not included in field time or field efficiency accounting. Field efficiency for a particular machine varies with the size and shape of the field, pattern of field operation, crop yield, moisture, and crop conditions. The following activities and situations account for the majority of time loss in the field:

- ✓ turning and idle travel;
- ✓ materials handling (if not done on-the-go);
- ✓ cleaning clogged equipment; machine adjustment (if not done on-the-go);
- ✓ lubrication, refueling, chain tightening (besides daily service);
- ✓ waiting for other machines;
- ✓ repairs (parts replacement or renewal made in the field);
- ✓ operators personal time'.

Agricultural material dispensing or in-gathering operations like planting, fertilizer application and crop harvesting will require in addition to work area traversed, the material through-put capacity. Such material processing capacity measure is helpful in field dosing rate or material collection rate assessment and is more important than the field area traversed. The material capacity or throughput of the machine can be gotten from the area-based capacity by multiplying the latter with the crop yield per unit area for harvesting operation or area dosing rate for planting or agrochemical applications.

### 2.1.3 Factors affecting field machine performance

Najafi and Torabi Dastgerduei (2015) reported that productivity increase and production costs decrease is demanded in farming from global competition. This requires more efficient use of cropping machinery so as to reduce machinery cost, thereby reducing production cost and improving productivity. The field performance controlling factors need proper understanding for improved mechanized farming profitability. Machine field capacity or performance efficiency is affected by a number of factors as discussed below. Increasing size and width of machine, increasing travel speeds, or combining operations are options of increasing field operations productivity (Hunt, 2001). Reduction in the pieces of needed machinery and labour cost, and better timeliness of operations will result from the last option. Combining operations will lead to less idle resources and overhead costs. The reduction in the number of passes is desirable for soil compaction reduction, but will require higher-sized tractors. However increased tractor power positively correlates with increased tractor weight and by extension, increased ground tyre pressure, which is contrary to soil compaction reduction.

I) Implement working width: From the mathematical definition of field machine capacity (Equation 2.1), machine capacity has direct linear variation with the implement operation width. Tractor size, soil type and condition, field speed, and implement draft requirements affect matching implement type selection (Grisso *et al*, 2012) as do implement width. A bigger sized implement will accomplish a given field work faster than a smaller one at the same speed of operation. Proper economic evaluation of machinery working width alternatives must therefore be made in machinery size selection. The power required by field implements increases as the implement size increases. Issues of field work quality like soil tilth and compaction, ergonomics and environmental impact among others should not be overlooked in machinery width selection. Larger implements lead to increased hitching difficulties, increased purchase costs and more transportation difficulties and costs, and maneuverability problems.

II) Speed of field operations: Increased operation speed minimize the required operation time while maximizing field capacity and the efficiency of the implement. Time wastage and in some cases poor work quality for some tillage operations ensue from excessively slow field speeds. Proper operations speeds depend on the work quality requirements, tractor maneuverability, driver's comfort, and available power limitations. Increasing field operations speed gives greater field capacities and loading on the power unit and more efficient engine fuel consumption efficiency. Higher speeds of field operations demand more alertness from the operator for accurate steering and the machine units manipulations.

Limits of operators' capabilities, machinery and operations types and conditions dictate the safe limits of operations speed. The seedbed requirements for example, limit tillage operation speeds to that maximum that does not throw the soil into an unacceptable position or produce an unacceptable clod fragmentation. Ability of the implement to effectively meter and place the seed, and excessive crop losses limit seeding and harvesting operations speeds respectively. To ease ergonomic demands and the attendant fatigue, manufacturers are providing instrumentation that indicates the several simultaneous mechanical operations functions for complex machines such as combine harvesters. Such however still requires the monitoring of these gauges by the driver. Manufacturers nowadays aid operators with visual and audio monitors to indicate malfunctions.

Oduma *et al* (2015) reported theoretical field capacity to directly vary linearly as speed in tillage and planting operations on sandy-loam soils of Ebonyi State, Nigeria. They observed higher ratio of effective operation time to total operation time at lower speeds than at higher speeds. Increased fuel consumption per hectare was reported for the disc ploughing, harrowing and ridging, and for planting operations with speed increase.

III) Field patterns: The pattern of tractor and equipment track through the field affect the field efficiency of the operation. The time spent for turning the tractor-implement combination or self propelled equipment in the headland ie at end of the field is an unproductive time. The ratio of the turning time to the total operation time (ie the operation's field efficiency) is a function of the field pattern. Minimizing the number of unproductive turns is desirable and the choice of the field pattern to be adopted is a machinery management issue. Field boundaries and the maneuverability of the self-propelled machine or the tractor-implement combination affects field pattern choice (Hunt, 1999a and Bakhtiari *et al*, 2011).

IV) Field geometry: Long rectangular fields can permit turning times as low as 2 % to 3 % of the total time, which small, irregular, or hilly fields may not achieve (Hunt, 1999a). Acute angles increase turning times while field size does not affect total turning times for a given field shape. In the cases of triangular field, aligning the direction of travel with the longer field side gives lowest total turning time. Angled headland creates an extra problem of double processing. This extra travel causes losses in time, fuel, and applied materials. The loss in time is extremely high if the angle is less than 30 degrees. Our local agricultural fields are traditionally small, fragmented and scattered and follow odd-shaped boundaries. Such are expected to exhibit low field capacities and efficiencies.

Wide-angled field geometry can permit machine-engaged turns for compliant operations in which case only small unprocessed crescents will arise. Increased inefficiency of operations will result from extra passes of the implement required to process such unprocessed areas. Same goes for the other areas missed when implements were disengaged from operations during turns. Increased implement width yields less number of turns, but will require greater turning arcs and time as well (Hunt, 2001 and Kepner *et al*, 2003).

V) Field conditions: Field topography, surface cover, pedoclimatic factors, etc also affect field operation capacity. Travel up a slope demands higher draft than along a level land, while travel down a slope requires less operation draft. Trash, plant stalk, stubble, etc surface covers affect cutting and penetration forces differently. The traction of the tractor is also influenced by such surface covers. Again, the useful power/ work extracted from the amount developed in the tractors drive train is affected by soil resistance to wheel rolling and consequently the surface cover. Where the soil has root growth, extra resistance is offered by such root network leading to increased required specific draft.

Humus content (from decaying organic matter) also affects soil structure and strength. Moisture content of soils affects the shear strength and penetration resistance of the soil. Soil compaction results when soil moisture content is high, and puddling occurs when moisture is excessive. Environmental factors like solar radiation, wind speed, relative humidity *inter alia* affect soil moisture. Soil moisture affects field workday availability will be treated in a later section. Harrigan and Roosenberg (2002) reported that draught is not easily predicted as it can vary greatly in the same soil depending upon conditions which can be higher in dry, hard soil or hay and grass sod than when the soil is moist and friable or in annually tilled ground.

VI) Operational/operator parameters: According to Harrigan and Roosenberg (2002) Draft is greatly affected by tillage depth, but varies with implement weight, disc angle, blade spacing and diameter, soil strength, crop residue cover and many other factors. Operator skill and experience influence the maintenance of the required depth, speed and overlaps and skips and consequently affect field capacity. Rest and other idle/non-productive times also are operator-dependent.

### 2.1.4 Factors affecting equipment selection

Machinery's field capacity and efficiency, power requirement and availability, labour requirement, operation timeliness, costs and social factors are considered in machinery selection. The ease of operation and adjustment, and equipment suitability to the local soil and environmental conditions are also considered (Onwualu *et al*, 2006).

I) Suitability of machinery: Machines are designed purposively with specifications that depend on the intended uses and conditions of the machine deployment. Adaptation of such machines will be needed for areas or conditions that are at variance with the ones machines were designed for. For adoption of mechanical alternative of executing a task, a satisfactorily performing machine must be available. An appropriate mechanization technology must be suitable to the technical, economic, social and political characteristics of the intended farm situation. Machinery field capacity is important in choosing a suitable machine for any given farm type and size.

Large-scale farming ventures require the selection of tractors with large enough power and matching implements for cost-effectiveness. Land tenure, land leveling limits in paddy field size, preponderance of hilly area, management scale, *inter alia* result in small farm sizes in Nigeria for which the use of large and medium-sized tractors is uneconomical. Odigboh (1985) stated that agricultural machinery designed and manufactured for industrialized countries' farmers for their mostly temperate crops are generally unsuitable to tropical pedoclimate and crops. Additionally, the complexity and high cost of alien machines put them beyond the technical competence and financial reach of our local farmers. The mechanization equipment for Nigerian tropical crops like cassava is unavailable overseas and has to depend on indigenous engineering initiatives and efforts. Small size, light-weight, simple structure, good maneuverability and ease of operation, repair and maintenance of small tractors make them more attractive to our local small-scale farms.

Again the low level of technical knowledge and management abundant in rural areas makes small tractors more adaptable to Nigerian agricultural conditions and farming requirements (Ademiluyi and Oladele, 2008). Walking tractors for example are suitable to the features of vast paddy field. The Wheel performance is the key point in determining the performance of walking tractors in paddy fields. Iron wheels equipped on walking tractors are more economical than high-lug tires (Gupta and Kumar, 2001). Unlike in the Asian countries, walking tractors has not been widely accepted by Nigerian farmers on account of its high vibration (Nwuba, 2009).

II) Economics of field operations: The primary aim of any venture; agro-businesses inclusive is profitable returns. Studies in tractor and machinery selection can help ensure timely field operations completion at minimum cost. The power-machinery system capacity or size dictates their costs thereby determining the profitability of the given farming system (Dash and Sirohi, 2008). Over-sizing the power source or the machinery reduces labour and timeliness costs, but leads to increased equipment overhead costs. On the other hand selection and use of under-sized implements may result in higher labour and timeliness cost, which ultimately reduces the improved net returns from low fixed costs. Thus the criticality of optimum size farm machinery selection lies in both the very significant cost implications and the difficulty of reversing the decision once the machine is procured.

**2.2 Costing Farm Machinery**

The expenses of any business must be recovered from the returns and at a profit. This explains investors' effort to maximize returns and/or minimize business expenses. Understanding and sound management of the components of the machinery cost items is necessary for profitable machinery management. Machinery costs enter farm management in three areas:

- ✓ minimizing costs of production,
- ✓ selecting the profit-maximizing crop mix, and
- ✓ considering structural or technological changes, such as farm expansion or contraction, or alternative tillage systems (Kastens, 1997).

Machinery costs analysis is important for hiring/leasing of machinery as well as for individual business or cooperative machinery ownership. Machinery costs are in two parts; fixed costs and variable costs. Fixed costs are always incurred once the machinery is procured and is independent of the machine use, while variable costs vary according to the machinery use; the volume of operation and use hours. Darling and Green (1999) presented: capital recovery (investment costs), insurance, storage, taxes and licensing, under ownership costs and fuel, lubricants, repairs and operator wages as the cost structure to be considered in machine costing under operating costs.

### 2.2.1 Fixed costs

Insurance, depreciation, interest (/opportunity costs), shelter, workshop and registration costs according to Davies and Patton (2000), constitute fixed costs. Regardless of the annual use, this category of machinery costs remains relatively constant. The machine useful life has more effect on the annual fixed cost than the annual use. Kepner *et al* (2003) stated that annual fixed costs are inversely proportional to the annual use. Hunt (2001) asserted that interest on investment, taxes, housing and insurance are independent of use, but depends on calendar year-time, while depreciation and repair costs are affected by both.

I) Depreciation of machinery: Depreciation accounts for the reduction in machine value with the passage of time because every substance experiences a continual decay. The accumulated depreciation along with the salvage value should be able to replace the machine at the end of the useful life. Hunt (2001) stated the reasons for machine depreciation as:

- ✓ the need to change the existing capacity owing to changed operational scale,
- ✓ failure of irreplaceable or economically irreparable parts,
- ✓ increase in the expense of operation and
- ✓ obsolescence arising from availability of better machines.

With less intensive use, the depreciation per hectare rises, since depreciation is spread over fewer hectares (Kastens, 1997). Hunt (2001) and Kepner *et al* (2003) gave the common methods of evaluating annual depreciation.

1- Estimated value method: Here a realistic determination of the machine value is done for each given year. The machine depreciation is the difference between the value of the machine at the end of each year and its value at the start of that year. This approach is no doubt tedious and the validity of the obtained depreciation depends on the reliability of the process adopted.

2- Straight line method: The method according to Hunt (1999b) and Kepner *et al* (2003), is the simplest, and charges an easily calculated yearly amount evaluated as:

$$\Phi = \frac{P - Sv}{\Gamma} \qquad (2.3)$$

where:

$\Phi$ = annual depreciation, ₦/yr

$P$ = purchase price, ₦

$Sv$ = salvage value or selling price, ₦

$\Gamma$ = economic life of equipment, yr, (Kepner *et al*, 2003).

For general application in which the actual value of ($Sv$) is not known 10 % of the purchase price may be appropriately used to estimate it (Hunt, 1999b and Ali Osman, 2011). This makes Equation 2.3 become:

$$\Phi = \frac{0.9P}{\Gamma} \tag{2.4}$$

3- Declining balance method: A uniform rate is applied each year to the remaining value (includes salvage value) of the machine at the beginning of the year. The depreciation amount is different for each year of the machine's life. As reported by Hunt (2001), the depreciation is gotten from Equations 2.5 to 2.7:

$$\Phi = V_n - V_{n+1} \tag{2.5}$$

$$V_n = P\left(1 - \frac{x}{\Gamma}\right)^n \tag{2.6}$$

$$V_{n+1} = P\left(1 - \frac{x}{\Gamma}\right)^{n+1} \tag{2.7}$$

where:

$\Phi$ = amount of depreciation charge for year n+1,

$n$ = age of the machine at beginning of year in question, yrs

$V_n$ = remaining value at any time $n$, ₦ or $

$x$ = ratio of depreciation rate used to that of straight-line method. $1 \leq x \leq 2$. The method is called a double declining-balance method when $x=2$. A maximum value of 1.5 is assigned to $x$ for used machines.

4- Sum of the year digits method: The digits of the estimated number of years of the machine life are added together and used to divide the difference of the total machine life and the remaining life including the year in question. The fractional quotient is multiplied with the difference of purchase price and the salvage value to obtain the depreciation charged each year (Hunt, 2001) as shown in Equation 2.8:

$$\Phi = \frac{\Gamma - n}{YD}(P - Sv) \tag{2.8}$$

where: $YD$ = sum – of – the years digits, yr
other variables being as previously defined.

5- The sinking fund method: This method considers depreciation as a process of establishing a fund that will draw compound interest. The uniform annual payments to this fund that their sum with their accumulated interests should by the end of the machine life purchase another equivalent machine. The sinking fund method is primarily advantageous for use with a planned replacement interval policy. It is however not very flexible enough for high early obsolescence chances. It most closely approximates the actual depreciation of equipment with a slow early depreciation rate and a fast final rate near the end of the machine's life. The formulae for the sinking-fund annual payment ($SFP$) and the remaining equipment values were given by Hunt (2001) as in Equations 2.9 and 2.10:

$$SFP=(P-Sv)\frac{i}{(1+i)^L-1} \quad (2.9)$$

$$V_n=(P-Sv)\left[\frac{(1+i)^L-(1+i)^n}{(1+i)^L-1}\right]+Sv \quad (2.10)$$

The comparative performance of the above depreciation methods for an assumed 10 years machine and salvage value of 10 % machine purchase price are shown in Table 2.1. As can be seen from the table, sum-of-the-years digits and double-declining-balance methods give a more rapid depreciation of the equipment during the earlier years than the straight line method. While these earlier 2 methods appear closer to real life situation, Hunt (1999b) stated that straight line depreciation can be employed in realistic depreciation estimation. He also reported that tax bodies may equally permit initial complete rapid depreciation of a machine and subsequent use of the machine without depreciation charge. Many researchers adopt straight line depreciation methods as it enables depreciation to be easily lumped into fixed costs along with other items in simple arithmetic expression.

II) Machine life employed in estimating deprecation: Depreciation calculation is based on a suitable value of machine life. According to Kepner *et al* (2003), there is usually no definite

Table: 2.1 Remaining annual value of machines with different depreciation methods^

| Method | End of year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Straight Line | 100 | 91 | 82 | 73 | 64 | 55 | 46 | 37 | 28 | 19 | 10 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sinking Fund* | | 100 | 94 | 88 | 80 | 72 | 64 | 55 | 45 | 34 | 23 | 10 |
| Double-declining-balance | | 100 | 80 | 64 | 51 | 41 | 33 | 26 | 21 | 17 | 13 | 10 |
| Sum-of-the-year-digit | | 100 | 84 | 69 | 56 | 44 | 35 | 26 | 20 | 15 | 13 | 10 |
| Actual Trade-in Values | Major Implements | 100 | 76 | 70 | 64 | 50 | 56 | 52 | 46 | 42 | 38 | 34 |
| | Minor Implements | 100 | 74 | 68 | 62 | 58 | 54 | 50 | 46 | 40 | 36 | 32 |

^Values are percentages of purchase price for assumed 10-yr life and 10 % salvage value
*Sinking fund is computed on 8 % interest compound annually
Source: Hunt (2001)

time at which a machine suddenly becomes irreparable; rather machine repair cost gradually increases to a point where it becomes uneconomical to continue effecting repairs on the machine. Hunt (2001) highlighted 3 concepts of machine life. Physical life or service life of a machine terminates with the failure of irreplaceable or irreparable part eg via parts unavailability. Accounting life is based on predicted (wear-out) life of surveyed existing like machines. Economic life is the period from machine purchase to the point where it is more economic to replace it than to continue using it. This may arise from uneconomic repair cost or obsolescence. Engineering economic tools exist for evaluating challenger-defender alternatives for determining the economic lives of machines which is employed in estimating depreciation. High annual machine use hours leads to early retirement based on wear-out while low usage will lead to retirement based on obsolescence. The wear-out lives and annual use of some farm machinery is shown in Appendix A1.

III) Deprecation and inflation rate: Whereas depreciation should afford the replacement of any machine at its life end, the accumulated money value may be inadequate to purchase a new machine due to increased inflation rate. An inflation rate of more than 10 % is of immense consequence (Dahab, 2000). Consumer price index compares a good’s value at a given time with that at a base period and gives the indication of inflation rate. The effect of inflation can be taken care of by relating the machine purchase price to a future price of a machine (Kastens, 1997). Also, they suggested that the effect of the inflation on depreciation can be reflected in the straight line method for example by replacing the purchase price in Equation 2.3 with the future value of the current price $P$.

IV) Interest on investment: Hunt (2001) reported that interest on investment in a farm machine is usually included in operational cost estimates, since money used to buy a machine cannot be used for another productive enterprise. The amount invested in a machine is greater during its early life than during later years since an amount is written off each year as depreciation. Field and Solie (2007) stated that, in calculating annual interest on a capital invested in the machine, it is customary to choose a constant rate of interest over the machine life. This interest is charged on both the purchase price and salvage value as shown in the following equation (Hunt, 1999b):

$$I = \frac{r\left(P + Sv\right)}{2} \tag{2.11}$$

where:

| | |
|---|---|
| $I =$¿annual interest charge | ₦ or \$ |
| $r =$¿rate of interest | (dimensionless fraction) |
| $P =$¿purchase price | ₦ or \$ |
| $Sv =$¿salvage value or scrap selling price | ₦ or \$. |

When $Sv$ is evaluated as 0.1 of purchase price $P$ Equation 2.14 becomes:

$$I = P \times 0.55\, r \tag{2.12}$$

V) Taxes and duties: Duties and levies of sorts are payable on goods and premises. Annual sanitation levies are paid on premises in all states of Nigeria and should form part of fixed costs. Custom duties are paid on imported items in Nigeria. Agricultural outfits in Nigeria are currently exempted from machinery import duties and are charged reduced duties and levies. These incentives and a 5-years tax-free operation are part of government's effort to encourage establishment of some enterprise types, (Fonteh, 2013). However Value-Added Tax (VAT) is practiced in Nigeria as in many parts of the globe. Agricultural production machineries in Nigeria enjoy tax relief.

Subsidizing of tractors and implements purchase prices for small scale farmers is done in Nigeria under certain programmes as government incentives for agro-production promotion. Takeshima *et al* (2013) reported that existing commercial market for imported tractors in Nigeria, has small effective demand that is limited to private owner-operators. Such operators usually accumulated sufficient capital through expansion of business after acquiring subsidized tractors. Putting the combined taxes and equipment related duties in the form of percentage machinery purchase price makes it easier for mathematical manipulation. Hunt (2001) assessed the annual cost of taxes in the US to be about 1-5 % of the purchase price for a 10–year machinery life.

VI) Cost of shelter: Some equipment managers do not shelter their equipment. However sheltering of equipment prolongs the life especially the surface/coating. Oluka and Nwani (2013) stated that shelter can retard machinery deterioration and reduce average repair cost. Oluka (2000) maintained that the shelter types and complexities determine the cost. Field and Solie (2007) recommended 0.75 % of machinery purchase price as annual shelter cost estimate.

VII) Insurance Costs: Insurance policies enhance the investor's ability to bear risks encountered in the course of the business, thereby encouraging enterprises. Hunt (2001) assumed the annual charge for insurance as 0.25 % of the original price respectively. Kastens (1997) considered Taxes, insurance and shelter as typical fixed machinery cost that usually amounts to a set percentage of the machinery market value. ASABE (2006) prescribed that if the actual data are unknown, the following percentages of the purchase price can be used: 1 % for taxes, 0.75 % for shelter and 0.5 % for insurance, or 2 % for the total. The engineering unit of the Nigerian National Agricultural Extension and Research Liaison Services (NAERLS) reported an average insurance rate of 5 % of machine purchase price, (Yiljep and Gwarzo, undated). 6 % of the purchase price was recommended as the combined taxes, insurance and shelter costs for agricultural machinery cost estimation. Premium of 6 % of purchase price was charged for comprehensive insurance of agricultural tractors by the ending period of this study in Nigeria (Oasis Insurance, 2016). Olarinmoye (2017) reported a prevailing insurance cost of 4 - 5 % of the machine value in Nigeria.

Though charges for taxes, insurance and shelter may be comparatively small, they should not be ignored in farm machinery costing (Hunt, 1999b). For simpler mathematical handling, the costs was combined into a lump sum and integrated into the fixed cost factor (γ) evaluated as a percentage of the purchase price. See Equation 2.13. The lump taxes, shelter and insurance costs was evaluated as 2 % of machine purchase price.

$$\gamma = 100\left[\frac{0.9}{\Gamma} + 0.55r + 0.015\right] \qquad (2.13)$$

where γ = fixed cost as a percentage of purchase price. %

The depreciation and interest cost built into his expression were as evaluated with Equations 2.4 and 2.11.

### 2.2.2 Variable cost

This portion of machinery costs as said earlier varies with annual use and includes items like fuel, oil, lubricants, labour and repair and maintenance costs. Field and Solie (2007) stated that while variable cost are usually estimated on hourly basis, they can also be expressed on per unit field size, crop output and any other appropriate measure. Oluka (2000) reported that tractor variable costs constituted 26.6% of the total ownership in Nigeria.

I) Costs of fuel: Hunt (2001) mentioned that, the fuel and oil consumption is measured or estimated and multiplied by their respective prices to determine their cost. The fuel consumption is gotten by multiplying the equivalent PTO power needed for the operation (*Π*) with the specific fuel consumption (ϰ). The specific fuel consumption of a diesel engine for an operation is related to the power utilization ratio q, as follows (Srivastava *et al*, 2006):

$$Q = \Pi\varkappa = \Pi\left[3.91 + 2.64\,q - 0.203\left(173 + 738\,q\right)^{0.5}\right] \qquad (2.14)$$

where:

$\Pi$ = equivalent PTO power needed for the operation, kW

$\varkappa$ = Specific fuel consumption, l/kW.h

$q$ = ratio of equivalent PTO power required to the maximum PTO power for the operation.

Kazmami and Ahmed (1996) found a positive relationship between fuel consumed and age of different tractor models. Yassin (2001) reported that, fuel costs will depend on the type of work done and tractor power and load. Adewoyin and Ajav (2013) studied the fuel consumption of some tractor models for ploughing operations in some sandy-loam soils of Nigeria. They found the fuel consumption to vary linearly with tillage depth. Oduma *et al* (2015) found that disc plough had the highest fuel consumption rate followed by disc harrow and next by disc ridger, while planter had least.

II) Oil and lubricant costs: Field and Solie (2007) predicted annual oil consumption as the volume per hour of engine crank case oil replaced times by the annual replacements frequency recommended by the manufacturer. They gave the following equation for a diesel tractor's oil consumption ($OC$):

$$OC = 0.00021\,\varrho + 0.00573 \quad \text{l/hr} \qquad (2.15)$$

where $\varrho$ = the rated engine power kW.

ISU (2005) mentioned that usually an allowance of 15 % fuel cost should be made for lubricant and oil consumption in the US. Jekayinfa et al (2005) used 15% of the fuel cost to estimate the cost of lubricants in tractor cost studies in Nigeria.

III) Labour costs: Manpower involvement in utilizing agricultural machinery includes the machine work scheduling, maintenance, attendance and operation. Kepner *et al* (2003) stated that labour charge should be based upon prevailing wage rate. The labour cost per hectare is inversely proportional to the field capacity of the machine. The use of large implement for given total area per year decrease the labour cost per hectare but increase the implement fixed cost per hectare. Labour cost for the owner operator should be determined from the alternative opportunity costs of the owner time, while for the hired operator, a constant hourly rate is appropriate.

IV) Repair and maintenance costs: Hunt (1999a) defined maintenance as the process of correcting or retarding deterioration in the equipment. He stated that machine use is most significant cause of equipment deterioration, and that labour and parts costs for changing replacement parts and reconditioning renewable parts constitute repair cost. Rusting of iron, oxidation of rubber and aging of paint, on the other hand, are time-dependent maintenance problems. Simple maintenance operations like regular checks for fuel, oil, and coolant levels, tension in belt and chain drives, loose bolted connections and changing filters and lubricants aid better machine performance. Plugged radiator cores, and excessive build-up of dirt, dust, and crop materials around the engine and in the implement mechanisms prevent best machine performance and need clearing.

The heavy loss implication of having downtime during critical field operations makes machinery managers to go to the extent of over-maintaining their machines some times in order to ensure reliability and operations timeliness. Maintenance cost, is relatively minor and is usually lumped with the much larger repair cost under repair and maintenance costs. Repair and maintenance costs vary highly for different places because of soil, weather, crop condition and even operators skill (and keenness) differences (Hunt, 2001). Çanakci *et al* (2011) stated that regional and specific farm conditions should be considered when determining appropriate data for machinery selection.

The various components of a machine incur more maintenance cost as the machine ages. (Oluka, 2000) reported that repair costs tend to increase with machine age. It should be an important in influencing the optimal time for machinery replacement. Hunt (2001) stated that maintenance cost per hour of use tends to remain constant as a machine becomes older, and depends on machine type. Deterioration through normal wear is directly related to use, whereas component failures are more random with respect to time and become more predictable only as accumulative trend over the service life of the machine. The accumulated repair and maintenance cost ($ARM_n$) for accumulated use hours was given by Hunt (2001) as a 3rd order polynomial function. Kastens (1997) reported it as a logarithmic function shown in Equation 2.16.

$$ARM_n = RF_1 \times P\left(\frac{AH_n}{1000}\right)^{RF_2}, \qquad \text{if } AH_n \leq EUL \qquad (2.16)$$

Else

$$ARM_n = RF_2 \times \left(\frac{EUL}{1000}\right)^{RF_2} \times \left[1 + RF_1\left(\frac{AH_n - EUL}{EUL}\right)\right], \text{ (for } AH_n > EUL\text{)} \qquad (2.17)$$

where:

$ARM_n =$ ¿ accumulated repair and maintenance cost, ₦ or $

$RF_1 \wedge RF_2 =$ ¿ repair factors, dimensionless

$P =$ ¿ purchase price, ₦ or $

$AH_n =$ ¿ Accumulated use hours, hr

$EUL =$ ¿ Estimated Useful Life, hr

Values of $RF_1$ and $RF_2$ for some farm machinery can be seen in Appendix A1.

The repair and maintenance cost ($RM_n$) for any year *n* is gotten from:

$$RM_n = ARM_n - ARM_{n-1} \qquad (2.18)$$

Kastens, (1997) argued that machinery management styles affect the annual repair and maintenance cost and suggested that the simulated cost should be multiplied by a factor between 0.75 and 1.25 to reflect this. Calcante *et al* (2013) and Jekayinfa *et al*, (2005) used the power model in the study of self-propelled combines in Italy and Nigeria respectively. Abubakar *et al* (2013) developed model for determining the accumulated tractor repair and maintenance cost ($ARM_n$) from seventy five MF 375 Tractors in Kano Metropolis, Nigeria as:

$$ARM_n = 0.005\, AH_n^{1.2} \qquad (2.19)$$

They recommended that mathematical models developed for tractor repair and maintenance should be used for only those conditions they were developed for.

### 2.2.3 Estimating total machinery costs

According to Kepner *et al* (2003), the total machinery cost per unit of work covered involves the following factors:

- ✓ annual use of implements in hours
- ✓ effective field capacity of implements in hectares per hour
- ✓ total operating costs for implements
- ✓ total operating cost per hour (repairs, fuel and lubricants) for implements.

- ✓ cost per hour or per hectare for tractor power required by implements that are not self propelled and
- ✓ labour cost per hour.

Machinery cost analysis provides a framework for combining net cash flows for several machine operations, or machinery services, into a single annual value.

The annual machinery costs associated with one cropping/tillage scenario can thus be directly compared with those from another scenario, or with machinery hire charges. Such charges are market-based and a competing source of machinery operations whose rates can be used to validate simulated costs. Hire rate nonetheless are poor in analyzing structural or technological farm changes. Researchers combine the machinery costs by representing them as percentages of purchase price for ease of mathematical manipulation Hunt (1999b). He evaluated the fixed cost using the lump annual fixed cost percentage which he estimated as 16 % of the purchase price. Adding annual repairs and maintenance costs, fuel, oil and labour costs; as variable costs and tractor use costs to this fixed cost yields total annual cost. The annual cost for a field machine according to Hunt (1999b) can be approximated as:

$$AC=\left(\frac{\gamma}{100}\right)P+\frac{A}{C_e}\left[\left(\frac{\Delta}{100}\right)P+L+O+F+T\right] \qquad (2.20)$$

where:

$AC=$ ¿ annual cost of operating machine, ₦/hr or \$/hr

γ = annual fixed cost percentage, %

$A=$ ¿ area cultivated by the farmer (annually), ha

$P=$ ¿purchase price of machine, ₦ or \$

$C_e=$ ¿effective field capacity in (ha/hr) as seen in Equation 2.1.

$\Delta$ = hourly repair and maintenance costs, as % of purchase price per hour.

$L=$ ¿ labour rate, ₦/hr or \$/hr

$O=$ ¿ oil and lubricant cost, ₦/hr or \$/hr

$F=$ ¿ fuel cost, ₦/hr or \$/hr

$T=$ ¿ fixed cost of tractor use for machine, ₦/hr or \$/hr

($T$ = 0 for self-propelled machines).

Determination of tractor fixed costs ($T$) involves the same approach that has been discussed for implement (Hunt, 1999b). The hourly cost is based on the total annual operating time for the tractor rather than the annual use with the particular implement involved. In Nigeria, Igbeka (1986) found that the cost of plowing was highest, while that of ridging was marginally higher than harrowing. He stated that it is not possible to compare costs of operation for different countries because there are many factors such as labour, fuel, lubricant costs and purchase price which vary from one country to another.

### 2.3 Duration of Operation

In any field operation, the total area to be worked and the field capacity of the machine deployed will determine the required working days. Hunt (2001) reported that to predict the amount of work that can be accomplished, the time available within the optimal period for the required operation must be known. For a given field machine operation, the total required time is a function of the machine capacity and the available working days. The time available varies considerably from year to year as weather conditions vary.

#### 2.3.1 Timeliness in farm operations

With the right conditions of temperature, soil moisture etc a planted seed can always germinate and survive. However, necessary conducive conditions must exist during the crop’s later developmental stages for it to yield maximally. Even the produced fruit need to be gathered successfully for the value of the crops to reflect in the returns on the investments. If operation is delayed, value of crop may be reduced due to changes in quantity and/or quality. Cropping operations has a window period for their performance so that the eventual output will be maximized or the operation cost minimized. The choice of the cropping season for any crop should be such that the subsequent development and harvest stages and needed operations will fall within periods that will guarantee minimal costs and optimal harvest with respect to the crop quantity and quality. According to Gunnarsson (2008) and Najafi and Torabi Dastgerduei (2015), when the operation is not performed on time, value of the crop may decrease in quantity and or quality, which is the economic consequences of performing a field operation at non-optimal time; called timeliness costs (ASABE, 2006).

Insufficiency of conducive-condition growing period, build-up of pests or disease pathogens, intra seasonal variations in weather, and even losses to foraging by pastoral herdsmen are some reasons for timeliness losses. Timeliness costs are higher when cropping periods are reduced; as in multiple cropping or in regions that experience winter or prolonged rainy or dry periods. Kastens (1997) stated that timeliness costs may be especially high in wet season.

Van den Berg *et al* (2007) reported that for optimal cropping of second season rice crop in the Chinese Zhejiang province only one week is available for transplanting. Delays in planting ultimately postpone crop maturity and harvesting, which may eventually delay next season's planting. In such a case any delay in harvesting the first season's rice crop will ultimately bring about serious consequences in the second season rice crop.

Timeliness is a subject of considerable attention in selection of machinery (Mas'oud, 2005; Gunnarsson, 2008 and Hunt, 1999b). Increasing energy prices and rapid rate of mechanization has made minimizing machinery cost increasingly important. This can be enhanced by ensuring timely farm operations and crop value maximization (Najafi and Torabi Dastgerduei, 2015). Efficient crop management and machinery selection demands giving special attention to timeliness costs in relation to crop establishment, spraying chemical, harvesting, and soil compaction (Ekman, 2000 and Chapman *et al*, 2008).

According to Kepner *et al* (2003) environment and growth conditions affect timeliness factors. De Toro (2005) reported that timeliness costs are subject to annual variations, since they are affected by weather. Accurate results can be gotten by calculating timeliness losses in terms of changes in both quantity and quality of yield. Such arises because quality parameters such as nutrient content change as a result of delay in farm operations, especially harvesting.

Proper timing of all cropping operations or the otherwise, affect timeliness costs. Costing of timeliness is however tuned mostly to sowing and harvesting which are seen to be most critical. Gunnarsson (2008) reported that the majority of timeliness costs in grain and forage studies, were caused by delays in the start of sowing or harvesting, with only a smaller proportion arising from other operations beside sowing or harvesting. Changes in crop return due to timing of sowing and harvesting for various states in the USA are published by ASABE (2011) in form of timeliness coefficients. No generalized formulae exist for timeliness cost calculation, since timeliness costs are highly location-, crop-, and year-specific (Kastens, 1997 and Hunt, 1999b).

The timeliness costs; ie indirect penalty on the machine for losses in crop for carrying out the operations outside this period according to him can be acceptably predicted as a simple linear reduction in crop value. El Hassan (2004), Zaied *et al* (2014) and Najafi and Torabi Dastgerduei (2015) used the following expression developed by Hunt (1999b) for timeliness cost evaluation:

$$\Psi = \frac{A}{C_e}\psi \tag{2.21}$$

where:

$\Psi$ = annual timelines cost, ₦ or $

$\psi$ = annual timelines cost per hour, ₦/hr or \$/hr.

$$\psi = \frac{K' A^2 YV}{C_e ZG\lambda\omega} \quad (2.22)$$

$K'$= timeliness loss factor, $day^{-1}$

$A$ = cropped area, ha

$Y$ = yield per hectare, ton/ha

$V$ = yield value, ₦/ton or \$/ton

$G$ = hours of work per day, h/day

$\omega$ = number of differing optimum operation periods, dimensionless

$\lambda$= probability of working days during the period, dimensionless

$Z$= schedule factor; $Z$= 4 if the operation schedule can be balanced evenly about the optimum time. A $Z$ value of 2 is used if the operation either commences or terminates at the optimum time.

The timeliness cost coefficient $K'$ is an indication of the reduction in the crop value per day of the operation delay beyond the stipulated period. Najafi and Torabi Dastgerduei (2015) reported that ownership or renting of tractor might have considerable effect on timeliness cost, as renting machinery for farm operations has the probability of facing high timeliness cost. They applied a linear programming model to determine the optimum point; considerable machinery cost difference and feasible field size- for buying or renting machinery to minimize timeliness cost. The majority of farmers in their studied small farms rented farm machinery, especially for ploughing, planting, and harvesting. Under these circumstances, farmers may not have access to farm machinery at optimum time and may incur a timeliness cost.

They saw the problem as most daunting in developing countries because of the dominance of small farms and financial constraints. These lead most farmers to renting their needed machinery for farm operations through contractors. The machinery contractor will equally add a mark-up as his reward, to the actual machinery cost in the hiring price. For the owner-user situation, efforts will be made both in the selection and management of the machinery to ensure as much as possible the availability of the machinery at the time it is critically needed. When the indirect-cost of failing the complete the operation within the optimum time is charged against the machine, the annual machinery cost will according to Hunt (1999b) be as shown in Equation 2.23.

$$AC=\left(\frac{\gamma}{100}\right)P+\frac{A}{C_e}\left[\left(\frac{\Delta}{100}\right)P+L+O+F+T+\psi\right] \tag{2.23}$$

### 2.3.2 Available field work days

For the evaluation of field operations duration, estimation of available suitable work days within the window of the timely operation period should be made. Field operations are difficult or impossible to perform under adverse soil conditions. Khani *et al* (2011) reported that accurate information on the number of suitable days for field operations is important in design, development, and selection of efficient machinery systems for crop production. Ahaneku and Onwualu (2007) relayed that the amount of time available throughout the year for field operations is determined by two major factors; the soil moisture content and the vagaries of weather. Physiological growth of a plant is affected by different weather variables and environmental factors. The effects are more significant under rainfed cropping and should affect cropping timing. Suitable fieldwork days are random in nature, as they are determined from random weather-related events (primarily rainfall and temperature).

I) Estimating suitable work days: Probability of a working day ($\lambda$) according to Ahaneku and Onwualu (2007) is the fraction of workable days to all days in a work season. This is used in management of agricultural mechanization, including timeliness cost, optimum capacity of a machine and the required machine capacity determination. The workability / tractability of the soil depend on the soil moisture content which can be evaluated from soil and weather variables. Rotz and Harrigan (2005) reported that selection of the optimal machinery set for long-term production on the farm depends upon accurate assessment of the days available for performing each field operation.

Planting and harvesting the operations are greatly restricted by the soil moisture. The soil must be moist enough to wet the planted seeds for the necessary biochemical reactions of germination. Equally, too dry soil will present very high resistance to digging tools. Uprooting operations eg harvesting cassava will be ineffective as the force that can free the tubers from the soil crust will be high enough to first break the tubers, leaving the stumps in the soil; which results in harvest losses. In a poor season, little time may be available for performing one or several field operations under acceptable conditions. Existence of a favorable weather pattern and a friable soil is necessary during the available or possible time for completing the field work. Such period should be long enough to discourage working excessively long hours, or working in unsatisfactory conditions.

The weather interacts both with the soil to vary soil workability for tillage operations and with the crop to vary yield and moisture content at maturity for harvesting operations. The influence of the weather on soil tractability affects all operations to a greater or lesser extent. Provided that all the relevant operating conditions can be specified for the soil and the crop, suitable workdays can be identified. Ahaneku and Onwualu (2007) estimated the daily suitable fieldwork days for tillage in Ilorin north central Nigeria.

II) Effect of daily field work hours on required work days: According to Edwards (2009), a given farm area ($A$) in hectares, needs an implement field capacity ($C_e$) predicted (with the physical method) as:

$$C_e = \frac{A}{AD \times G} \tag{2.24}$$

where:

$AD$ = available working days annually days

The denominator represents the annual available hours for the operation ($h_{AV}$)

$$h_{AV} = AD \times G \tag{2.25}$$

where $h_{AV}$ = the available annual working hours for the operation, hr.

Opara (1987) employed Equation 2.25 for power and machinery selection in modeling the optimum farm size a farmer can effectively cultivate under work rate limitation and timeliness constraints for Nsukka area, Nigeria.

Hours of work put in on a suitable day into the farm operations plays a significant role in timely completion of such operations. Where the mechanized operations is rendered by the public service or organized private sector outfits, Nigeria labour unions demands limiting work period to 8 hours daily, (which includes one hour break). On the other hand, most small scale and even some medium scale agricultural production outfits have extended working hours like 7 am to 6 pm schedules. The human factors capabilities and work pressure requirements are paramount determinants in some human-powered household farming activities' duration. In such cases daylight availability determines the work duration. Paid overtime and multiple shift work arrangements can be employed in extending working hours in the public and organized private sectors' outfits. The daily field time hours will vary for different shift arrangements.

## 2.4 Cropping Operations

Different farming operations are needed in cropping any particular crop. Such operations range from land clearing and preparation to the matured crop harvesting. Mechanization is operation-specific as each operation is mechanized using a specific set of machinery.

### 2.4.1 Land clearing and development

Vegetative growth most times must be removed before further cropping operation can proceed. This becomes more glaring when the growth can obstruct the field vehicle or impede or get in the way of the implements. Strong tree or shrub roots impair the free movement of soil-engaging implements and need to be removed either during the felling of the above-ground vegetation or by subsequent operations. In our traditional hand tool agriculture, tree stump removal is not usually practiced. The farmer meanders his way to any spot he wants to execute the subsequent field operations on.

The boughs that re-sprout from the stumps are chopped off to prevent the stump from competing with the crops for light and nutrients. Economic trees are even planted or allowed to grow in the farms to add to the farm revenues. Excessive shading from such trees is controlled through de-limbing the trees; which is usually done during land clearing before planting. The removed vegetative root and stem materials must be removed from the land via windrowing, burning, etc operations. Levelling, contouring/terracing, sloping may also be necessary for hilly fields or fields that will be irrigated.

The top soil which is essential for plant is preserved as much as possible during agricultural land clearing and development, which differentiates agricultural land clearing from land clearing for constructional purposes. Construction of drainages and irrigation structures are also done during land development. Manual clearing operations is mostly employed in our traditional agriculture. Hand tools like matchet and cutlass are deployed for light vegetation brushing. For thicker stem shrubs and trees the axe and matchet are used in the above-ground vegetation clearing. Stumps of trees and bigger shrubs will need digging around them and severing the roots; that would have gotten into the way of soil engaging tools and implements with the aid of matchet, cutlasses and mattock. Various machinery and equipment exist for land clearing operations. This study did not cover land clearing and development operations.

### 2.4.2 Tillage operations

Tillage is undertaken to prepare soils for productive use and is usually aimed at modifying the top soil. The arable layer of soil, which contains organic matter and sustains plant life is of interest during tillage. Odigboh (1999) and Graham *et al* (2007) described tillage as the physical, chemical and biological manipulations of soil for the production of optimum conditions of seed germination, emergence and seedling establishment. Tillage is done to:

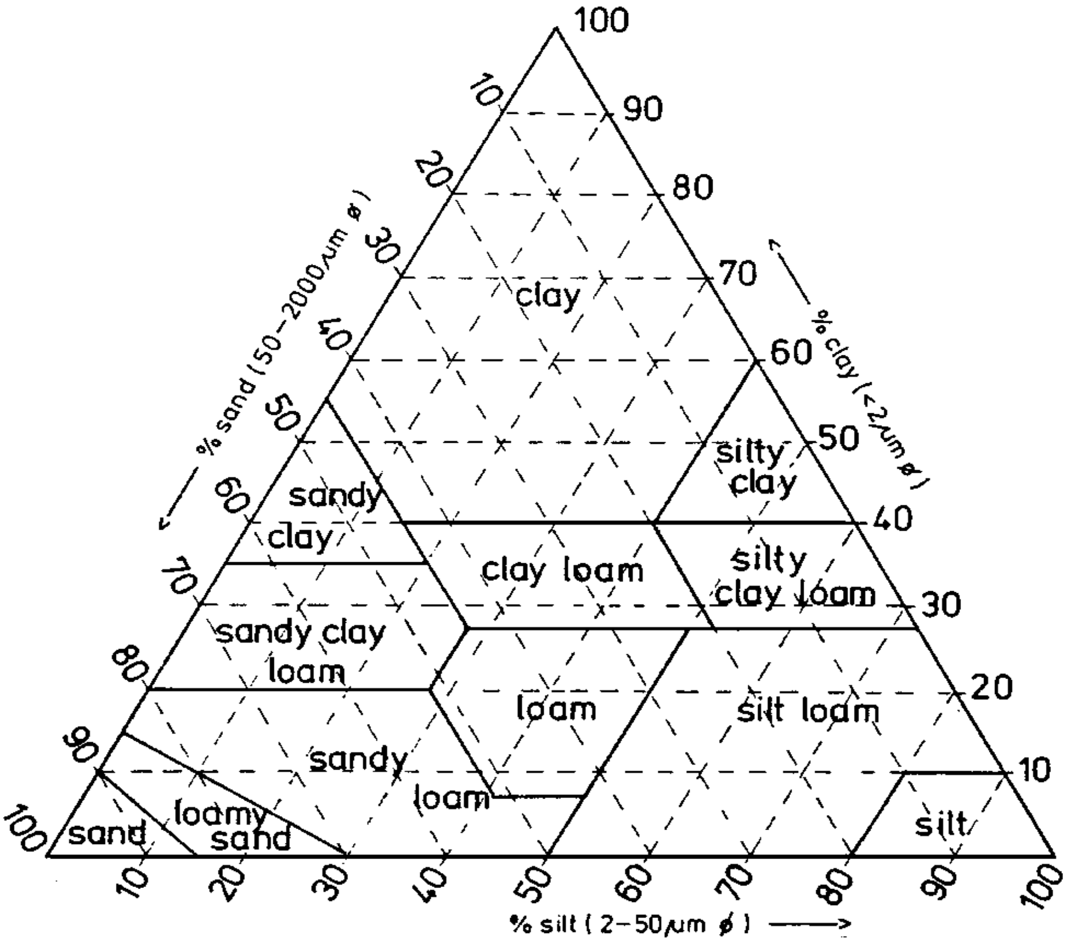
- ✓ clear virgin soils of plants and animals; to make it fit for agricultural use.
- ✓ Introduce seeds into the soil and secure a good environment for introducing seedlings into the soil for further development.
- ✓ control weeds and soil-inhabiting animals, eg crickets, mice, etc.
- ✓ obliterate the surface irregularities caused by traffic on the soil, since most operations in mechanized agriculture depend on level surfaces.
- ✓ Provide adequate soil structure by distributing clods and porosity.

Plants need fine soil around the seeds, which should be covered by small clods for protection while porosity must not be too high under the seeds.

Tillage is primarily done for seedbed preparation, providing a good medium for plant growth, improved water infiltration and conservation, weed and erosion control (Oforim 1995). Tillage operation demands higher energy than any other farm operations, beside land clearing and development. Energy required for manual tillage operations in Nigeria is beyond the human endurance limit. The required bending posture also imposes extra drudgery on the worker (Nwuba, 2009).

Nigerian farmers has more readily adopted engine- and draft-animal-powered mechanization options for tillage than for other farm operations (Takeshima *et al*, 2013), possibly because of this. Most engine-powered agricultural machinery available in Nigerian farms include tractors, tillage equipment and in some cases, nothing else. DAT operations where practiced in the country involves more of tillage and transportation. Appropriateness of soil moisture content plays an important role in the timing of tillage operations. In addition to making the soil conducive for the crop to be planted, tillage is also important because of their timeliness consequence and that of the subsequent cropping operations.

I) Factors influencing tillage: Timing and location factors affect tillage greatly, thus tillage methods and equipment used must thus be location specific. They also influenced by technological availabilities. Two of such edaphic factors are soil texture and structure. Soils' smallest mineral particles are divided into 3 classes based on their diameters: sand (for particles between 2 mm and 0.05 mm), silt (particles between 0.05 mm and 0.002 mm) and clay (particles smaller than 0.002 mm). A soil's texture class is evaluated from the plot of the percentages of these 3 particle classes in a textural triangle (Scheffer and Schachtschabel, 1992), see Figure 2.1. It is an important characteristic of agricultural soils. Soil aggregates are formed from the agglutination of soil particles, and reducing these crumbs to diameters smaller than 50 mm is the optimum aim of tillage. Porosity is thereby created, encouraging percolation and protection against erosion.




Source: Scheffer and Schachtschabel, 1992.
Figure 2.1: Soil textural classification triangle

Soil type and moisture content affect produced soil tilth and tillage-power requirement. Sands and sandy soils (light soils) are easily tilled at all moisture content, but are however suitable for agriculture because of poor water retention. Silty and loamy soils (medium soils) are best agricultural soils. They can be tilled with less power requirement and over a wider moisture regime than clay soils (heavy soils). Clay soils are very hard at low moisture content and consequently very difficult or near impossible to cultivate under such conditions. Plasticization occurs at high moisture content in clay making crumbling almost impossible and producing very high draft forces in tillage. In Anambra State, southeastern Nigeria tractorized tillage is carried out after the first rain in clayey soils (Onyeokoro, 2016) when the rain has wetted the soil enough to soften it. Alternatively, in the flood prone zones, tillage is done after the soils have dried sufficiently after the flood has receded; which comes up in November-December (ASADAP, 2016).

II) Tillage machinery and systems: Primary tillage is done to cut and invert soil slices so as to bury vegetation and trash, produce a distribution of smaller and larger soil clods. Primary tillage operations include ploughing and subsoiling; which is done to break the deeper layers of compacted soil, and enhance water percolation through the soil layers. Removal of the previous crops and existing shrubs roots from deeper soil layers can also be accomplished through subsoiling. Secondary tillage is aimed at producing fine soils for seedlings and a good soil structure.

Conventional, minimum and zero tillage systems are practiced in agriculture. The tillage work volume, required power and number of machines and costs decrease in that order. The time required for zero tillage and minimum tillage has been showed to be as low as 35 % and 57 % of that for conventional tillage respectively. Energy requirements were shown to be about >90 kWh/ha, 60 kWh/ha and 10 kWh/ha; for conventional, reduced and zero tillage systems respectively, (Weise and Bourarach, 1999 and MWPS, 1992). Nigeria practices mostly conventional tillage system.

Tillage draught is also affected by depth and soil moisture content Ahaneku *et al*, 2004). Initial penetration of cassava's fibrous root and the root thickening into tubers needs sufficiently loose. Planting on tilled flatland or ridges gives no significant difference in cassava yield (Leihner, 2002). Ploughing and harrowing are required for rice field preparation. Ridging is needed mostly as a soil conservation practice for upland rice in hilly fields, land leveling and bund making are additionally required for swamp rice plots.

### 2.4.3 Planting operations

Seeding of the intended crop is done to introduce the crop seeds or seedlings to the prepared ground for germination and subsequent development of the crop so as to realize the harvest desired in cropping investment. Rice planting can be effectively done on the flats, except where soil conservation practices will require ridging. Even so planting on the flats can be done and ridges made latter with listers during weeding operation. This will afford nutrient re-scooping as well as beating of timeliness constraints. Planting of cassava may be done on the flat or ridges, the latter being additionally more advantageous for easier harvest (uprooting). Cassava planting is infeasible and not recommended during dry, cool or flooded periods (Leihner, 2002). Rice planting is done in nurseries with later transplanting to tilled fields.

### 2.4.4 Weeding/cultivation operations

Weeding removes unwanted vegetation which can compete with the planted crops for light and nutrients. Weeding is absolutely critical in the cropping cycle, as the penalty in crop yield for late weed control is heavy. More than 30 % of yield is commonly lost because of weed infestation (Sims and Kienzle, 2006). There are chemical, mechanical and thermal methods of weed removal. Timely weeding of the farm is necessary in cassava and rice farms as it enhances optimum yield from the field. Weeds are killed with herbicides prior to rice transplanting, while the flood in rice swamps further helps in controlling weeds. Cassava farms should be kept weedfree during their early growth period.

### 2.4.5 Harvesting operations

Gathering in produced crops helps in realizing the returns and utility of the various cropping activities. Timeliness of rice and cassava harvests is critical for the amelioration of losses to pests and adverse weather effects. While all field operations of rice production have highly mechanized systems, Odigboh (1985) asserted that cassava being a tropical crop has to depend on indigenous efforts and initiatives for its mechanization. Prototypes of mechanical cassava planter (of 0.35 ha/hr field capacity), and (0.35 ha/hr capacity) harvester (Opara, 1987) have been designed and fabricated in Nigeria. The planters have incorporated ridging mechanism, while the versions of the harvesters are based on digging action. A front mounted Stem Cutter and other cassava field and processing machinery; including a Human-powered Weeder have also been fabricated in Nigeria. Yulan *et al* (2012) designed and fabricated a Chinese prototype of a digging-pulling cassava harvester with successful field trials.

## 2.5 Farm Machinery Selection Models

Models for machinery selection provide a decision support to farm the manager. Suitable models for the given farm scenario makes appropriate machine selection possible. Thus, modelling machinery selection needs keen effort.

### 2.5.1 Modeling; a solution approach to engineering problems

A model is an idealized representation of real system. In engineering, real world behaviours are conceptualized, described and evaluated mathematically, and the solution applied to the real life situations. The inter relationships of the model's variables and parameters must be captured in functional interaction that can predict, simulate or describe the system outputs from the inputs. What if analysis can as such be carried out without expending the real world experimentation costs that would have been otherwise needed. Models can be physical, analogue, logical or mathematical.

The computer because of its processing speed is a great asset in solving the complex mathematical computation or logical processing of models' problem solution. Linear programming (LP) is one of the most widely used mathematical modeling techniques. LP problems include minimum-cost route for driving through a set of locations, transportation of materials from different sources to different destinations, etc. The least-cost method is one of the suitable algorithms used for solving such transportation problems. It concentrates on the minimum-cost routes and assigns highest feasible units of the decision variables to it, achieving better starting solution thereby (Taha, 2007). Integer programming, non-linear and dynamic programming, conditional optimization and unconstrained mathematical models also are used.

### 2.5.2 Some models for field machinery size selection optimization

Najafi and Torabi Dastgerduei (2015) reported that since finding minimum cost with simple mathematical methods is not feasible, most of the models used are based on the mathematical programming. No separate mathematical function can satisfy the required criteria for reliable machine selection. The solution of any optimization mathematical function must then be backed by other models that reckons with the unconsidered criteria. Most models developed by researchers for field machinery selection are suitable for a particular crop or crop rotation and location. The models that are not limited to crop specific conditions are too comprehensive with a broad application resulting in lower sensitivity.

Two key approaches to selecting farm machinery are the physical and economic models. The physical method matches tractor power and implement width by considering soil conditions, soil tractive force, and engine power and operation speed (Bol and Mohammed, 2005). Awulu *et al* (2016) employed this approach in which they suggested a set of empirical formulae for the process. They developed a nomograph for selecting farm equipment on this basis. Economic or physicals variables based single objective quantitative models are traditionally used by researchers in machinery selection. Most economic models follow the Hunt's cost minimization (least-cost) or LP model.

Variables like machine fixed costs, labour, crop yield, field efficiency, timeliness of operation and scheduling time were utilized in the economic models for farm machinery selection. These models were based on the least cost model developed by Hunt (1999b) or LP minimization. Takeshima *et al* (2013) simulated Nigerian farm households' behavior in farm size choice in mechanization adoption for land preparation. Total household excess farm produce sales and off-farm revenues were maximized in an LP model subject to monthly family food production and liquidity sustenance, *inter alia*. Sogaard and Sorensen (2004) used a non-linear programming model for annual costs minimization of individual Danish farms. Awulu et al (2016) developed a graphical user interface driven mathematical program for matching tillage implement to tractor size. The computer mode predicts the draft and power requirement and selects a matching tractor for the implement.

Dash and Sirohi (2008) reported that some of the optimization techniques used by previous researchers for farm machinery selection have limitations. They used the Hunt's least-annual cost (differential calculus) method for optimization of farm power and machinery selection for paddy-wheat cropping system in India. Cropped area, soil type, number of operations for each crop, crop rotation and time available for each operation were the required inputs. The available sizes of tractor and matching implements and timeliness of operation were also taken into consideration. Bol and Mohammed (2005) developed a mathematical algorithm from the Hunt's least cost model and the tractive force model. They selected physical and economic- optimum tractor-implement combination within the constraints of available power, costs, soil types, and conditions.

According to Hunt (1999b) the annual cost equation allows the machinery manager to compare ownership, renting and hiring machine, as well as alternative machines, DAT and even hand tool technology methods. The economically appropriate equipment size can thus be selected. In employing the model, the effect of timeliness in different areas of the world must be considered. Farm production is both season- and weather-dependent. Good farm management requires that the selected machinery must complete all field operations on schedule in both good and bad climatic conditions. Because machinery selection is based on anticipated machine performance and costs, approximations of the variables relationship is permitted.

Machine capacity is considered as the most pertinent selection variable and power seen as non-limiting. Operation speed is assumed as the maximum for effective field operation (Hunt, 2001). Influence of the available field work days on timeliness cost, difficulty in predicting or controlling the available field work days and consequences of the machinery costs, further complicates optimum machinery capacity determination from farm size (De Toro, 2005). Additionally, optimal work organization and machinery utilization (Sorensen, 2003) and farming different crops or varieties with different maturation dates improve timeliness. Joint use of farm machinery enables farmers to take advantage of advanced technology- (De Toro, 2005), to reduce timeliness cost. This shows that proper equipment size selection will potentially save farm machinery and operation costs and consequently increase profits.

Mohammed *et al* (2011) developed a computer model that uses Hunt's theoretical basis, integer linear programming (LP) technique and PERT and Critical Path method to minimize overall systems costs, from machinery performance data and economic data. Zaied *et al* (2014) developed a computer programme to predict implement performance parameters. Such parameters were total field time, theoretical field capacity, effective field capacity, and field efficiency using the adjusted Hunt's equation in Sudan.

Crop yield, area cropped, average turning time and other time loses, and labour, machine and tractor costs and timeliness factor were some of the input variables. Others were expected daily available field work time, probability of a working day etc were used as inputs. Najafi and Torabi Dastgerduei (2015) determined timeliness cost and its effects on cropping mix in Marvdasht region of southern Iran. They applied LP to illustrate the effects of removing timeliness effects on crops yields and farmers' revenue. They additionally showed for which group of farmers buying their needed machinery is more economical than renting it, and optimum point for timeliness cost minimization.

### 2.5.3 The calculus technique for minimization problems

Calculus is an unconstrained-variables mathematical technique. It is composed majorly of differentiation and integration and is a very useful tool for solving engineering problems. Integration handles effectively summation and multiplication mathematical functions; volume of revolution, moment of inertia and area bounded by a set of curves inclusive. Differentiation which is the reverse process of integration solves problems like obtaining instantaneous values of mathematical expression. Such includes rate of change of a curve with respect to a given variable, slope of a curve and turning points of a curve.

Minimum and maximum values (turning points) of a mathematical expression can be obtained by differentiating the expression with respect to the dependent variable in question. The result of this differentiation- the derivative of the expression is set to zero and solved to give the values of the dependent variable at which the turning point exists. Evaluating the second derivative of the mathematical expression with the solved dependent variables points confirms the nature of the turning points as follows:

- ✓ a maximum for negative second derivative
- ✓ a minimum for positive second derivative, and
- ✓ an ordinary point of inflection for zero second derivative values.

Local *extrema* can thus be established for any differentiable mathematical expression and their values obtained following the above procedure.

### 2.5.4 Hunt's least cost equation

The Hunt's approximated annual cost, ($AC$) with the timeliness cost gives the total annual machinery cost (Hunt, 1999b) as shown in Equation 2.23. The hourly cost of the tractor ($T$) is evaluated from the product of annual tractor's fixed cost and the fraction of the total expected annual use of the tractor expended on the operation (ø). Tractor hiring rates can be used when the proposed tractor cost cannot be evaluated or tractor hiring is proposed. The tractor hourly cost was assumed by Hunt (2001), to be independent of the machinery size; for the ease of formulating the model.

Optimum sizes of the needed field machinery can be determined from Equation 2.24 based on the time available and later matched with the power of the available tractors. Determining the machine size (width of machine, $w$) for which the annual machinery cost is minimum was done following the steps below. The first derivative of the annual machinery cost equation with respect to machinery width. Equating the derivative to zero and solving for the machinery width was employed in estimating the least-cost machinery width. Srivastava et al 2006 differentiated the annual cost based on machine field capacity and obtained the least-cost machine size in terms of machine capacity ($C_e$).

### 2.5.5 Hunt's least cost model for optimum field machinery size selection

In effecting the differentiation, Hunt (2001) represented the relevant parameters in the Equation (2.23) with their machinery width-based equivalents. Machine capacity ($C_e$) was also replaced with its equivalent expression in terms of working width and operation speed given in Equation 2.1. Labour and tractor costs were considered independent of machine width. The optimum width obtained for selecting least-cost machine is as shown in equation 2.26 below:

$$w = \sqrt{\frac{Ac}{\mu Se}\left(L + T + \psi\right)} \qquad (2.26)$$

where:

$w$ = least-cost width of the machine, m

$A$ = size of farm to be processed with the machine, ha

$S$ = average speed of operation, km/hr

$e$ = field efficiency , a dimensionless decimal

$c$ = a constant ($c$ =10 when field capacity in ha/hr is evaluated from $S$ in km/hr, $w$ in m and $e$ a dimensionless field efficiency), dimensionless

$\mu$ = annual implement depreciation per machine width, ₦/m or \$/m

$L$ = labor cost per hour, ₦/hr or \$/hr

$T$ = tractor cost per hour, ₦/hr or \$/hr

$\psi$ = timeliness cost per hour, ₦/hr or \$/hr.

Srivastava *et al* (2006) gave the least-cost machine size in terms of machine capacity ($C_e$) as shown in Equation 2.27.

$$C_e = \sqrt{\frac{A}{\mu_c}\left(L_c + T_c + \psi_c\right)} \quad (2.27)$$

where the additional variables are defined as follows:

$C_e$ = least-cost capacity of the machine, ha/hr

$\mu_c$ = annual implement depreciation per machine capacity, ₦/ha

$L_c$ = labor cost per hectare, ₦/ha or \$/ha

$T_c$ = tractor cost per hectare, ₦/ha or \$/ha

$\psi_c$ = timeliness cost per hectare, ₦/ha or \$/ha.

Zaied *et al* (2014) selected least-cost machine size based on optimum capacity selection instead of optimum width of machine. Equation 2.30 can be adopted for machinery selection across power sources. In such cases, the annual implement fixed cost per implement/tool size must be represented as annual implement fixed cost per capacity ($\mu_c$). The labour, tractor and timeliness costs must also be represented as labour, tractor and timeliness costs per hectare ($L_c$, $T_c$ and$\psi_c$). Determining the optimum field capacity ($C_e$) will fit machine selection across the 3 mechanization power sources technologies more than using optimum width ($w$).

Ismail and Abdel-Mageed (2010) studied the energy and labour requirements of wheat harvest in Egypt. Combine, reaper-thresher and manual harvest-thresher systems alternatives was compared in their study based on machine capacity. Indeed equipment width and operational speed determination will be more cumbersome than assessing the work output (ie field capacity) in simple hand tool operation. Considering machinery selection across power sources will need machine work output and cost estimations for DAT and hand tool technologies. The needed human energy per cropped area can be estimated by considering the average power of one labourer (Nwuba, 2009), and the required rest time (Odigboh, 1999).

### 2.5.6 Optimum machinery size selection for multiple-crop farm

According to Hunt (2001), Equation 2.28 below predicts the combined crops annual machinery cost $AC_c$ for a farm having 2 crops (1 and 2):

$$AC_c = \left(\frac{\gamma}{100}\right)P + \left\{\frac{A_1}{C_{e1}}\left[\left(\frac{\Delta}{100}\right)P + L_1 + O_1 + F_1 + T_1 + \psi_1\right] + ¿ \frac{A_2}{C_{e2}}\left[\left(\frac{\Delta}{100}\right)P + L_2 + O_2 + F_2 + T_2 + \psi_2\right]\right\}$$

(2.28)

The required optimum machinery width $w_c$ for such farm was as shown in Equation 2.29.

$$w_c = \sqrt{\frac{c}{\mu}\left\{\frac{A_1}{S_1 e_1}\left(L_1 + T_1 + \psi_1\right) + \frac{A_2}{S_2 e_2}\left(L_2 + T_2 + \psi_2\right)\right\}} \qquad (2.29)$$

Such models are applicable where the cropping operations are coinciding (ie they are to be carried out within the same time frame). The matching tractor power for any selected implement should also be predicted for comprehensive machine selection.

## 2.6 Cost of Mechanized Transport Operation

I) Components of mechanized transport operation: The annual transport cost considered for tractor size selection is made up of a tractor cost component ($T_t$) and a labour cost component ($CT_L$) (Hunt, 2001). The annual transport labour cost equation was given as:

$$CT_L = h_t \times L \qquad (2.30)$$

where additionally, $h_t$ = annual tractor transport work hours, hr.

The following expression evaluates the annual tractor transport work hours, $h_t$.

$$h_t = \frac{B_t m_t D}{q \Pi} \qquad (2.31)$$

where:

$h_t$ = annual transport hours, hr

$B_t$ =unit mass material transportation energy required per unit distance (including energy to make the return trip) , kW.hr/t.km

$m_t$ = mass of material (tractor inclusive) transported annually, t

$D$ = distance to the field, km

$q$ = ratio of the deployed tractor power to its maximum PTO power

$\Pi_x$ = maximum tractor PTO power, kW

The energy required for transporting a unit mass per unit distance at a 0.05 coefficient of rolling resistance; the empty return trip inclusive, is given by Hunt (2001) as 0.27 kW.hr/t.km. The maximum value of $q$ for transport was given as 0.8. This makes the transport hours

$$h_t = \frac{0.27\, m_t\, D}{q\, \Pi_x} \tag{2.32}$$

The transport tractor fixed cost component was given as:

$$T_t = \pi_t \Pi_x = ø_t \frac{\beta}{100} t\, \Pi_x \tag{2.33}$$

where:

$T_t$ = annual tractor fixed cost for the machinery transport operation, ₦ or $

$\pi_t$ = machinery transport annual tractor fixed cost per PTO power, ₦/kW or $/kW

$B$ = fixed cost factor percentage for the tractor, %

$ø_t$ = fraction of tractor annual use deployed in the tillage implement transport for tillage operation, dimensionless decimal

$t$ = tractor cost per unit PTO power, ₦/kW or $/kW

The annual machinery transport cost can be evaluated as:

$$CT = T_t + h_t L \tag{2.34}$$

where: $CT$ = annual transport cost, ₦ or $

Tractive power for tillage and transport operations is evaluated with the drawbar power.

II) Estimating transport fuel cost: The energy cost transport operation is a prominent component of mechanized transport operation cost. The fuel cost can easily be integrated into Equation 2.34 if the hourly tranport fuel cost is estimated. Tractor hourly transport fuel cost is given as

$$fl_t = \frac{\Pi_x \sigma}{H} \tag{2.35}$$

where:

σ = fuel price, ₦/l or $/l

$H$ = fuel efficiency at the percentage of the tractor power loading used, kW.hr/l.

Field and Solie (2007) reported that the engine size and the percentage power load affect the fuel consumption. Fully-mounted tillage machinery is transported in a lifted position and the required power can be evaluated like that of drawn non soil-engaging implements. The required transport drawbar power was evaluated as a function of the rolling resistance (Kepner *et al*, 2003) and converted to its equivalent PTO power ($\Pi_t$) as in Equation 2.36.

$$\Pi_t = \frac{F_N \times R_R \times S}{3.6 \times 0.9\, E} \tag{2.36}$$

where:

$F_N$ = static vertical force on the tractor drive wheels, kN

$R_R$ = coefficient of rolling resistance on the tractor drive wheels, dimensionless.

II) Minimizing total machinery transport distance: Using the same farm machinery for the operations on a number of scattered farms requires following an optimum route for a minimized transport cost. The shortest route can be formulated as an LP transportation problem (Taha, 2007) as in Equation 2.37.

$$Min\, D = \sum_{k=1}^{l} \sum_{j=1}^{m} D_{kj} C_{kj} \qquad (2.37),$$

subject to the constraints on the jobs order, machine availability, etc. These constraints are written as mathematical expressions and usually include the non-negativity constraint in Equation 2.38.

$$D_{kj} \geq 0 \qquad (2.38)$$

where $k$ is the $k^{th}$ source and $j$ is the $j^{th}$ destination.

He variable $C_{kj}$ takes care of the flow conservation constraint in the Dijkstra's Algorithm (Taha, 2007), which is one of the techniques used in solving such problems.

$C_{kj}$ = amount of flow in arc $(k, j)$; ($C_{kj}$ = 1 if arc $(k, j)$ is on the shortest route, else $C_{kj}$ = 0)

## 2.7 Heavy Tillage Machinery Selection Model

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

$$AC_g = \mu w + \frac{A}{C_e} fl + T \qquad (2.37)$$

where:

$fl = ¿$ field processing hourly fuel cost, ₦/hr or \$/hr

$AC_g = ¿$ annual cost of tillage, ₦/yr or \$/yr

$T$ = annual tractor fixed cost for the tillage operation, ₦ or \$

The annual tractor fixed cost is evaluated as:

$$T=\pi \Pi_x=ø \frac{\beta}{100} t \Pi_x \quad (2.38)$$

$\pi$ = annual tractor fixed cost per PTO power for the tillage operation, ₦/kW or \$/kW.

The value of $\pi$ is evaluated from tractor fixed cost percentage ($\beta$), the tractor cost per PTO power ($t$) and the fraction tractor annual hours used in the tillage operation (∅) as shown in Equation 2.39.

$$\pi=ø \frac{\beta}{100} t \quad (2.39)$$

ø = fraction tractor annual hours used in the tillage operation, decimal

Repair cost for tractor and implement was considered as not basic for the implement speed-size selection problem for a given farm size (Hunt and Wilson, 2015). They also argued that lubricant cost is proportional to the covered area and not necessarily determined by the chosen implement size. Oil and lubricant cost thus was not considered in their model. They were silent about labour cost.

### 2.8.1 Evaluating fuel consumption and draught for heavy tillage work

To obtain the optimum width as was done for non-tillage machinery the hourly fuel cost ($fl$), must be expressed in terms of $w$ and effective field capacity $C_e$ and $\Pi_x$ in compatible terms too. Fuel cost per hour ($fl$) according to Hunt and Wilson (2015) is expressed as

$$fl=\frac{\Pi_B}{0.96\,E}\eta \quad (2.40)$$

where:

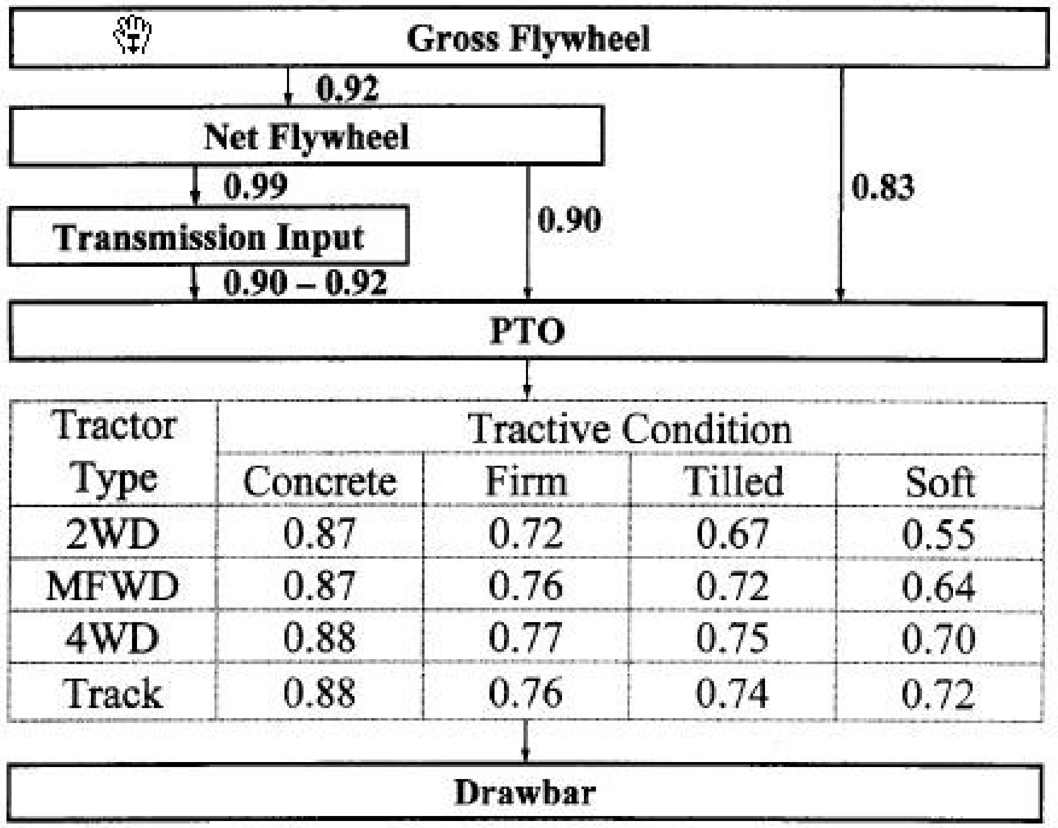
$\Pi_B$ = tractor drawbar power required to pull the tillage implement, kW

$fl=$¿tillage fuel cost per hour, ₦/hr or \$/hr

$0.96=$¿ ratio of axle power to PTO power

$E$ = tractive efficiency (ratio of draw bar power to axial power which is affected by soil type and condition). See Figure 2.2.

$$\eta=\frac{\sigma}{H} \quad (2.41)$$




| Tractor Type | Tractive Condition | | | |
|---|---|---|---|---|
| | Concrete | Firm | Tilled | Soft |
| 2WD | 0.87 | 0.72 | 0.67 | 0.55 |
| MFWD | 0.87 | 0.76 | 0.72 | 0.64 |
| 4WD | 0.88 | 0.77 | 0.75 | 0.70 |
| Track | 0.88 | 0.76 | 0.74 | 0.72 |

(Source: Roberson, 2010)
Figure 2.2: Tractor power conversion factors

The ratio 0.96 is due to tractor's internal power transmission losses (Zoz and Grisso, 2003). The plough's tractive drawbar power is given by Hunt and Wilson (2015) as:

$$\Pi_B = w \times \frac{d}{36}\left(C_1 + C_2 S^2\right) S \tag{2.42}$$

where:

$d$ = depth of tillage operation, cm

$C_1$ , $C_2$ = soil-dependent draught constants.

Speed of tillage operation in Equation 2.42 can be replaced with its equivalent obtained from the basic effective field capacity equation. This makes the tractive drawbar power

$$\Pi_B = \frac{C_e d}{3.6 e} \Theta \tag{2.43}$$

where $\Theta = \left(C_1 + C_2 \frac{100 C_e^2}{w^2 e^2}\right)$ (2.44)

Tillage fuel cost per hour can also be expressed in like terms. Equally, the required maximum PTO power of tractor ($\Pi_x$) according to Hunt and Wilson (2015) can be expressed for tillage operations as:

$$\Pi_x = \frac{C_e d}{2.66\, e\delta} \Theta$$ (2.45) where δ= percentage of the tractor power required by the operation, %.

### 2.8.2 Annual cost equation for heavy tillage machinery

The annual cost equation for heavy tillage operations was expressed by Hunt and Wilson (2015) as in Equation 2.46.

$$AC_g = \mu w + \frac{Ad}{2.66\, e} \eta\, \Theta + \frac{C_e d}{2.66\, e\delta} \pi\Theta \qquad (2.46)$$

Following the example of the general machinery cost $AC_g$ was differentiated with respect to implement width, and the derivative solved to get the width for minimized tillage machinery cost. The least-cost width developed by Hunt and Wilson (2015) using this approach is as shown below:

$$w = \sqrt[3]{\frac{C_2 d}{\mu e^3} \left[ 75\, A\eta\, C_e{}^2 + \frac{75}{\delta} \pi\, C_e{}^3 \right]} \qquad (2.47)$$

Their method for evaluating Equation 2.47 involved imputing a prior arbitrary implement field capacity value, along with the other concerned variables. The implement width so selected is eventually compared with implement sizes available in the market, and a suitable size or a combination of sizes is chosen.

## 2.9 Selecting Optimum Size of Matching Tractor

All the intended operations to be powered by tractors are considered when choosing a tractor size to match the selected farm implements. Such operations include field, processing and transport works (Hunt, 2001). Effective tractor power is selected when the power source for an implement is neither overloaded nor is the generated power under-used. The power expended in field machines is made of the power required to overcome rolling resistance [RR] and the power required for the equipment function- say seeding, soil tillage, etc. The combination of these 2 power components varies from one machine to another. Rolling resistance is affected by the soil moisture content, surface cover condition, load sharing and machine functional power rate. Where there are insufficient data, empirical data or rough values of draught for one soil type can be estimated from that obtained in another known soil type. Forward travel speed affects plough draught significantly as do organic matter content, tillage depth and root development. The least cost power required for the field operations and transportation in a farm is determined as follows (Hunt, 1999b):

$$PWR = \sqrt{\frac{100}{\beta t} \times \sum_{i}^{n} \left( \frac{A_i E_{Bi} L_i}{q_i} \right)} \qquad (2.48)$$

where:

$PWR$ = the least cost power level for the farm, kW

$A_i$ = the area of the individual field operations *i,* ha

$E_{Bi}$ = the energy needed for operation *i,* kW.hr/ha

$L_i$ = the operator's labor rate for operation *i,* ₦/hr or $/hr

$q_i =$ ¿ required tractor power to maximum PTO power (as previously defined) for operation *i,* decimal

∑ indicates a sum of the evaluations for all the operations.

The tractor fixed cost factor ($\beta$) can be determined as was done for the implement by combining the relevant cost items. Dash and Sirohi (2008) employed the above expression in the evaluation of matching tractor size for his farm implement selection model development for Indian farms. Their minimum power size selected even for fractional ha farm sizes was 11 kW, which was the minimum tractor power size available in the market.

## 2.10 Machinery Selection for Fragmented Scattered Farms

By the proper selection of the kind and size of machines for an intended job, the job's machinery cost can be reduced. Such selected machine will be most economically suitable if the volume of work will allow the machine's wear-out life to be realized in normal use before significant machine obsolescence sets in. Fragmented farms will not provide enough workload to permit economic selection of mechanically powered farm machinery. Such arises for selection of above 11 kW/ha accomplished in the deployment of the machinery selection model developed by Dash and Sirohi (2008) as cited earlier. Ironically fragmented farms constitute the bulk of our local agricultural production enterprises. The low level of mechanization adoption in Nigerian agriculture could be attributed partly to this. Najafi and Torabi Dastgerduei (2015) has reported the small scale farmers in developing countries as facing daunting problems in farm machinery acquisition because of their small farm size and capital poverty.

Some approaches to circumvent this farm size insufficiency problem include machinery sharing and hiring. Wolfley (2008) modelled the contractual terms and impacts of machinery sharing on two 2023 ha farms engaged in machinery sharing. A Nash equilibrium game theory model was applied for determining the theoretical optimal sharing rules under net present value maximization. Adama *et al* (2009) proposed the establishment of Centres for Community Farms (CCF) at various locations in Nigeria for enhancing mechanization of small farms in the country. ‘Membership of each centre is to be limited to farmers sharing common boundaries, so that the fragmented contiguous land holdings will be pooled (into a bigger combined farm) while maintaining the natural boundary between the farms’.

Larsén (2008) compared Swedish partnership and non-partnership farms and reported that partnership farms have on the average larger land and total output, but not lower capital costs. The farm efficiency of machinery- and labour-sharing for the different forms of partnership farms was generally higher. The highest machinery efficiency scores were reported for farms that shared all machinery with other farms. Lai *et al* (2015) studied consolidation of small farm in the Chinese provinces of Hebei and Shandong. The study indicated that consolidating farms of 0.31 ha average sizes into 2.6 ha plots increased machinery use by about 10 %, and crop production from 0.5 % to 1 %. Oukil and Zekri (2015) applied inverse data envelopment analysis on farms in the Batinah agricultural area Oman to evaluate the economic efficiency of small farms for potential merging and resource reallocation decisions.

Larsén (2008) reported that farmers like maintaining some level of independence in their individual farm enterprises even when they go into cooperation. It is worthy of note that the fields of the farmers that may agree to such economic cooperation and machine sharing may not always be contiguous. Merged scattered fields will not easily yield to the simple lump-field model assumption. Such lump-field assumption could have allowed the economic application of the Hunts least-cost equation for machinery selection to small farms. It is therefore necessary to factor in the scattered nature of our small-holder farms if group machinery sharing will be attempted. These machinery selection models can also be adopted.

## 2.11 Summary of Related Literature

Minimizing production cost and maximizing profit of modern farming systems require sound planning models, complex economic decisions and higher levels of technical management.

Power and machinery jointly constitute about 60 % of the total non-land inputs to the crop production system (Dash and Sirohi, 2008). Thus, selecting proper size farm power and equipment to permit economic production in a farm is of paramount importance. The agricultural economic risks due to timeliness needs, soil type and conditions, type of crops and cropping system make machinery selection researches a necessity. Same goes for management practices, labour availability, weather uncertainty and high cost of inputs relative to product value.

All farm power and machinery selection models known to the author are not suitable for application to small farms. The smallest machinery selected with the model developed by Dash and Sirohi (2008) for example was of 11.76 kW size tractor power even for fractional hectare farms. The required machinery for such farm size should have been of much less size. Nigerian agriculture is dominated with fragmented scattered farms that will find the use of large machines unaffordable and uneconomical (Takeshima and Salua, 2010 and Odigboh, 1999), leading to their continued reliance on hand tool mechanization. Odigboh (1999) reported the need for an official handtool mechanization deemphasizing policy and promotion of higher level engine power mechanization technology. The undignified image of peasant farmers will begin to change, making farming more attractive to the youths. As such, a model that also caters for economic machinery selection for fragmented scattered farms will be more appropriate for our agriculture.

Machinery-sharing has been reported to result in increased cultivated land area, value of total output and farm efficiency in partnership farms (Larsén, 2008). Consolidation of small farms leads to increased machinery use (Lai *et al*, 2015). Adama *et al* (2009) proposed a solution to the problems posed by small farm size to farm mechanization in Nigeria. Their proposed Centres for Community Farms (CCF) pools was however limited to small-sized farms sharing common boundaries. The bigger farm size formed from the fragmented contiguous land holdings will afford a more economic engine-powered mechanization. The merging of farms with appreciable separation distance (ie non-contiguous farms) on the other hand will not easily yield to the simple lump-field model assumption intrinsic in the Hunt's least-cost equation for machinery selection.

Factoring in the scattered nature of our small farms for possible group machinery sharing is

therefore needed. This study is thus aimed at developing models for selecting minimum-cost machinery capacity for scattered non-contiguous farms, including small-sized ones. The annual cost equation developed by Hunt (2001) with timeliness cost integration as shown below is effective in farm machinery selection based on cost minimization.

$$AC=\left(\frac{\gamma}{100}\right)P+\frac{A}{C_e}\left[\left(\frac{\Delta}{100}\right)P+L+O+F+T+\psi\right] \tag{2.49}$$

The optimum-cost width Equation (2.56) can be obtained from applying differential calculus to Equation 2.55 for minimum-cost machine size determination. This machinery width model according to Hunt, (1999b) allows economically appropriate machine selection, and can assist in decisions on outright ownership versus renting or hire alternatives as well as comparison with alternative machines or draught animal, and even hand tool methods choices.

$$w=\sqrt{\frac{Ac}{\mu Se}\left(L+T+\psi_1\right)} \tag{2.50}$$

El-Hassan (2004), Zaied *et al* (2014) and Najafi and Torabi Dastgerduei (2015) *inter alia* used this model developed by Hunt (1999b) for machinery selection. The annual cost equation and the optimum width selection equation according to Hunt and Wilson (2001) can also be used for multiple-crop situation with slight variations as shown in Equations 2.51 and 2.52 respectively.

$$AC_c=\left(\frac{\gamma}{100}\right)P+\frac{A_1}{C_{e1}}\left[\left(\frac{\Delta}{100}\right)P+L_1+O_1+F_1+T_1+\psi_1\right]+¿\frac{A_2}{C_{e2}}\left[\left(\frac{\Delta}{100}\right)P+L_2+O_2+F_2+T_2+\psi_2\right] \tag{2.51}$$

$$w_C=\sqrt{\frac{c}{\mu}\left[\frac{A_1}{S_1e_1}\left(L_1+T_1+\psi_1\right)+\frac{A_2}{S_2e_2}\left(L_2+T_2+\psi_2\right)\right]} \tag{2.52}$$

The general optimum machinery width selection using Equation 2.49 for tillage operations, according to Hunt and Wilson (2015) will yield erroneously large width values. They reported that optimum tillage machinery width should be rather selected using Equation 2.53.

$$w=\sqrt[3]{\frac{C_2 d}{\mu e^3}\left[75\,A\eta\,C_e^{\,2}+\frac{75}{\delta}\pi\,C_e^{\,3}\right]} \tag{2.53}$$

The annual machinery cost according to them should be evaluated with Equation 2.54.

$$AC_g=\mu w+\frac{Ad\,\sigma}{2.66\,He}\Theta+\frac{C_e d}{2.66\,e\delta}\pi\Theta \tag{2.54}$$

The evaluation of the least-cost width from Equation 2.53 according to Hunt and Wilson (2015) requires the use of a prior arbitrary machinery field capacity ($C_e$). This approach of determining machine width using a prior arbitrary width-dependent machine capacity value was considered in this study as needing improvement. These machinery selection and cost models are equally not suitable for use on pool farms with significant inter-field transport distances. Pooling small farms for economic application of engine-powered mechanization faces this hurdle and may need adjustment the application of the foregoing models.

**Observed Knowledge Gap:** The knowledge gaps that this study sought to fill are as follows:

-The previous machinery selection models are not suitable to small farms as they yield machinery sizes that are not economic for small farms. Whereas combining small farms can help the farms use mechanical-powered machines economically (Larsen, 2008 and Adama *et al*, 2009), selection of machinery with the existing models for such combined farms is suited only to the farms with common boundaries. Machinery selection models that are equally suited to fragmented farms with no common boundaries (ie non-contiguous farms) will enhance the engine-powered mechanization of such farms. This may provide a possible solution to two chief bottlenecks to farm mechanization viz: small holdings and capital poverty. These 2 conditions impede engine-powered mechanization of agriculture and are abundant in Nigeria and other developing countries.

-The Hunt-Wilson (2015) least-cost tillage machinery width selection model evaluation is based on the use of a prior arbitrary machinery field capacity ($C_e$). This study sought to develop a machinery size selection that circumvents the use of a size dependent parameter for minimum-cost machine size selection.

-Operation labour cost was not considered in the Hunt-Wilson (2015) least-cost tillage machinery width selection model. For any given farm size however, machinery operation labour is affected by the size of machine used and has been shown by Srivastava *et al* (2006) to significantly affect the total machinery cost.

-These previous models cannot be suitable for machinery selection for the multi-crop multi-farm case as in non-contiguous combined farms.

-Multiple crop-farm machinery sharing considered in those models were for coinciding farm operation time windows. Overlapping operation windows situation was not treated. Both coinciding and overlapping operation time windows are all encountered in practical situations and should be considered for machinery sharing in multi-farm or multi-crop cases.

## CHAPTER THREE

## MATERIALS AND METHOD

### 3.1 Definition of terms

I) Machinery field capacity:

The effective field capacity is the actual rate at which a field is processed. It is expressed as follows:

$$C_e=\frac{S\,w\,e}{c} \qquad (3.1)$$

where :

| | | |
|---|---|---|
| $C_e$ = | effective field capacity | ha/hr |
| $S=$¿ | operation forward speed | km/hr |
| $w=$¿ | working width of machine | m |
| $e=$¿ | field efficiency of operation, | (a decimal dimensionless factor) |
| $c=$¿ | a constant; $c$ has a value of 10, (Hunt, 1999b; Field and Solie, 2007). | |

Given the hours available for an operation ($h_{AV}$), the required basal field capacity to process the concerned farm size is expressed as:

$$C_e=\frac{A}{h_{AV}} \qquad \text{(Edwards, 2009)} \qquad (3.2)$$

where:

| | | |
|---|---|---|
| $A=$¿ | farm area to be processed | ha |
| $h_{AV}=$¿ | available hours for the operation | hr. |

The available hours is evaluated as follows:

$$h_{AV}=AD\times G \qquad \text{(Srivastava \textit{et al}, 2006)} \qquad (3.3)$$

where:

| | | |
|---|---|---|
| $AD=$¿ | available days | days |
| $G=$¿ | working hours per day | hr/day |

II) Machinery costing:

1- Annual fixed cost ($FC$) is evaluated as:

$$FC=P\left(\gamma/100\right) \qquad \text{(Field and Solie, 2007)} \qquad ₦ \text{ or } \$ \qquad (3.4)$$

where:

| | | |
|---|---|---|
| $\gamma$ = annual fixed costs percentage, | | % |
| $P$ = machine purchase price, | | ₦ or $ |

The annual fixed costs percentage (γ) was evaluated by (Hunt, 1999b and Field and Solie, 2007) as:

$$\gamma = 100\left[\frac{1-S_v}{\Gamma} + \frac{1-S_v}{2} \times r + ts\right] \quad \% \qquad (3.5)$$

where:

$\Gamma$ = economic life of equipment, yr

$S_v$ = salvage value factor (salvage value as a fraction ofthe purchase price),

$r$ =average rate of interest over machine life, dimensionless fraction

$ts$ =fraction of machine purchase price expended as annual lump insurance, taxes and shelter costs,

The first term in the bracket in Equation 3.5 is the annual depreciation factor; evaluated with the straight line method. The second term is the fraction of machine purchase price charged as annual interest and the third, the lump taxes, shelter and insurance costs. All the factors are as percentages of machinery purchase price. Hunt (1999b) suggested that the simpler straight line method can be used for estimating depreciation for the ease of mathematical manipulation, and that 0.1 of the purchase price can be assumed for unknown equipment salvage value. See Equation 3.6.

$$\Phi = \frac{0.9P}{\Gamma} \qquad (3.6),$$

where $\Phi$ = annual depreciation, ₦/yr or \$/yr.

According to Kepner *et al* (2003) annual cost estimation can be simplified by lumping the taxes, shelter and insurance costs together and representing them as a percentage of purchase price. They are shown as ($ts$) in Equations 3.5 and 3.7.

This gives the annual fixed costs percentage (γ) as:

$$\gamma = 100\left[\frac{0.9}{\Gamma} + 0.55r + ts\right] \quad \% \qquad (3.7)$$

2- Variable costs:

These costs vary directly as the cropped area and include fuel, labour, oil, lubricant and tractor use costs. Hunt (1999b) simplified the estimation of annual machinery cost by multiplying the sum of the hourly rate of the variable costs with the machine use hours.

III) Annual Transport Cost: Hunt (2001) evaluated the labour cost for annual tractor transport as follows:

$$CT_L = h_t \times L \qquad (3.8)$$

where:

$h_t =$ ¿ annual tractor transport work hours, hr

$L =$ ¿ the local labour rate, as explained earlier. ₦/hr or $/hr

$$h_t = \frac{0.27\, m_t D}{q\, \Pi_x} \qquad (3.9)$$

where:

$m_t =$ ¿ mass of material (tractor inclusive) transported annually, t

$D =$ ¿ distance to the field, km

$q =$ ¿ ratio of required tractor output power to maximum PTO power,

$\Pi_x =$ ¿ maximum tractor PTO power, kW

0.27 is the unit mass material transportation energy ($B_t$) in kW.hr/t.km, based on standard tractor performance data at 0.05 average rolling resistance coefficient (Hunt, 2001). The maximum value of $q$ for transport or any other operation is given as 0.8 (Roberson, 2012). The annual transport cost $CT$ equation according to Hunt and Wilson (2015) is:

$$CT = \pi_t \Pi_x + h_t L \qquad (3.10)$$

where:

$CT =$ ¿ annual transport cost, ₦ or $

$\pi_t =$ ¿ tractor annual fixed cost per PTO power expended in the tillage implement transport for tillage operation, ₦/kW or $/kW

Tractor hourly transport fuel cost is given as

$$fl_t = \frac{\Pi_x \sigma}{H} \qquad (3.11)$$

where:

$fl_t$ =transport fuel cost, ₦/hr or $/hr

σ =fuel price, ₦/l or $/l

$H$ =fuel efficiency at the percentage tractor power loading used, kW.hr/l

The required drawbar power for implement transport according to Kepner *et al* (2003) is a function of the static vertical force on the tractor drive wheels, the coefficient of rolling resistance on the tractor drive wheels and the forward travel speed the tractor as in Equation 3.12. The required drawbar power was divided by the maximum tractor power to obtain the percentage power loading for selecting the fuel efficiency ($H$) for transport operations.

$$\Pi_t = \frac{F_N \times R_R \times S}{3.6 \times 0.96\, E}$$

(3.12)

where:

$\Pi_t$ = equivalent PTO power of the drawbar transport power, kW

$F_N$ = static vertical force on the tractor drive wheels, kN

$R_R$ = coefficient of rolling resistance on the tractor drive wheels, dimensionless

0.96 = ratio of drawbar power to PTO power,

$E =$ ¿ tractive efficiency ($E$ has a maximum value of 0.77), decimal

(Hunt, 2001). All other variables were as previously defined.

### 3.2 Theoretical Considerations and Model Development

It is helpful to clarify the fundamental principles on which a model is developed so as to ensure its dependable application. Knowledge of the basic assumptions made to simplify the model development process also clarifies the conditions for its proper application. The models development utilized the concept of annual cost estimation which relies heavily on field capacity measures. Cost optimization with the differentiation method employed by Hunt (2001) and Hunt and Wilson (2015) was also followed in the models development.

#### 3.2.1 Hunt's least-cost general machinery selection model

The general annual cost model for farm machinery was obtained by adding up these cost components. Hunt (1999b) employed differentiation to obtain the least-cost width model for farm machinery selection. Machinery selection for a 2-crop farm was also treated.

Total Annual Machinery Costs ($AC$):

According to Hunt (1999b) the annual cost components are summed up to give the annual machinery cost as follows:

$$AC = \left(\frac{\gamma}{100}\right) P + \frac{A}{C_e}\left[\left(\frac{\Delta}{100}\right) P + L + O + F + T\right] \quad \text{₦ or \$} \quad (3.13)$$

where the additional variables:

$\Delta$ = hourly repair and maintenance costs of machine as a percentage of machine purchase price %

$O =$ ¿ hourly oil and lubricant cost of machine, ₦/hr or $/hr

$F =$ hourly fuel cost of machine, ₦/hr or $/hr

$T =$ hourly tractor cost of machine, ₦/hr or $/hr.

$$T = \pi \Pi_x \quad (3.14)$$

where $\pi =¿$ operation's tractor annual fixed cost per PTO power, ₦/kW or \$/kW.

In developing the machinery width selection model Hunt 1999b differentiated the annual machinery cost with respect to the machine width and solved the derivative to get the least-cost width. The machine price was represented as price per width and other variables in their width containing equivalent forms. The purchase price per incremental implement width was used to estimate the price per width (Hunt, 2001) so as to accommodate the flexibility of choice of width.

$$p=\frac{P_2-P_1}{w_2-w_1} \qquad \text{₦/m or \$/m} \qquad (3.15).$$

where subscripts 1 and 2 refer to the basic implement size and its next larger size respectively.

Another category of cost, timeliness cost is necessary in assessing a machine's suitability for completing a given job within the required time. This is the penalty levied on the machine for its failure to complete the job within the acceptable time, leading to losses in crop value. This indirect cost is evaluated as:

$$\Psi=\frac{A}{C_e}\psi=\frac{K' A^2 YV}{C_e ZG\lambda\omega} \qquad (3.16)$$

where additionally:

$\Psi$ = annual timelines cost, ₦ or \$

$\psi$ = annual timelines cost per hour, ₦/hr or \$/hr

$K'$ = timeliness loss factor, $day^{-1}$

$Y$ = yield per hectare, t/ha

$V$ = yield value, ₦/t or \$/t

$Z$ = schedule factor; $Z$ = 4 if the operation schedule can be planned on both sides of the optimum time. $Z$ = 2 if the operation either commences or terminates at the optimum time,

$\omega$ = number of cropping seasons in a year, (Srivastava *et al*, 2006).

The timeliness cost coefficient $K'$ represents the daily decimal reduction in the crop value measured as crop value loss per day of operation delay beyond the stipulated period. $K'$ is crop- and location-specific. For each cropping season there is the farm operation window period that leads to no losses in crop performance from ill-timing of operation. Farmers based on their experience request for mechanized operations only within this optimal period. When timeliness cost is considered the annual machinery cost becomes:

$$AC=\left(\frac{\gamma}{100}\right)P+\frac{A}{C_e}\left[\left(\frac{\Delta}{100}\right)P+L+O+F+T+\psi\right]$$ ₦ or \$ (3.17)

The general annual farm machinery cost for a 2-crop farm is given as:

$$AC_C=\left(\frac{\gamma}{100}\right)P+\frac{A_1}{C_{e1}}\left[\left(\frac{\Delta}{100}\right)P+L_1+O_1+F_1+T_1+\psi_1\right]+¿\frac{A_2}{C_{e2}}\left[\left(\frac{\Delta}{100}\right)P+L_2+O_2+F_2+T_2+\psi_2\right]$$

(3.18)

where the additional variable

$AC_C=¿$ annual farm machinery cost for a 2-crop farm, ₦ or \$ (Hunt, 2001)

Variables subscripted 1 refers to crop 1 values of the variable and those subscripted 2, the values of the variables for crop 2. Equation 3.18 is applicable for coinciding timing of the given operation for both farms.

**3.2.2 Hunt's least-cost model for optimum field machinery size selection**

The optimum-cost width for selecting least-cost machine is as shown in Equation 3.19:

$$w=\sqrt{\frac{Ac}{\mu Se}(L+T+\psi)}$$ (3.19)

where:

$w$ = least-cost width of the machine, m

$\mu$ = annual implement depreciation per machine width, ₦/m or \$/m (Hunt, 2001)

Srivastava *et al* (2006) gave the least-cost machine size in terms of machine capacity ($C_e$) as shown in Equation 3.20.

$$C_e=\sqrt{\frac{A}{\mu_c}(L_c+T_c+\psi_c)}$$ (3.20)

where the additional variables are defined as follows:

$C_e$ = least-cost capacity of the machine, ha/hr

$\mu_c$ = annual implement depreciation per machine capacity, ₦/ha or \$/ha

$L_c$ = labor cost per hectare, ₦/ha or \$/ha

$T_c$ = tractor cost per hectare, ₦/ha or \$/ha

$\psi_c$ = timeliness cost per hectare, ₦/ha or \$/ha

The least-cost width selection model for such farm is as in Equation 3.21.

$$w_C=\sqrt{\frac{c}{\mu}\left[\frac{A_1}{S_1e_1}(L_1+T_1+\psi_1)+\frac{A_2}{S_2e_2}(L_2+T_2+\psi_2)\right]}$$ (3.21)

where $w_c$ = least-cost width for a 2-crop farm (with mono-crop plots) m

### 3.2.3 Hunt-Wilson's least-cost tillage machinery selection models

I) Annual cost for heavy tillage implement: Hunt and Wilson (2015) have argued that employing the optimum-cost machine width equation (3.19) for heavy tillage machine will yield erroneous large values. This arises from the fact that the tractor cost should not be treated as independent of machine width. The tractor price is far higher than such tillage machine price and should influence the chosen minimum-cost machine width more. They developed the annual tillage machinery cost model in Equation 3.22 based on the implement fixed cost, fuel cost and tractor fixed cost.

$$AC_g = \mu w + \frac{A}{C_e} fl + \pi \Pi_x \qquad (3.22)$$

where additionally:

$fl=$¿ hourly fuel cost, ₦/hr or $/hr

$AC_g=$¿ annual cost of tillage, ₦ or $

Fuel cost for tillage operations was given by Hunt (2001) as:

$$fl = \frac{\Pi_B}{0.96\,E}\eta \qquad (3.23)$$

where:

$\Pi_B=$¿ tractor drawbar power required to pull plough, kW

$fl=$¿ fuel cost per hour, ₦/hr or $/hr

$$\eta = \frac{\sigma}{H} \qquad (3.24) \text{ and}$$

$\sigma=$¿ fuel price, ₦/l or $/l

$H=$¿ fuel efficiency at % of the maximum power loading used, kW.hr/l

Tillage drawbar power requirement ($B$) is given as:

$$\Pi_B = w \times \frac{d}{36}\left(C_1 + C_2 S^2\right) S \qquad (3.25)$$

where $d=$¿ depth of tillage operation, cm

The product of machine width and speed ($wS$) in Equation 3.25 were replaced with $\frac{10C_e}{e}$, which is their equivalent expression derived from the basic effective machine capacity formula in Equation 3.1. Similarly, the $S^2$ inside the bracket were replaced with its equivalent expression; $\frac{100C_e^{\ 2}}{w^2e^2}$. The drawbar power was therefore transformed into Equation 3.26. This is done to produce an annual cost expression that can be differentiated with respect to machine width. The derivative will then be solved to obtain the minimum-cost width.

$$\Pi_B = \frac{C_e d}{3.6e}\Theta \tag{3.26}$$

where $C_1 + C_2\frac{100C_e^{\ 2}}{w^2e^2} = \Theta$ (3.27)

Applying the tractive efficiency value of 0.77, the hourly fuel cost now becomes

$$fl = \frac{C_e d}{2.66e}\eta\Theta \tag{3.28}$$

The equivalent PTO power required for the tillage operation also becomes:

$$\Pi = \frac{C_e d}{2.66e\delta}\Theta \tag{3.29}$$

where δ = percentage power loading of the tractor (Hunt, 2001).

The annual tillage machinery cost then becomes

$$AC_g = \mu w + \frac{Ad}{2.66e}\eta\Theta + \frac{C_e d\kappa}{2.66e}\Theta \tag{3.30}$$

where the ratio of the operation's tractor fixed cost per PTO power $\pi$ to the percentage power loading κ is given in Equation 3.31.

$$\kappa = \frac{\pi}{\delta} = \frac{\beta}{100\delta}\varnothing t \tag{3.31}$$

where

$\pi$ = operation's tractor annual fixed cost per PTO power, ₦/kW or \$/kW.

$\beta$ = tractors annual fixed cost factor %

$\varnothing$ = fraction of tractor's annual use hours deployed to the operation

$t$ = tractor's purchase price per PTO power ₦/kW or \$/kW.

II) Least-cost width for heavy tillage implement: Hunt and Wilson (2015) differentiated the annual tillage machine cost equation (3.30) with respect to machine width and obtained the least-cost width model shown in Equation 3.32.

$$w = \sqrt[3]{\frac{\Omega\alpha}{\mu}} \tag{3.32}$$

where:

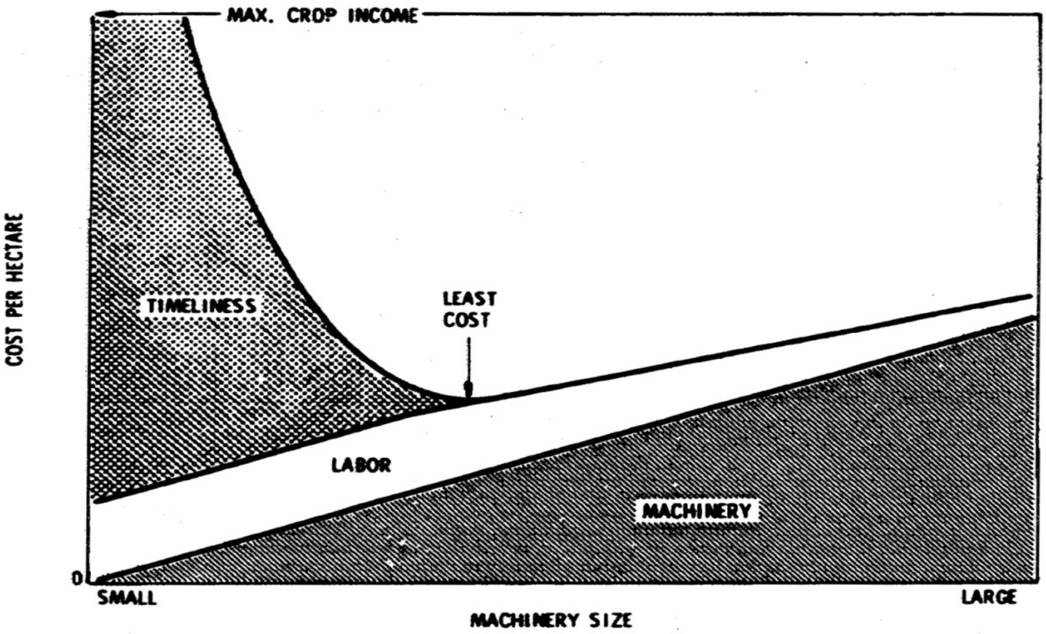
$$\Omega = \frac{C_2 d}{e^3} \quad (3.33)$$

$$\alpha = 75\, A\eta C_e^{\,2} + 75\kappa C_e^{\,3} \quad (3.34)$$

In evaluating this least-cost width, Hunt and Wilson (2015) recommended the use of a prior value of machine capacity ($C_e$) the user desires.

## 3.3 Development of the mathematical models

The Hunt-Wilson's tillage machinery selection and annual cost models in Equations 3.32 and 3.30 did not consider the field processing labour cost in determining the least-cost machine size. However, Srivastava *et al* (2006) reported that annual machinery minimum-cost size has the three key components of influence, namely timeliness penalty cost, labour cost and machinery non-labour costs. See Figure 3.1. The labour cost contributes to the total machinery cost as shown in the figure. Also the labour cost per hectare can be seen to be affected by the selected machine size as it varied with the machinery size variation. Therefore the field processing labour cost was treated as important in the minimum-cost tillage machinery sizing. It was therefore incorporated into the tillage machinery selection model developed in this study.




Source: Srivastava *et al* (2006)
Figure 3.1: Key cost components in minimum-cost machinery size selection

### 3.3.1 Basic assumptions for the model development

The following assumptions were made for the minimum-cost tillage width selection model development:

-Farm and crop parameters like area, required operations, operation time windows, etc are known.

-Only the cost items that affect machinery size selection are considered.

-Tractor cost is not independent of machine width.

-Tractor and implement repair cost is not basic for speed–size selection for a given farm size.

-Lubricant cost is proportional to the covered area and not necessarily to machine width.

-Operation depth, speed and field efficiency are treated as non-varying within a field (though they may possibly vary within a field because of differing spatial field conditions.

-The time taken to transport machine to the field or back was not accounted for.

-Field geometry, topography, vegetation and soil moisture was not considered.

### 3.3.2 A labour cost-inclusive tillage machinery selection model

The labuor cost is obtained as the product of the hourly labour rate ($L$) and the tillage labour hours ($h$). The hours of tillage operation is estimated from the farm size and the effective field capacity as in Equation 3.35.

$$h=\frac{A}{C_e} \tag{3.35}$$

Incorporating the operation's labour cost as a product of the hourly labour rate ($L$) and field work hours ($\frac{A}{C_e}$) into the Hunt-Wilson's annual tillage machinery cost changes the annual machinery tillage cost as:

$$AC_g=\mu w+\frac{A}{C_e}\left(fl+L\right)+\pi\,\Pi_x \tag{3.36}$$

Equally, incorporating the expression for hourly fuel consumption from Equation 3.28, and tractor cost required for the tillage operation from Equation 3.29 gave the annual tillage machinery cost into Equation 3.37:

$$AC_g=\mu w+\frac{A}{C_e}L+\frac{Ad}{2.66e}\eta\Theta+\frac{C_e d\kappa}{2.66e}\Theta \tag{3.37}$$

Differentiating Equation 3.37 with respect to machine width and solving for minimum annual cost width (see Appendix B1) gave the minimum-cost width as:

$$w=\sqrt[3]{\frac{\Omega}{\left[\mu+K\rho\right]}\left[\frac{100\,A\,C_e\,e}{\varphi}L+\alpha\right]} \tag{3.38}$$

where:

$$K=\frac{0.0375\,\pi}{\delta} \tag{3.39}$$

$$\varphi = C_2 S^2 d \tag{3.40}$$

$$\rho = C_1 S d \tag{3.41}$$

The capacity variable ($C_e$) in the labour containing term can be replaced with its area-available hours function-equivalent to ease the mathematical solution. This brings in the the reckoning of available hours variable ($h_{AV}$) into the minimum-cost width model as follows:

$$w = \sqrt[3]{\frac{\Omega}{[\mu + K\rho]}\left[\frac{100 A^2 e}{\varphi h_{AV}} L + \alpha\right]} \tag{3.42}$$

It also serves as a means of eliminating the width-dependent capacity variable contained in the Hunt-Wilson (2015) minimum-cost tillage width model. Operation timeliness in the machinery width selection is also brought into focus. Equation 3.37 can be observed for the calculus test for the sufficiency condition for a minimized annual cost equation. It can be showed that the second derivative of the annual cost equation (3.37) will have a minimum value at the turning point in question. See Appendix B2.

### 3.3.3 Minimum-cost tillage machinery capacity selection model

This study sought to circumvent the use of a prior arbitrary value of machine capacity (that is equally width-dependent) in selecting machine width. The least-cost implement size determination can be based on field capacity (Srivastava *et al*, 2006 and Zaied *et al*, 2014). Determining the optimum tillage implement size in terms of field capacity instead of width requires replacing the implement price per width ($p$) with price per capacity ($p_c$).

Here, $p_c = \dfrac{P_2 - P_1}{C_{e2} - C_{e1}}$ (3.43)

where:

| | | |
|---|---|---|
| $p_c$ | = price per incremental capacity, | ₦/ha or $/ha |
| $P_1$ | = price of a desirable capacity machine available in the market, | ₦ or $ |
| $P_2$ | = ¿price of next larger capacity machine available in the market | ₦ or $ |
| $C_{e1}$ | = ¿ capacity of the desirable machine available in the market | ha |
| $C_{e2}$ | = ¿capacity of the next larger machine available in the market | ha |

The developed minimum-cost field capacity selection model is shown in Equation 3.44 as derived in Appendix B3.

$$C_e = \frac{0.075\,A\eta\tau + \sqrt{(-0.075\,A\eta\tau)^2 + 0.4(\mu_c + K(\rho - 2\tau))SAeL}}{2\mu_c + 2K(\rho - 2\tau)} \quad (3.44)$$

where:

$$\mu_c = \frac{\gamma}{100} p_c \quad (3.45)$$

is the implement annual fixed cost per unit capacity, and

$$\tau = C_2 S^3 d \quad (3.46)$$

is the dynamic power requirement per unit width of the implement.

Representing some block variables in Equation 3.44 with the simpler ones shown in Equations 3.47 to 3.49 yields the feasible solution shown in Equation 3.50 in simpler-terms.

$$\mu_c + K(\rho - 2\tau) = a' \quad (3.47)$$

$$-0.075\,A\eta\tau = b' \quad (3.48)$$

$$-0.1\,SAeL = c' \quad (3.49)$$

$$C_e = \frac{-b' + \sqrt{b'^2 + 4a'c'}}{2a'} \quad (3.50)$$

### 3.3.4 Tillage machinery size selection model with operation labour cost exclusion

To demonstrate the effect of the labour cost on the minimum-cost width, the tillage machinery selection model was also developed without the inclusion of the labour cost.
The further assumption made for this case was:
-Model does not account for field processing labour cost.

Excluding the field operation labour cost in the annual tillage machinery cost brings the model to the form derived by Hunt and Wilson (2015). See Equation 3.51.

$$AC_g = \mu w + \frac{Ad}{2.66\,e}\eta\,\Theta + \frac{C_e\,d\kappa}{2.66\,e}\Theta \quad (3.51)$$

To solve for minimum-cost machinery width the annual tillage machinery cost was differentiated with respect to implement width. The derivative was solved to get the implement width for minimized tillage machinery cost as was done for the previous operation labour cost-included case. See Appendix B3. The derived minimum-cost width model is shown in Equation 3.52.

$$w = \sqrt[3]{\frac{\Omega\alpha}{(\mu + K\rho)}} \quad (3.52)$$

To avoid the need of a prior value of the width-dependent machine capacity recommended by Hunt and Wilson (2015) for selecting machine width, the minimum-cost tillage machine size model was evaluated in terms of machine capacity. See the derivation in Appendix B4. The minimum-cost tillage machine capacity was obtained as

$$C_e = \frac{0.075\, A \eta \pi}{\left[\mu_c + K(\rho - 2\tau)\right]} \qquad (3.53).$$

A close look at Equation 3.53 shows that farm size ($A$) appears prominently in the numerator, and should have glaring influence on the tillage implement selection with the model. Same goes for the implement annual fixed cost per unit capacity ($\mu_c$) which also featured in the square root part of the numerator and prominently in the denominator. The operation's fraction of the tractor's annual fixed cost per PTO power ($\pi$) appeared in the square root part of the numerator and more apparent effect in the denominator. It should also affect machine capacity. Fuel price which is integrated as fuel price utility factor ($\eta$) appeared in the numerator. It also featured in the soil static power required to pull a unit width of the implement ($\rho$) and its dynamic counterpart ($\tau$). It should all affect selected capacity. The available working hours ($h_{AV}$) presence in Equation (3.42) serves as a kind of operation timeliness consideration for the minimum-cost machinery width selection. However the working hour variable did not reflect in the minimum-cost field capacity selection equation (3.44). This available time variable is not present in the minimum-cost width and capacity equations when the tillage operation labour cost is absent in the annual cost model.

### 3.3.5 Tillage machinery cost modelling for pool farm holdings

Farm machinery selection with the general least-cost model gave uneconomic bigger machinery sizes choice for small scale farms as was pointed out concerning the model used by Dash and Sirohi (2008). The specialized tillage machinery selection model was developed based on the same principles as the general model and may behave likewise. Consolidating small farms into a big enough size was shown earlier as a solution to this problem but is limited to farms having common boundaries. The least-cost machine width selection model can be adapted to suit such pool farms, including small farms.

Further assumptions for the pool farm machinery sharing modeling:

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

-The effect of field geometry, topography and other inter-field varying are not considered.

-These variables constituting the annual cost are considered same for same operations in closely related crops or farm locations, but may differ for the different crops or plots.

This caters for the possible occurrence of such scenario. Since the same operator and operator mate were expected to man the machinery from one field to another, the labour rate ($L$) was seen as constant for the different crops and farms. For ease of the problem solving, average value of the field efficiency ($e$) of the operation for the given location was employed, even though factors like field geometry, soil types, vegetative cover (especially presence of roots) affect field efficiency. Average values of the tillage speed and depth were also used. Percentage tractor loading and the emanating fuel efficiency will vary with differing fields and was treated as such.

The general annual machinery cost and the least-cost width models developed by Hunt (2001) for a 2 crop farm situation were adjusted to cater for multi-crop multi-farmer scenario. The cropped areas were $A_1$ and $A_2$ for crops 1 and 2 respectively. The farm scenario can be modified such that the cropped areas are owned by farmers 1 to m, and the crops vary from 1 to n as in Equation 3.54.

$$AC_P = \left(\frac{\gamma}{100}\right)P + \sum_{j}^{m}\sum_{i=1}^{n}\left\{\frac{A_{ij}}{C_{eij}}\left[\left(\frac{\Delta}{100}\right)P + L_{ij} + O_{ij} + F_{ij} + T_{ij} + \psi_{ij}\right]\right\} \qquad (3.54)$$

where additionally:

$AC_P =$¿ annual farm machinery cost for multi-crop multi-farmer case, ₦ or $.

Variables subscripted $i$ refers to crop $i$ values of the variables and those subscripted $j$, the values of the variables for farmer $j$. Equation 3.54 fits a scenario of coinciding timing of the given operation for all the farm plots.

The least-cost width selection model for such farms is as in Equation 3.55.

$$w_P = \sqrt{\frac{c}{\mu}\sum_{j}^{m}\sum_{i=1}^{n}\left\{\frac{A_{ij}}{S_{ij}e_{ij}}\left(L_{ij} + T_{ij} + \psi_{ij}\right)\right\}} \qquad (3.55)$$

where $w_P =$¿ least-cost machinery width for multi-crop multi-farm case, m.

I) Annual tillage machinery cost models for pool farm holdings: If $j$ farmers having $i$ crops and and coinciding operation time window share a piece of tillage machinery, the combined annual machinery cost ($AC_{gP}$) can be adapted from the Hunt (2001) 2-crop farm machinery cost model as follows.

$$AC_{gP} = \mu w + \sum_{j}^{m}\sum_{i=1}^{n}\left\{\frac{A_{ij}}{C_{eij}}L + \frac{A_{ij}d}{2.66e}\eta_{ij}\Theta_{ij} + \frac{C_e d}{2.66e}\kappa_{ij}\Theta_{ij}\right\} \qquad (3.56)$$

where $AC_{gP} =$¿ annual tillage machinery cost for multi-farm multi-crops scenario, ₦ or $

Variables subscripted *i* refers to crop *i* values of the variable and those subscripted ***j*** the values of the variables for farm ***j.***

Variables subscripted $i$ indicated their values may change for different crops' plots, while those subscripted $j$ indicated their values may change for different farmer's plots. Variables without subscript were considered constant for the different crops or farmers.

Since the same operator and operator mate were expected to man the machinery from one farm to another, the labour cost ($L$) was seen as constant for the different crops and farms. For ease of the problem solving, field efficiency ($e$) was taken to remain constant with different farms even though factors like field geometry, soil types, vegetative cover (especially presence of roots) affect field efficiency. Tillage speed and depth were also assumed constant. Because of varying soil types percentage tractor loading δ and the emanating fuel efficiency $H$ will vary with different fields and was treated as so.

The derived minimum-cost tillage machinery width model for the multi-crop pool farm is as shown in Equations 3.57, see appendix B-5.

$$w_P=\sqrt[3]{\left[\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\Omega_{ij}\left(\frac{100\,A_{ij}C_e e}{\varphi_{ij}}L+\alpha_{ij}\right)}{\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}K_{ij}\,\rho_{ij}}\right]} \tag{3.57}$$

where $w_P$ = minimum-cost tillage machinery width for multi-farm multi-crop scenario, m.

The minimum-cost tillage machinery capacity model for the multi-crop multi-farm machinery sharing case with coinciding operation timing was also derived in appendix B-6 as in Equation 3.58.

$$C_{eP}=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left(-b''_{ij}\right)+\sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(b''_{ij}\right)^2+4a''_{ij}c''_{ij}\right]}}{\sum_{j=1}^{m}\sum_{i=1}^{n}2a''_{ij}} \tag{3.58}$$

where:

$C_{eP}=$¿ minimum-cost tillage machinery capacity for multi-farm multi-crop scenario, ha/hr

The models can also serve for the cases of the plots being under the ownership of the same or different farmers farming same crop or different crops. Such models can also be useful when machinery hiring investment is intended instead of the farmers' outright ownership of the machinery.

For the case when the operation labour cost is removed, the annual tillage machinery cost of the multi-crops multi-farm case will be as in Equation 3.59.

$$AC_P = \mu w + \sum_{j=1}^{m} \sum_{i=1}^{n} \left[ \frac{A_{ij} d \eta_{ij}}{2.66 e} \Theta_{ij} + \frac{C_e d}{2.66 e} \kappa_{ij} \Theta_{ij} \right] \qquad (3.59)$$

The steps employed in deriving the minimum-cost machinery width model are shown in appendix B-7. The minimum-cost machinery width obtained is shown in Equation 3.60.

$$w_P = \sqrt[3]{\frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \Omega_{ij} \alpha_{ij}}{\left( \mu + \sum_{j=1}^{m} \sum_{i=1}^{n} K_{ij} \rho_{ij} \right)}} \qquad (3.60)$$

The minimum-cost field capacity of the machinery for such multiple-crop combined farms was derived appendix B-8 and shown in Equation 3.61.

$$C_{eP} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} 0.075 A_{ij} \eta_{ij} \pi_{ij}}{\mu_c + \sum_{j=1}^{m} \sum_{i=1}^{n} K_{ij} \left( \rho_{ij} - 2 \tau_{ij} \right)} \qquad (3.61)$$

II) Tillage machinery cost models with transport cost consideration for pool farms: Adama *et al* (2009) proposed Centres for Community Farms (CCF) programme which combines small farms with common boundaries into a big lump size fit for engine-powered mechanization. Inter-farm machinery transport for such a scenario involves insignificant time losses. A different situation will arise when spatially separated small farms are pooled together, see Figure 3.1. Treating the farms as a lump field for the application of the minimum-cost machinery selection model will not hold for such farms with appreciable inter-field machinery transport distance. A substantial proportion of the time that could have been used for field processing may be spent on the transportation of the machinery between the farms. Hunt (2001) included time to transport machinery to the field as part of the total time for a field operation. Therefore the time lost to inter-field machinery transportation need to be considered in choosing an adequate machine size for processing the pool farm.

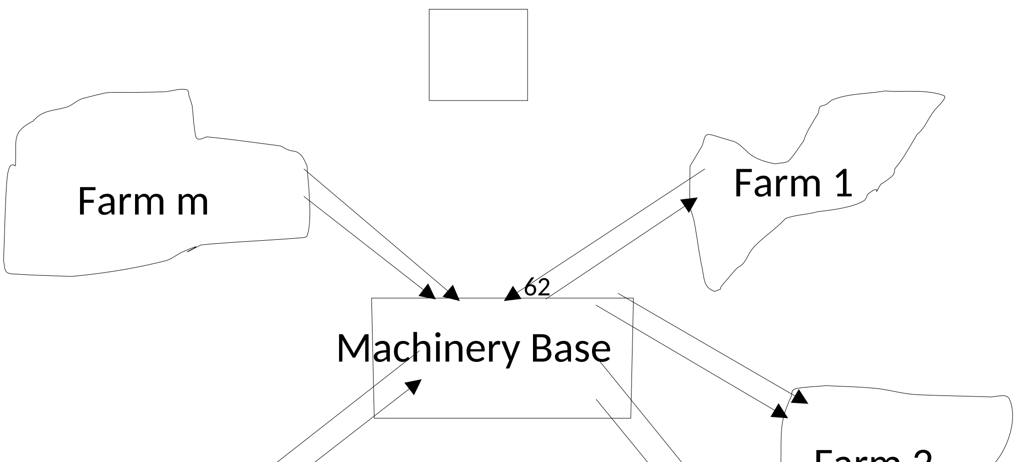



Figure 3.2 Scattered pool m small farms serviced from a single machinery base

The further assumptions made for the pool farm machinery selection model development are shown below.

-The farms within any given town/area are taken as a lump farm so as to simplify the model evaluation.

-The machinery transport distance considered is consequently limited to that needed to bring the machinery to and fro its base to the concerned town 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.

-Inter farm transportation distance influences the required machinery size. This affects the machinery cost not only through possible untimely completion of the field processing, but also through the cost of the machinery transportation itself.

-The sequence (*ie* order) of processing the plots was not considered.

-Only the distance from the machinery base to and fro the farm plots was considered.

The annual machinery transport cost is composed of the associated tractor fixed cost, labour cost and fuel cost expended; and can be evaluated as

$$CT = \pi_t \Pi_x + h_t L + h_t fl_t \qquad (3.62)$$

where:

$AC$ = annual transport cost, ₦ or $

$fl_t =$ ¿ hourly transport fuel cost, ₦ or $.

The annual machinery and transport cost equation becomes:

$$AC_{TP}=\mu w+\sum_{j=1}^{m}\sum_{i=1}^{n}\frac{A_{ij}}{C_e}L+\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\frac{A_{ij}d\eta_{ij}}{2.66\,e}\Theta_{ij}+\frac{C_e d\kappa_{ij}}{2.66\,e}\Theta_{ij}+CT_{ij}\right] \quad (3.63)$$

where $AC_{TP}$ = transport-cost incorporated annual machinery cost for multi-crop pool farm with inter-field machinery transport cost incorporated, ₦ or $.

The expression for the machinery transport cost in Equation 3.63 had no machine width component. The differentiation of the machinery transport cost with respect to machine width will yield zero. Therefore the minimum-cost machinery width and capacity models derived for the transport cost-incorporated pool farm case were same as for the transport cost-excluded cases. See Equations 3.57 and 3.58.

For the machinery operation labour cost-excluded case the annual machinery and transport cost was expressed as:

$$AC_{TP}=\mu w+\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\frac{A_{ij}d\eta_{1j}}{2.66e}\Theta_{ij}+\frac{C_e d\kappa_{ij}}{2.66e}\Theta_{ij}+CT_{ij}\right] \quad (3.64)$$

where $AC_{TP}$ = transport-cost excluded annual machinery cost for multi-crop pool farm with inter-field machinery transport cost incorporated, ₦ or $.

The minimum-cost machinery width and capacity models derived for the no transport cost models (Equations 3.60 and 3.61 respectively), was also obtained for this machinery transport cost-included case.

III) Accounting for the machinery transport time loss in the machinery selection models: The minimum-cost machinery width and capacity selection models derived for the machinery-sharing pool farm with transport cost-incorporated, did not reflect the machinery transport impact. Some time that could have been used for field processing is lost to the inter-field machinery transportation, making the selected tillage machinery capacity inadequate. The tillage machinery capacity ($C_{eR}$) required to adequately process $A$ hectares of farm land will need adjustment of the previously selected $C_e$ to accommodate this machinery transport time loss as in Equation 3.65.

$$h_{AV}=h-h_t=\frac{A}{C_{eR}} \quad (3.65)$$

where:

$h_{AV}$ = actual time available for field processing after transport time loss, hr

$h$ = time needed by the previously selected capacity $C_e$ to process the field, hr

$C_{eR}$ = tillage machinery capacity adjusted for transport time loss, ha/hr

$h_t$ = machinery transport time, hr

Replacing the machinery transport time ($h_t$) and the field processing time ($h$) needed under the previously selected capacity $C_e$ with their previously derived expressions gives the new required field capacity as:

$$C_{eR}=\frac{A}{\left(\frac{A}{C_e}-\frac{0.27\, m_t D}{q\,\Pi_x}\right)} \tag{3.66}$$

The derived machinery capacity was also verified for meeting the adequate processing of the given field within the available working time. The basal machinery size was estimated as:

$$C_{eQ}=\frac{A}{\left[\left(AD\times G\right)-\frac{0.27\, m_t D}{q\,\Pi_x}\right]} \tag{3.67}$$

where $C_{eQ}$ = the basal implement capacity required given the suitable available working time and its reduction by the machinery transport time $h_t$, hr

**3.3.6 Machinery selection for multiple-crop farms with overlapping operation period**

The general machinery annual cost and selection models proposed by Hunt (2001) for multiple crops and the tillage machinery models proposed so far in this study for multiple farms hold only for coinciding operations period, as illustrated in Figure 3.3. If the crops operations period overlap as in Figure 3.4 then the annual cost equation should consider additional coinciding use of the machinery in the operation only for the time period b (the shaded portion). For mechanized cropping operation of farms with overlapping periods, the machinery capacity needed will be at its peak during the period of overlap. Such demand for a piece of machinery in a given period may arise from either different crops/farmers needs or both. During the demand overlap period, the required machinery capacity for each crop/farm should include the capacity need from other crops/farms occurring within that period. The annual machine cost equation for the given crop 1 operation period ($AC_{TP1}$) is as shown in Equation 3.68.

$$AC_{TP1}=\mu w+AC_{1TP}+\left(\frac{b}{b+c}\right)AC_{2TP} \tag{3.68}$$

where:

$AC_{TP1}$ = machinery and transport cost for crop 1 whose operation period overlaps with that of crop 2, ₦ or \$

$AC_{1TP}$ = machinery and transport cost for crop 1, ₦ or \$

$AC_{2TP}$ = machinery and transport cost for crop 2, ₦ or \$

| |
|---|
| CROP 1 |
| CROP 2 |

Coinciding Operations Period

Figure 3.3 Time frame for coinciding operations

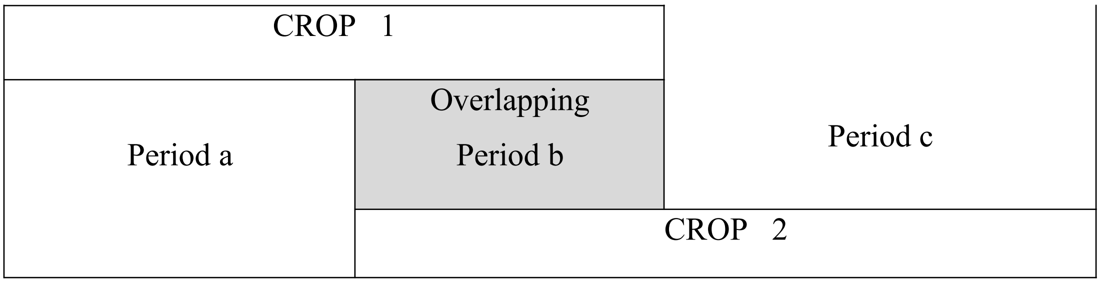



Figure 3.4: Time frame for overlapping operations

$$AC_{1TP} = \sum_{j=1}^{m} \left[ \frac{A_{1j}}{C_e} L + \frac{A_{1j} d \eta_{1j}}{2.66e} \Theta_{1j} + \frac{C_e d \kappa_{1j}}{2.66e} \Theta_{1j} + CT_{1j} \right] \quad (3.69)$$

$$AC_{2TP} = \sum_{j=1}^{m} \left[ \frac{A_{2j}}{C_e} L + \frac{A_{2j} d \eta_{2j}}{2.66e} \Theta_{2j} + \frac{C_e d \kappa_{2j}}{2.66e} \Theta_{2j} + CT_{2j} \right] \quad (3.70)$$

$AC_{2TP}$ = machinery cost for crop 2 with machinery transport cost-incorporated, ₦ or $

Similarly, the annual machinery and transport cost equation for crop 2 operation period ($AC_{TP2}$) will be as shown in Equation 3.71 for the transport cost-included case.

$$AC_{TP2} = \mu w + AC_{2TP} + \left( \frac{b}{a+b} \right) AC_{1TP} \quad (3.71)$$

where $AC_{TP2}$ = annual machine cost for crop 2 whose operation period overlaps with that of crop 1, ₦ or $

When machinery operation labour cost is excluded, the machinery cost for crop 1 becomes

$$AC_{1TP} = \sum_{j=1}^{m} \left[ \frac{A_{1j} d \eta_{1j}}{2.66e} \Theta_{1j} + \frac{C_e d \kappa_{1j}}{2.66e} \Theta_{1j} + CT_{1j} \right] \quad (3.72).$$

For crop 2 it becomes

$$AC_{2TP} = \sum_{j=1}^{m} \left[ \frac{A_{2j} d \eta_{2j}}{2.66e} \Theta_{2j} + \frac{C_e d \kappa_{2j}}{2.66e} \Theta_{2j} + CT_{2j} \right] \quad (3.73)$$

In a two-crop pool farm with overlapping operation period the machine width required for processing the tillage operation within crop 1 tillage period is:

$$w_{P1}=\sqrt[3]{\frac{\sum_{j=1}^{m}\left[\Omega_{1j}\left(\frac{100\,A_{1j}C_{e1j}e}{\varphi_{1j}}L+\alpha_{1j}\right)+\left(\frac{b}{b+c}\right)\Omega_{2j}\left(\frac{100\,A_{2j}C_{e2j}e}{\varphi_{2j}}L+\alpha_{2j}\right)\right]}{\mu+\sum_{j=1}^{m}\left[K_{1j}\rho_{1j}+\left(\frac{b}{b+c}\right)K_{2j}\rho_{2j}\right]}} \quad (3.74)$$

where: $w_{P1}$ = minimum-cost machine width needed for a tillage operation within crop 1 tillage period under overlapping operation period condition, m.

For crop 2 it is:

$$w_{P2}=\sqrt[3]{\frac{\sum_{j=1}^{m}\left[\Omega_{2j}\left(\frac{100\,A_{2j}C_{e2j}e}{\varphi_{2j}}L+\alpha_{2j}\right)+\left(\frac{b}{a+b}\right)\Omega_{1j}\left(\frac{100\,A_{1j}C_{e1j}e}{\varphi_{1j}}L+\alpha_{1j}\right)\right]}{\mu+\sum_{j=1}^{m}\left(K_{2j}\rho_{2j}+\left(\frac{b}{a+b}\right)K_{1j}\rho_{1j}\right)}} \quad (3.75)$$

where: $w_{P2}$ = minimum-cost machine width needed for a tillage operation within crop 2 tillage period under overlapping operation period condition, m.

The higher of these two sizes should be utilized and should be able to cater for the need of both crops under the given conditions.

The minimum-cost tillage machinery capacity selection models were derived following the steps outlined in appendix B-7 for the 2-crop pool farm with overlapping operation periods as

$$C_{e1}=\frac{\sum_{j=1}^{m}\left[-b''_{1j}-\left(\frac{b}{b+c}\right)b''_{2j}\right]+\sqrt{\sum_{j=1}^{m}\left[\left(b''_{1j}\right)^2+\left(\frac{b}{b+c}\right)\left(b''_{2j}\right)^2+4\left[a''_{1j}c''_{1j}+\left(\frac{b}{b+c}\right)a''_{2j}c''_{2j}\right]\right]}}{2\sum_{j=1}^{m}\left[a''_{1j}+\left(\frac{b}{b+c}\right)a''_{2j}\right]} \quad (3.76)$$

where $C_{e1}$ is the required machinery capacity for crop 1 operation period.

The field capacity is made up of the amount needed for crop 1 during the total period of operation ($a+b$) plus that for crop 2 during the overlap period ($b$). Similarly for crop 2 the required machinery capacity $C_{e2}$ will also consider crop 1 machinery need within the period as obtained in Equation 3.77. Thus an equivalent farm area can be utilized rather than the (total) nominal farm size in selecting the needed machinery size.

$$C_{e2}=\frac{\sum_{j=1}^{m}\left[-b''_{2j}-\left(\frac{b}{a+c}\right)b''_{1j}\right]+\sqrt{\sum_{j=1}^{m}\left[\left(b''_{2j}\right)^2+\left(\frac{b}{a+c}\right)\left(b''_{1j}\right)^2+4\left[a''_{2j}c''_{2j}+\left(\frac{b}{a+c}\right)a''_{1j}c''_{1j}\right]\right]}}{2\sum_{j=1}^{m}\left[a''_{2j}+\left(\frac{b}{a+c}\right)a''_{1j}\right]} \quad (3.77)$$

For the transport cost-excluded case the required machine width and capacity for the given crop 1 tillage operation period are as shown in Equations 3.78 and 3.79 respectively.

$$w_{P1}=\sqrt[3]{\frac{\sum_{j=1}^{m}\Omega_{1j}\alpha_{1j}+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m}\Omega_{2j}\alpha_{2j}}{\mu+\sum_{j=1}^{m}K_{1j}\rho_{1j}+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m}K_{2j}\rho_{2j}}} \qquad (3.78)$$

$$C_{e1}=\frac{0.075\left[\sum_{j=1}^{m}A_{1j}\eta_{1j}\pi_{1j}+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m}A_{2j}\eta_{2j}\pi_{2j}\right]}{\mu_c+\sum_{j=1}^{m}K_{1j}\left(\rho_{1j}-2\tau_{1j}\right)+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m}K_{2j}\left(\rho_{2j}-2\tau_{2j}\right)} \qquad (3.79)$$

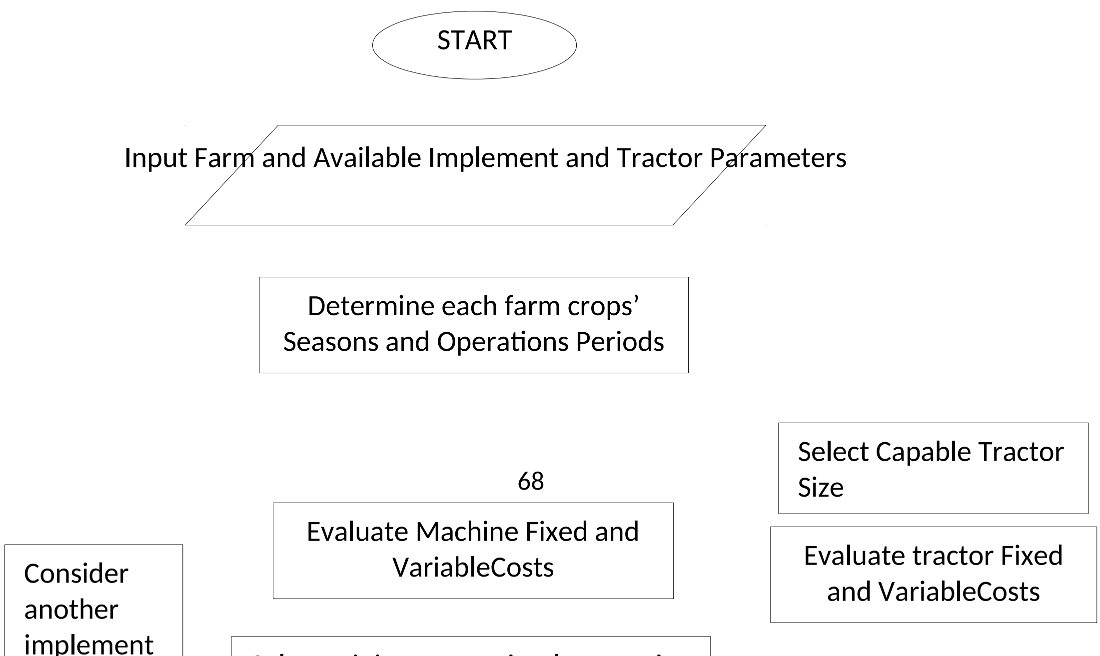
For crop 2 tillage operation period they are:

$$w_{P2}=\sqrt[3]{\frac{\sum_{j=1}^{m}\Omega_{2j}\alpha_{2j}+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m}\Omega_{1j}\alpha_{1j}}{\mu+\sum_{j=1}^{m}K_{2j}\rho_{2j}+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m}K_{1j}\rho_{1j}}} \qquad (3.80)$$

$$C_{e2}=\frac{0.075\left[\sum_{j=1}^{m}A_{2j}\eta_{2j}\pi_{2j}+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m}A_{1j}\eta_{1j}\pi_{1j}\right]}{\mu_c+\sum_{j=1}^{m}K_{2j}\left(\rho_{2j}-2\tau_{2j}\right)+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m}K_{1j}\left(\rho_{1j}-2\tau_{1j}\right)} \qquad (3.81)$$

### 3.4 Computer Modelling of the Study Models

The flow chart for the model evaluation process is as in Figure 3.5. The computer programme for the model application is shown in Appendix C-1 and was written in MATLAB following the algorithm presented in Figure 3.5.



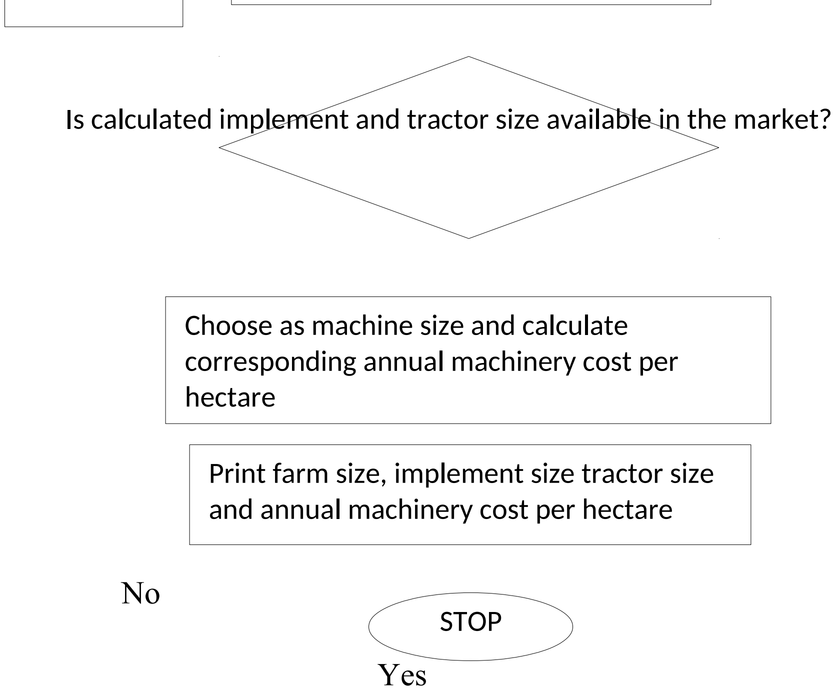



Figure 3.5: The minimum-cost machinery capacity selection model flow chart

### 3.5 Model validation apparatus and materials

To test the model's validity the values of the relevant parameters for evaluating the machinery annual costs and field capacity were obtained from the studied locations. The evaluated costs and machinery capacity obtained from the models were compared with those obtained from the existing Hunt-Wilson models.

#### 3.5.1 Apparatus and Materials Used

Materials used for the model validation include:

- ✓ Small-scale cassava and rice farms of different sizes
- ✓ Existing relevant farm records
- ✓ Structured questionnaires
- ✓ Recording materials

Farm Machinery:

- ✓ Common farm power and machinery used for cassava and maize tillage in the:

MF 425 Tractor

MF 435 Tractor

MF 440 Tractor

MF 470 Tractor

Swaraj 780 Tractor

3-Bottom Plough: Baldan AF 3 and

4-Bottom Plough: Baldan AF 4,

20-Disc Offset Harrow; Baldan SPR 20 and

24-Disc Offset Harrow; Baldan SPR 24

4-Disc, 2-Row Ridger; Baldan SD 4

Measuring Instruments:

Stop watch …. (0.01 s precision),

Tape Rules:- Crocodile 5m (0.5 mm precision)

Tucle 30 m (5 mm precision),

Builders Try Square- Framing Rafter X 650; 610 mm (1 mm precision)

(Magnetic Sticking) Liquid-bubble Plumb- Diamond brand 230 mm long.

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, Ministry of Agriculture Anambra State, southeastern Nigeria. Her public-private partnership; the E-Force outfit clients' farms were also studied. Farms studied varied from 0.5 to 22 hectares in size. The study lasted from 2014 to 2016. Farms studied for the model validation were located in different parts of Anambra state southeast Nigeria; located within latitudes 5º 20″ and 6º 40″ north and longitudes 6º 40″ and 7º 20″ east.

With capital at Awka, the state has 21 local government areas (LGAs). It has a tropical climate with 2 main seasons in a year; the dry season between mid October and mid March, and a bimodal rainy season lasting the rest of the year. The land area is 4,844km$^2$ in size and is 100% arable (Wikipedia, undated2). A good network of rivers and stream criss-crosses the state including the Niger, Anambra and Ezu Rivers. Some of the LGAs are of altitudes that are low lying. Such areas happen to be of serious agricultural relevance, but are coincidentally susceptible to flooding during a good part of the rainy season and the onset of the dry season.

The MF tractors were 4-wheel driven, while the Swaraj tractors were 2-wheel driven. The tillage implements were fully mounted disc implements. Details of the tractors and implements relevant to the study are listed in Table 3.1.

Table 3.1: Tractor and implement parameters relevant to the study

| Machiney /Parameter | Parameter Values | | | | |
|---|---|---|---|---|---|
| Tractor Model | MF 425 | MF 425 | MF 425 | MF 425 | Swaraj 780 |
| Drive Option | 4WD | 4WD | 4WD | 4WD | 2WD |
| Indicated Power (kW) | 48.5 | 53.7 | 61.1 | 89.5 | 48.5 |
| Weight (kg) | 2870 | 2870 | 3040 | 4210 | 3065 |
| | | | | | |
| Implement | Disc Plough | | Disc Harrow | | Disc Ridger |
| Model & Description | Baldan AF 3 3-Bottom | Baldan AF 4 4-Bottom | Baldan SPR 20 20-Disc Offset | Baldan SPR 24 24-Disc Offset | Baldan SD 4 2- Row, 4-Disc |
| Disc Diameter (m) | 0.71 | 0.71 | 0.66 | 0.66 | 0.71 |
| Weight (kg) | 402 | 502 | 670 | 740 | 506 |
| Max. Working Width (m) | 0.9 | 1.2 | 1.7 | 2.1 | 2.0 |
| Indicated Field Capacity (ha/hr) | 0.3100 | 0.4133 | 0.7507 | 0.9273 | 0.5702 |

Experimental Procedures:

Ploughing, harrowing and ridging operations were carried out in selected small farms at various locations of the study.

- ✓ Forward speed of the field operations were obtained by measuring the distance traversed with the 30m 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 implement working width also was measured with the 5 m tape rule.
- ✓ The farm size was obtained from the hiring outfit records.
- ✓ The time spent to process the field was measured with stop watch.
- ✓ The tillage depth was measured with improvised depth-guaging instrument. See Figure 3.6. The instrument has a builder's square that is dipped vertically into the tilled portion close by an untilled area; a magnetic sticking plum is sticked on top of the horizontal limb of the square to balance it horizontally and ensure the other limb is dipping vertically. The vertical distance from the square top to the surface of the untilled portion under the hanging horizontal limb was measured with a meter tape. The tillage depth was evaluated as the difference between the vertical square limb and this distance.

Figure 3.6: Tillage Depth Measuring Instrument

Computer Software Used:

- ✓ Latitude and longitude finder software; http://www.latlong.net/ was used to get the geographical locations of the studied farms and their geographical distance from the machinery hiring centre.
- ✓ Excel package of Microsoft Office 2007 (Microsoft Inc. USA) was used for evaluation and simulation of the developed models and mathematical analysis of the operations.
- ✓ Studied farms in locations prone to flooding was identified with Shuttle Radar Thematic maps (SRTM)
- ✓ TORA Optimization System Windows Version 2.00

Computer Hardware Used; HP EliteBook 6930p of 149 GB memory capacity and 4.0 GB RAM of 2.53GHz processing speed was used.

**3.5.2 Model validation**

Tillage operations were carried out in some of the farms serviced by the tractor and equipment hiring unit of the Anambra State Ministry of Agriculture Awka, Nigeria. Published data was also accessed to get some of the needed model parameters. The tillage operations records from the Anambra State Ministry of Agriculture Awka, Nigeria and her public-private partnership outfit was utilized for evaluating the tillage period, field crops planted and locations, farmers plots sizes. The extension unit of the ministry, the Lower Anambra River Basin Irrigation Project in Omor, Ayamelum LGA of Anambra State and the

Igbariam out-station of the National Root Crop Research Institute were the sources of primary data used.

Values of the models' variables collected from the studied farms were employed in evaluating the implement machinery capacity selected by the model. The least-cost width was equally selected with the Hunt-Wilson (2015) model based on the same farm parameters' input. The field capacity obtained with the study model was converted to the equivalent machine width and the 2 widths compared for validation of the model. The values of the required field capacity based on the available hours for the tillage operations in the study locations were also compared with those evaluated with the selection models based on the input parameters collected. Comparison of the developed models width and cost with those of the Hunt-Wilson model was done ANOVA using Excel Software. 1-on-1 groups ANOVA comparison was done with PAST software.

### 3.6 Study method

The data collected included:

- ✓ sizes of small-scale cassava and rice farms and their locations,
- ✓ types, sizes, economic life and purchase prices of implement and tractors available,
- ✓ types of soil in the cultivated area,
- ✓ type of crops grown and market prices of crops in particular locations.

The sources of secondary data were:

- ✓ ASAE and ASABE standards for machinery management where applicable,
- ✓ National Agricultural Extension and Research Liaison Services (NAERLS) farm machinery cost estimation data.
- ✓ NBS and CBN Statistical Bulletins and information bulletins from many dealers of agricultural machinery in Nigeria.

The secondary data collected included information about operation speeds, types and sizes of tractors and implements, operations field efficiency range for power requirements for the implements. All collected data was collated and analyzed to fit the model.

### 3.7 Fixed cost determination

The sharpness of the least-cost model is said to depend on the reliability of the fixed cost factors used (Hunt, 2001). The parameters of the fixed cost factors used in evaluating the model was based, as much as possible, on data that is compatible with the locality it was deployed in. Table 3.2 shows the factors employed for adapting the model to a Nigerian locality.

Table 3.2: Local cost parameters used in the model

| Machiney Parameter | Parameter Description (Units) | Values Recommended/ Used | |
|---|---|---|---|
| | | Machinery Type | Value |
| Machinery Fixed Cost Items | Interest Rate (%) | All | 6.56** |
| | Economic Life $\Gamma$(yrs) | Tractors | 8#-10* |
| | | Farm Implements | 5-6# |
| | Lump Taxes, Insurance and Shelter Costs $ts$ (% of purchase price) | All | 7 |
| Machinery Labour Cost $L$ (₦/hr) | Prevailing Local Rate | Operator | 500.00 |
| | | Operator Mate | 200.00 |
| Fuel Cost $\sigma$ (₦/l) | Prevailing Local Rate | Local Pump Price | 175.00 |
| Operations Returns | Ploughing | Harrowing | Ridging |
| Tractor & Machinery Hiring Charge /ha (₦) | 7,000 | 7,000 | 7,000 |
| Percentage Subsidized By Government % | 50 | 50 | 50 |

Sources: * Chigbo (2016)
#Yiljep and Gwarzo (undated)
**Estimated from https://nationaldailyng.com/2015/author/graphics

The machinery economic life ($\Gamma$), and the taxes, insurance and shelter cost factors were adopted from the Nigerian National Agricultural Extension and Research Liaison Services (NAERLS) recommendations, where possible. The engineering unit of the liaison services recommended that 6 % of the purchase price should be used as the sum of taxes, insurance and shelter costs.

Zero tax on agricultural machinery is currently prevailing in the country, while average insurance rate of 5 % (of purchase price of machine) was indicated from a recent survey of local banks and insurance companies (Yiljep and Gwarzo, undated). The local comprehensive insurance premium charged on agricultural tractors as at the time of this study varied from 4 % to 6 % of purchase-price (Oasis Insurance, 2016 and Olarinmoye, 2017). Thus 7 % of purchase price was used for tractors and implements as lump insurance, taxes and shelter costs. The machinery economic life employed in evaluating machinery depreciation was based the local experience in the studied area so as to adapt the fixed cost factors to Nigerian applications. The economic life used was 5-6 yrs for farm implements based on the experience of the tractor hiring outfit studied. For MF tractors the economic life used was 10 yrs based on local experience and information from dealers (Chigbo, 2016 and Opara, 1987).

The interest rate ($r$) was based on the local banks premium agricultural lending rates of Nigerian banks as shown in Table 3.3.

Table 3.3: 2015 lending rates of Nigerian banks offering premium agricultural loans

| Bank | Prime (Agric.) Lending Rate % |
|---|---|
| IBTC Bank | 5.5 |
| First City Monument Bank | 6.0 |
| Fidelity Bank | 6.0 |
| Access Bank | 7.0 |
| Sterling Bank | 7.0 |
| United Bank for Africa | 7.0 |
| Unity Bank | 9.0 |
| Wema Bank | 9.0 |
| Average (for 40%) of banks offering agric. loan facility at single digit rate | 6.56 |
| Remaining 60% of concerned Banks | 14% - 26.5% |

Source: https://nationaldailyng.com/2015/author/graphics

Forty percent of the banks offering such prime agricultural loans gave the loan at single-digit interest rate. The implements fixed cost was calculated from the component parts namely; shelter, taxes, depreciation, insurance and interest costs; as in the fixed cost equation. The prevailing operator labour rate in the studied area was used. The implement price per incremental width ($p$) /capacity ($p_c$) was evaluated based on the locally available implements' local operation speeds, field efficiencies and their local market prices as in Equation 3.82.

$$p_c = \frac{10(P_2 - P_1)}{(w_2 - w_1)Se} \tag{3.82}$$

The implement price per incremental width ($p$) was likewise evaluated as

$$p = \frac{P_2 - P_1}{w_2 - w_1} \tag{3.83}$$

### 3.8 Field and Tillage Conditions Determination

The soil texture dependent draught coefficients ($C_1$$C_1, C_2$, $C_1$) were selected based on the local soil

types as in Table 3.4. Where the draught factors for the soil type are not available, the factors for a close textural class were employed. Soil classes of the studied areas were obtained from

Table 3.4: Values of soil draught coefficients; $C_1$ and $C_2$ for various soil types

| Soil Type | $C_1$ | $C_2$ |
|---|---|---|
| Silty Clay1 | 7 | 0.049 |
| Decatur Clay loam | 6 | 0.053 |
| Silty Clay2 | 4.8 | 0.024 |

| | | |
|---|---|---|
| Davidson Loam | 3 | 0.021 |
| Sandy Silt | 3 | 0.056 |
| Sandy Loam | 2.8 | 0.013 |
| Sand | 2 | 0.013 |

(Source: Hunt and Wilson, 2015)

literature and are listed in Table 3.5. Surrogate soil class from a close-by location was used for any area where the soil class was unknown. Soil Texture triangle was consulted for choice of the soil class neighbour choice. Implement sale prices were obtained from local users and dealers. Machinery parameter like weight was gotten from machinery sales brochure. Depth and speed of tillage and field efficiencies obtained in the studied farms operations were used. The equivalent tillage PTO power ($\Pi$) was evaluated with Equation 3.84 as has been given earlier based on tillage drawbar power ($\Pi_B$) and the tractive efficiency $E$ as

$$\Pi = \frac{\Pi_B}{E} \qquad (3.84).$$

$$\Pi = \frac{\Pi_B}{E}$$

Medium tractive surface condition was employed for ploughing operation, and poor condition for subsequent tillage operations. These corresponded to 0.67 and 0.55 for 2WD, and 0.76 and 0.72 for 4WD tractors as reported by Zoz and Grisso (2003). Fuel price was obtained from the open market, while the standard fuel efficiency was selected from data adapted by Hunt and Wilson (2015) from Nebraska Tractor Tests, see Table 3.6. Where the exact percentage power loading for the fuel efficiency is not in the table, interpolation was used as recommended by Hunt and Wilson (2015). For operations having percentage power loading of less than 20, the fuel efficiency for 20 % power loading was employed.

### 3.9 Tillage Machinery Costs and Capacities Determination

The minimum-cost tillage machine capacities ($C_e$) selected with the developed models were converted to equivalent minimum-cost width using Equation 3.85.

$$w = \frac{10C_e}{Se} \qquad (3.85)$$

The resulting minimum-cost widths were compared with the least-cost width selected by the

Table 3.5: Soil texture classes of some parts of Anambra state, Nigeria

| Location/ (LGA) | Particle Size | | | Textural Class | Sample Depth (cm) |
|---|---|---|---|---|---|
| | Sand | Silt | Clay | | |
| Nteje1 (Oyi)<br>Nteje2 (Oyi)^ | 18.8<br>82.0 | 41.6<br>04.0 | 39.6<br>14.0 | Silty clay loam<br>Sandy loam | 0-150<br>0-30 |
| Atani (Ogbaru) | 58.4 | 19.4 | 22.2 | Silty loam | 0-150 |

| | | | | | |
|---|---|---|---|---|---|
| Osamala (Ogbaru) | 62.0 | 16.0 | 22.0 | Sandy clay loam | 0-30 |
| Oroma Etiti (Amambra W.) | 24.0<br>49.6<br>52 | 20.0<br>14.8<br>3.6 | 56.0<br>35.6<br>44.4 | Clay<br>Sandy clay loam<br>Sandy clay | 0-30<br>0-130*<br>0-130* |
| Okija (Ihiala) | 82.0 | 02.0 | 16.0 | Silty loam | 0-30 |
| Ifite Ogwari (Ayamelum) | 16.0 | 56.0 | 28.0 | Clay loam | 0-30 |
| Umueje (Ayamelum) | 20.0 | 48.0 | 32.0 | Clay loam | 0-30 |
| Umumbo (Ayamelum) | 36.0 | 30.0 | 34.0 | Clay Loam | 0-30 |
| Omasi (Ayamelum) | 16.0 | 62.0 | 22.0 | Silty loam | 0-30 |
| Awka (Awka N.) | 82.0 | 06.0 | 12.0 | Loamy sand | 0-30 |
| Nanka (Orumba N.) | 70.0 | 02.0 | 28.0 | Sandy clay loam | 0-30 |
| Nawfija (Orumba N.) | 90.0 | 02.0 | 08.0 | Loamy sand | 0-30 |
| Nnewi (Nnewi N.)[#] | 84.82 | 2.45 | 12.73 | Loamy Sand | 0-30 |

Sources: Chukwu et al, 2009
^Igwe et al, 1995
[#] Phil-Eze, 2010
*Skoup and Co. Ltd, 1980

Hunt-Wilson (2015) model. The adequate field capacity required on the basis of available operation hours was also converted to equivalent required width for the comparison purpose. The corresponding minimized annual costs per hectare from these models were also compared likewise. The drawbar power required for the tillage was evaluated with the simpler variant of the previous drawbar power expression as shown in Equation 3.86.

$$\Pi_B = \frac{C_e d}{3.6e}\left(C_1 + C_2 S^2\right) = \frac{C_e d}{3.6e}\Theta \tag{3.86}$$

The operation's equivalent PTO power ($\Pi$ ) was divided by the maximum PTO power ($\Pi_x$) of the tractor selected to power the implement, from the available ones in the market for estimating the percentage loading. For evaluating the tillage machinery cost with no consideration of inter-field machinery transport, the simpler equivalent speed-term form of

Table 3.6: Fuel efficiency at tractor's maximum power percentage loading (kW.hr/ l)*

| Loading (% max PTO power) | Gasoline | Diesel | LP Gas |
|---|---|---|---|
| 100 average<br>2/3 range | 1.89<br>2.0 – 1.8 | 2.54<br>2.8 – 2.3 | 1.65<br>1.7 – 1.6 |
| 80 average<br>2/3 range | 1.7<br>1.8 – 1.6 | 2.46<br>2.6 – 2.3 | 1.46<br>1.6 – 1.4 |
| 60 average | 1.42 | 2.18 | 1.28 |

| | | | |
|---|---|---|---|
| 2/3 range | 1.5 – 1.3 | 2.4 – 2.0 | 1.3 – 1.2 |
| 40 average<br>2/3 range | 1.11<br>1.3 – 0.9 | 1.72<br>1.9 – 1.5 | 1.02<br>1.1 – 0.9 |
| 20 average<br>2/3 range | 0.72<br>0.8 – 0.6 | 1.19<br>1.3 – 1.0 | 0.72<br>0.9 – 0.7 |

*115% Nebraska Test fuel consumption
Source: Hunt and Wilson (2015)

annual tillage cost equations were used. Equations 3.87 and 3.88 gave such evaluation for the operation labour-cost inclusive and operation labour-excluded cases respectively. The effect of changing labour cost on the minimum-cost plough width selected with the models and the corresponding annual machinery cost was considered for a fixed farm size. The labour cost was varied by changing the labour rate per hectare. Labour rates of ₦550.00, ₦700.00, ₦850.00 and ₦1000,00 were used. However for investigating other outputs of the models a constant rate of ₦700.00 was employed. The annual plough machinery cost per hectare and the minimum-cost width obtained were predicted for such labour cost changes.

$$AC_g = \frac{\gamma}{100} P + \sum_{j=1}^{m} \sum_{i=1}^{n} \text{¿¿¿} \quad (3.87)$$

$$AC_g = \frac{\gamma}{100} P + \sum_{j=1}^{m} \sum_{i=1}^{n} \text{¿¿¿} \quad (3.88)$$

The coinciding operation annual tillage machinery cost equation with machinery transport cost incorporated was evaluated with Equation 3.89, for the operation labour cost-included case. The operation labour cost-excluded case was evaluated with Equation 3.90. Simplified versions of the machinery cost models derived by replacing the machine width and price per width product (*pw*) with the implement price (*P*) were used in the annual costs estimation.

$$AC_{TP} = \frac{\gamma}{100} P + \sum_{j=1}^{m} \sum_{i=1}^{n} \left[ \frac{A_{ij}}{C_e} L + \frac{A_{ij} d \eta_{ij}}{2.66 e} \Theta_{ij} + \frac{\kappa_{ij} C_e d}{2.66 e} \Theta_{ij} + CT_{ij} \right] \quad (3.89)$$

$$AC_{TP} = \frac{\gamma}{100} P + \sum_{j=1}^{m} \sum_{i=1}^{n} \left[ \frac{A_{ij} d \eta_{ij}}{2.66 e} \Theta_{ij} + \frac{\kappa_{ij} C_e d}{2.66 e} \Theta_{ij} + CT_{ij} \right] \quad (3.90)$$

The Hunt-Wilson annual machinery cost was evaluated with Equation 3.88, and its annual machinery and transport cost with Equation 3.90. The transported weight used for the transport labour and fuel costs estimation for any machinery selected was obtained as in Equation 3.91. The weight of the least implement capacity available in the market was chosen as the basal weight ($m_{tb}$) and was added to the selected machine proportionate weight to the incremental size. The tractor weigth was added to this estimated weight to evaluate the total machinery weight transported. The above weight estimation was considered appropriate since the machinery size model was based on comparative cost and not absolute cost.

$$m_{tw}=m_{tt}+m_{tb}+\frac{(m_{t2}-m_{t1})w}{(w_2-w_1)} \quad (3.91)$$

where:

$m_{tw}$ = total machinery weight transported, tonne

$m_{tt}$ = transport tractor weight, tonne

$m_{tb}$ = basal implement weight, tonne

$m_{t1}$ and $m_{t2}$ are the basal implement and the next larger implement weight respectively, tonne

The tillage machinery field capacity for the multi-crop pool farm with coinciding operation period was evaluated with Equation 3.92 for the labour cost-included case and Equation 3.93 for the labour cost-excluded case.

$$C_e=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}(-b'_{ij})+\sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[(b'_{ij})^2+4a'c'\right]}}{\sum_{j=1}^{m}\sum_{i=1}^{n}2a'} \quad (3.92)$$

$$C_e=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}0.075A_{ij}\eta_{ij}\pi_{ij}}{\mu_c+\sum_{j=1}^{m}\sum_{i=1}^{n}K_{ij}(\rho_{ij}-2\tau_{ij})} \quad (3.93)$$

The Hunt-Wilson least-cost tillage machinery width for the multi-crop pool farm was evaluated with Equation 3.94.

$$w_p=\sqrt[3]{\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\Omega_{ij}\alpha_{ij}}{\mu}} \quad (3.94)$$

Prior capacity $C_e$ values were required for evaluating the Hunt-Wilson least-cost width with Equation 3.94 as shown in Equation 3.95. The values of the prior capacity $C_e$ employed in evaluating the Hunt-Wilson least-cost width in this study were 0.3101 ha/hr for the plough, 0.7507 ha/hr for the harrow and 0.5702 ha/hr for the ridger. These sizes corresponded to the

$$\alpha_{ij}=75A_{ij}\eta_{ij}C_e^2+75\kappa_{ij}C_e^3 \quad (3.95)$$

smallest tillage implements sizes available readily in the local market since the the models are employed for small farms applications also in the study. Whereas higher farm sizes would require increased values of the chosen $C_e$, these same same values of the capacity were used all through the study. This limitation was as a result of the clumsiness involved and the dependence of the choice of this prior capacity on the user's experience. It has been stated that this study is aimed at improving this weakness of the Hunt-Wilson model *inter alia*.

For testing the circumvention of prior capacity need in evaluating the models developed in the study other values of the capacities were employed. The sizes used were based on the existing models' capacities or capacity projections with the differences in 2 nearest capacity sizes, or the workable sizes based on the implements functioning. Thus capacities of 0.2067 ha/hr, 0.3101 ha/hr, 0.4134 ha/hr and 0.5168 ha/hr were used for the plough. 0.5741 ha/hr, 0.7507 ha/hr, 0.9274 ha/hr and 1.040 ha/hr were used for the harrow and 0.2673 ha//hr, 0.5346 ha/hr, 0.8019 ha/hr and 1.0692 ha/hr for the ridger.

### 3.10 Proportion of tractor time used in machinery operation and transport

For pool farms with varying location transport distance, the proportion of tractor time utilized for tillage and transport operations were considered. The fraction of the total attributed time spent on the operation ($\o$) and the one spent on machinery transportation ($\o_t$) determined from the total processed field size $A$ and the annual hours of machinery transport $h_t$. Thus the proportion of tractor time utilized for tillage was computed with Equation 3.96.

$$\o = \frac{A}{C_e} / \left( h_t + \frac{A}{C_e} \right) \tag{3.96}$$

The proportion of tractor time utilized for transport was obtained with Equation 3.97.

$$\o_t = h_t / \left( h_t + \frac{A}{C_e} \right) \tag{3.97}$$

These tractor use hours fractions were multiplied with the annual tractor fixed cost to evaluate tractor cost for each activity. The tractor use cost for field processing ($\pi$) was computed with Equation 3.98 and the tractor use cost for field machinery transport ($\pi_t$) was computed with Equation 3.99.

$$\pi = \frac{\beta}{100} \o t \tag{3.98}$$

$$\pi_t = \frac{\beta}{100} \o_t t \tag{3.99}$$

For the scattered pool plots with overlapping operation period, the minimum-cost implement capacity for crop 1 was evaluated with Equation 3.100 and crop 2 with Equation 3.101.

$$C_{e1}=\frac{\sum_{j=1}^{m}\left[-b''_{1j}-\left(\frac{b}{b+c}\right)b''_{2j}\right]+\sqrt{\sum_{j=1}^{m}\left[\left(b''_{1j}\right)^2+\left(\frac{b}{b+c}\right)\left(b''_{2j}\right)^2+4\left[a''_{1j}c''_{1j}+\left(\frac{b}{b+c}\right)a''_{2j}c''_{2j}\right]\right]}}{2\sum_{j=1}^{m}\left[a''_{1j}+\left(\frac{b}{b+c}\right)a''_{2j}\right]}$$

(3.100)

$$C_{e2}=\frac{\sum_{j=1}^{m}\left[-b''_{2j}-\left(\frac{b}{a+c}\right)b''_{1j}\right]+\sqrt{\sum_{j=1}^{m}\left[\left(b''_{2j}\right)^2+\left(\frac{b}{a+c}\right)\left(b''_{1j}\right)^2+4\left[a''_{2j}c''_{2j}+\left(\frac{b}{a+c}\right)a''_{1j}c''_{1j}\right]\right]}}{2\sum_{j=1}^{m}\left[a''_{2j}+\left(\frac{b}{a+c}\right)a''_{1j}\right]}$$

(3.101)

The annual costs were evaluated with Equations 3.102 and 3.103 respectively.

$$AC_{TP1}=\mu w+AC_{1TP}+\left(\frac{b}{b+c}\right)AC_{2TP}, \qquad (3.102)$$

$$AC_{TP2}=\mu w+AC_{2TP}+\left(\frac{b}{a+b}\right)AC_{1TP}, \qquad (3.103)$$

Where the cost variables $AC_{1TP}$ for crop 1 and $AC_{2TP}$ for crop 2 were evaluated with Equations 3.104 and 3.105 for operation labour cost-included case, and Equations 3.106 and 3.107 for operation labour cost-excluded case in that order.

$$AC_{1TP}=\sum_{j=1}^{m}\left[\frac{A_{1j}}{C_e}L+\frac{A_{1j}d\eta_{1j}}{2.66e}\Theta_{1j}+\frac{C_e d\kappa_{1j}}{2.66e}\Theta_{1j}+CT_{1j}\right] \qquad (3.104)$$

$$AC_{2TP}=\sum_{j=1}^{m}\left[\frac{A_{2j}}{C_e}L+\frac{A_{2j}d\eta_{2j}}{2.66e}\Theta_{2j}+\frac{C_e d\kappa_{2j}}{2.66e}\Theta_{2j}+CT_{2j}\right] \qquad (3.105)$$

$$AC_{1TP}=\sum_{j=1}^{m}\left[\frac{A_{1j}d\eta_{1j}}{2.66e}\Theta_{1j}+\frac{C_e d\kappa_{1j}}{2.66e}\Theta_{1j}+CT_{1j}\right] \qquad (3.106)$$

$$AC_{2TP}=\sum_{j=1}^{m}\left[\frac{A_{2j}d\eta_{2j}}{2.66e}\Theta_{2j}+\frac{C_e d\kappa_{2j}}{2.66e}\Theta_{2j}+CT_{2j}\right] \qquad (3.107)$$

The operation labour cost-excluded case machinery field capacity for the two-crop pool farm with overlapping operation period was evaluated with Equation 3.108 for the crop 1 field operation period and Equation 3.109 for the crop 2 field operation period.

$$C_{e1}=\frac{0.075\left[\sum_{j=1}^{m} A_{1j}\eta_{1j}\pi_{1j}+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m} A_{2j}\eta_{2j}\pi_{2j}\right]}{\mu_c+\sum_{j=1}^{m} K_{1j}\left(\rho_{1j}-2\tau_{1j}\right)+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m} K_{2j}\left(\rho_{2j}-2\tau_{2j}\right)} \tag{3.108}$$

$$C_{e1}=\frac{0.075\left[\sum_{j=1}^{m} A_{2j}\eta_{2j}\pi_{2j}+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m} A_{1j}\eta_{1j}\pi_{1j}\right]}{\mu_c+\sum_{j=1}^{m} K_{2j}\left(\rho_{2j}-2\tau_{2j}\right)+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m} K_{1j}\left(\rho_{1j}-2\tau_{1j}\right)} \tag{3.109}$$

The Hunt-Wilson least-cost machine width for the two-crop pool farm with overlapping operation period was evaluated with Equations 3.110 for crop 1 field operation period. For crop 2 field operation period the least-cost width was evaluated with Equation 3.111. The Hunt-Wilson annual machinery and transport cost was evaluated as in Equations 3.106 and

$$w_{P1}=\sqrt[3]{\frac{\sum_{j=1}^{m} \Omega_{1j}\alpha_{1j}+\left(\frac{b}{b+c}\right)\sum_{j=1}^{m} \Omega_{2j}\alpha_{2j}}{\mu}} \tag{3.110}$$

$$w_{P2}=\sqrt[3]{\frac{\sum_{j=1}^{m} \Omega_{2j}\alpha_{2j}+\left(\frac{b}{a+b}\right)\sum_{j=1}^{m} \Omega_{1j}\alpha_{1j}}{\mu}} \tag{3.111}$$

3.107 for crops 1 and 2 tillage operation periods in that order, while the crops annual machinery cost was obtained with Equation 3.104 for crop 1 and Equation 3.105 for crop 2.

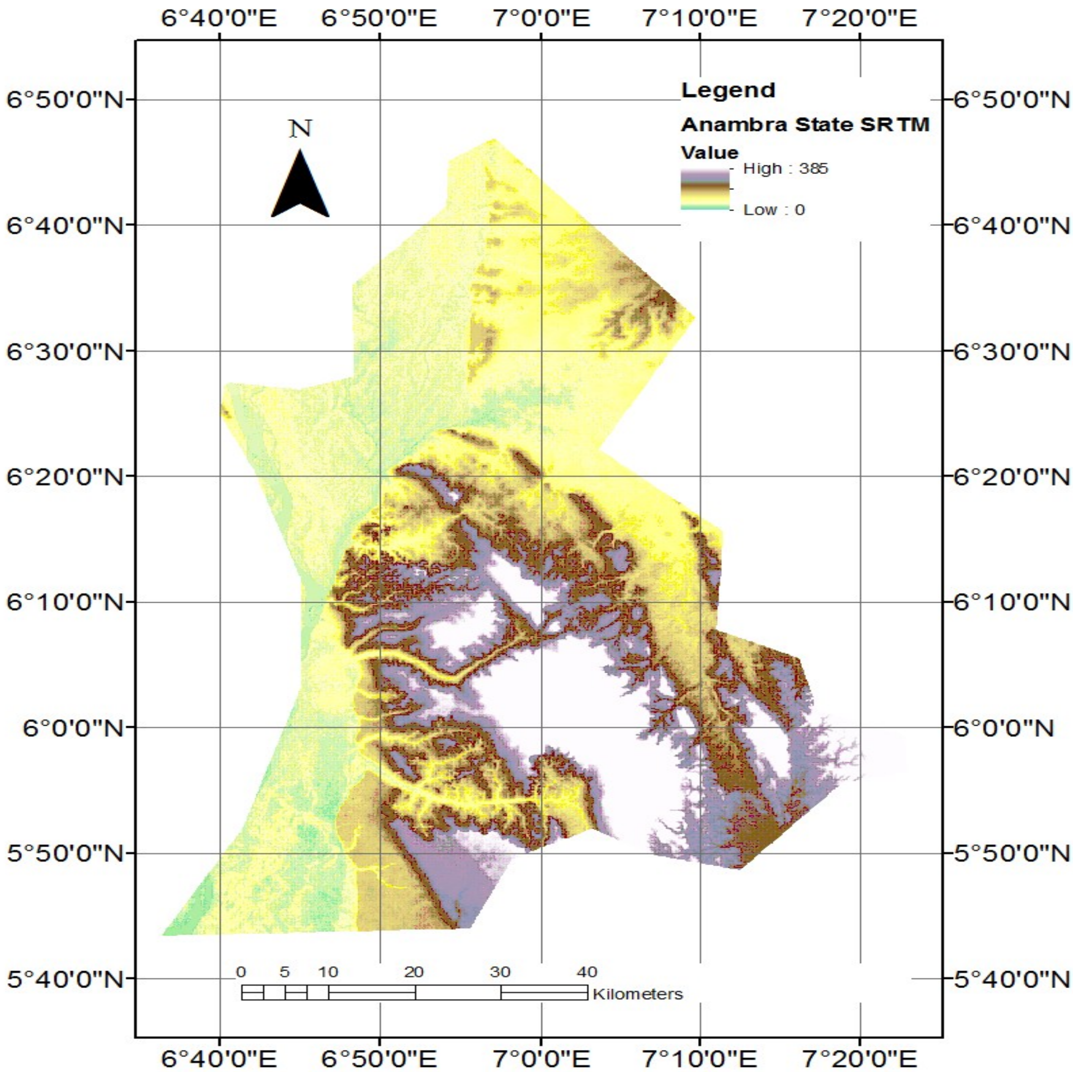
### 3.11 Tillage operation period for studied scattered pool farms

Excessive tillage draught was avoided by ensuring the soil is softened enough with rain. The IITA (undated) reported that ploughing should start as soon as the rain becomes steady and that in Nigeria this varies from:-

- ✓ March- Nov in the rain forest zone
- ✓ April- Aug in the Derived Savanah zone
- ✓ May- July in the Southern Guinea Savannah zone
- ✓ July- August in the Northern Guinea Savannah zone, (ICS/USAID, undated).

In Anambra State, tillage operations in low-lying areas with appreciable clay content should begin after the second rain (Onyeokoro, 2016). The studied locations' altitude was estimated with Shuttle Radar topographic Mission (SRTM) map of the state as shown in Figure 3.7, for assessing their vulnerability to flooding. Areas shaded green in the map were of zero altitudes, areas shaded yellow closer to zero in altitude while areas shaded purple and white of 385 m and above respectively altitude. The altitudes extracted from the map of the studied areas are listed in Table 3.7. Thus studied locations like Ayamelum and Anambra West and a little portion of Anambra East local government areas (LGAs) are of very low altitudes and are susceptible to flooding. The other studied locations like Awka North, Nnewi South, Orumba North and Orumba South LGAs are of higher altitudes and are not susceptible to flooding. The LGAs that grow rice and cassava in the state are also listed in Table 3.7 and shown in Figure 3.8. Nnewi South LGA grew only cassava while rice and cassava are grown in the other studied LGAs.

For evaluating the operation overlap coefficients, the study locations that are likely to experience flooding of their farms were grouped into a zone; zone 2 (denoted as $_{2Z}$ ). Those




Source: SRTM 30

Figure 3.7: Shuttle Radar Topographic Map (SRTM) of Anambra State Nigeria.

locations that may not experience flooding of their farmlands were also grouped into another zone; zone 1 ($_{1Z}$ in subcript). The group that experienced flooding ($_{2Z}$) consequently had further restrictions on planting and tillage timing, and was so noted in the study. Of the studied locations, LGAs like Ayamelum and Anambra West belonged to zone 2 ($2Z$) locations. The other studied LGAs; Awka North, Ihiala, Nnewi South, Orumba North, Orumba South and Oyi fall into locations that are not generally subject to flooding and are grouped as zone 1; ($1Z$).

The possible period that cassava and rice farmlands could be tilled for suitable planting of cassava or rice in the area studied was charted on a monthly time table as in Figure 3.9. In determining the hours available for field work, Sundays and Saturdays were excluded since

Table 3.7: Locations of the used cassava and rice fields

| Local Government Area | Longitude[#] (°) | Latitude[#] (°) | Altitude* (m) | Ecological Zone | Cassava* | Rice* |
|---|---|---|---|---|---|---|
| Anambra East | 6.945 | 6.390 | 33 | $1Z$ | Yes | Yes |
| Anambra West | 6.905 | 6.429 | 22 | $2Z$ | Yes | Yes |
| Awka North | 7.133 | 6.340 | 51 | $1Z$ | Yes | Yes |
| Ayamelum | 6.961 | 6.511 | 24 | $2Z$ | Yes | Yes |
| Nnewi South | 6.910 | 5.929 | 29 | $1Z$ | Yes[##] | No |
| Ihiala | 6.851 | 5.851 | 30 | $1Z$ | Yes | Yes |
| Orumba North | 7.192 | 6.080 | 144 | $1Z$ | Yes | Yes |
| Orumba South | 7.238 | 5.962 | 162 | $1Z$ | Yes | Yes |

Sources: * SRTM 30

[#] http://www.latlong.net/

**Derived from Figure 3.7

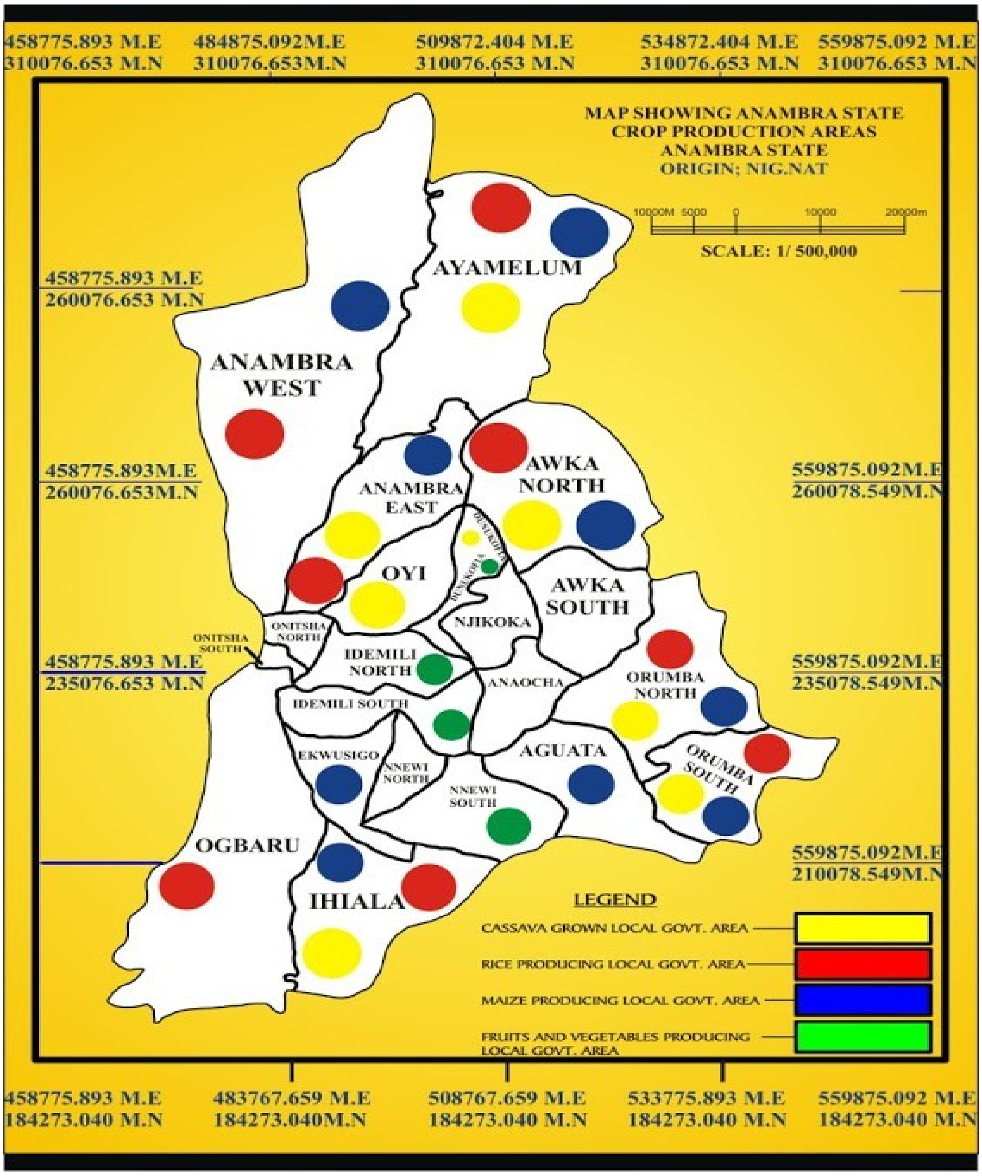
[##]Not indicated in Figure 3.8, but clients from location patronized the tractor hiring services.

they were non-working days for such hiring operations from the Hiring units. The total number of working days that the operation period spanned was evaluated for each crop's soil tillage operations for a given zone. The relevant days within the applicable periods and their differences were used to compute the overlap coefficients. The coefficients were expressed in terms of these periods' total working days and their relevant differences.

From the tillage operation time table (Figure 3.9), cassava planting in zone 1 ($_{1Z}$) locations of the state falls into 2 seasons. The total farm size to be processed was thus split into the two periods in the ratio of the working days available in each season. The total land area to be processed will thus be treated as an equivalent total area evaluated as the highest of the values of different farm sizes needing processing within the given time frame. Other zone's farms and crop's farms within the same or other locations needing same operation simultaneously are added to make up the total equivalent farm size as seen in Equations 3.108 to 3.109. The needed machinery size was then determined based on the equivalent land area evaluated from the equations.

### 3.12 Equivalent farm size model for overlapping operations timing farms

Within September to December cropping season the total area to be processed could be evaluated as an equivalent area. From the zone 1 (*1Z*) late cassava perspective the equivalent area is ($Aq_{C1Z}$) made up of *1Z* late cassava plots plus the overlap from *2Z* cassava plots:




Source: Anambra State Ministry of Agriculture Mechanization and Processing
Figure 3.8: Major crop growing areas of Anambra state, Nigeria

$$Aq_{C1Z} = ALC_{1Z} + \frac{b}{b+c} \times TAC_{2Z} \tag{3.112}$$

where:

$ALC_{1Z}$ = area for late cassava in zone 1

$TAC_{2Z}$ = total area for cassava in zone 2

$a$ = zone 1 late cassava tillage working days less the overlap

$b$ = zone 1 late cassava and zone 2 cassava working days overlap

$c$ = non-overlapping working days in zone 2 cassava.

Since cassava cropping in zone 1 (*1Z*) is in 2 seasons, the field processing of the cassava farms in this zone are assumed to be divided into these 2 seasons in the ratio of the available

<table>
<tr><th>Ecological' Zone</th><th colspan="12">Suitable Tillage Operation Dates For Rice and Cassava Cropping</th></tr>
<tr><td>1:<br>Igbariam<br>Ugbene<br>Omogho<br>Achalla<br>Umunze<br>Ukpor<br>Ihiala</td><td></td><td></td><td colspan="6">early cassava<br><br>rice $d$<br>$e$ $f$</td><td colspan="3">late cassava<br><br>$a$ $b$</td><td>$C$</td></tr>
<tr><td></td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td>2:<br>Omor<br>Omasi<br>Anambra W.</td><td></td><td></td><td colspan="4">early rice</td><td></td><td>late rice</td><td></td><td></td><td colspan="2">Cassava</td></tr>
</table>

*Developed from Sources Information

Sources: Nwabuike (2017)

Onyeokoro (2017)

NRCRI Igbariam Outstation (2017)

Figure 3.9: Studied areas rainfed cassava and rice cropping tillage seasons*

days for each season; namely 87 days for early cassava and 65 days for late cassava. Equation 3.112 becomes:

$$Aq_{C1Z} = \left(\frac{65}{65+87}\right) \times TAC_{1Z} + \frac{b}{b+c} \times TAC_{2Z} \quad (3.113)$$

where $ATC_{1Z}$ = total area for cassava in zone 1 (1*Z*) locations.

Evaluating the equivalent ($Aq$) from the *2Z* cassava season perspective we consider the *2Z* cassava plots and the overlapping *1Z* cassava plots, giving:

$$Aq_{C2Z} = \frac{b}{a+b} \times \left(\frac{65}{65+87}\right) \times TAC_{1Z} + TAC_{2Z} \quad (3.114)$$

The larger of these equivalent farm size values will be chosen for the equivalent farm area to be processed within September to December ($Aq_{S:D}$)

$$Aq_{S:D} = max\{Aq_{1Z}; Aq_{2Z}\} \tag{3.115}$$

Equally within March to July period zone 2 (*2Z*) rice, zone 1 (*1Z*) rice and zone 1 (*1Z*) early cassava can be planted whose plot must be tilled within this period. Whereas there is a possibility of second season rice planting during August, it exists only in very few locations of the studied area. The second season rice was therefore not considered in this study.

Similarly, within March to July season, the total area to be processed can be evaluated as the equivalent area ($Aq_{M:J}$). From zone 1 (*1Z*) rice perspective, the equivalent area ($Aq_1$) is given as:

$$Aq_1 = \frac{e}{e+d} \times AEC_{1Z} + AR_{1Z} + \frac{e}{e+f} \times ATR_{2Z} \tag{3.116}$$

where:

$AEC_{1Z}$ = area for early cassava in zone 1 (*1Z*), ha

$AR_{1Z}$ = area for rice in zone 1 (*1Z*), ha

$AR_{2Z}$ = total area for rice in zone 2 (*2Z*), ha

$e$ = number of zone 1 (*1Z*) rice tillage working days

$d$ = early zone 1(*1Z*) cassava working days less zone 1 rice working days

$f$ = zone 2 (*2Z*) rice working days less zone 1 rice working days

By inspection of Figure 3.9 *Aq1* gives the largest agglomeration of farm sizes than any other period of early cassava from zone 1. The $Aq_{M:J}$ (for March to July season) now becomes:

$$Aq_{M:J} = Aq_1 = \frac{87}{87+65} \times \frac{e}{e+d} \times TAC_{1Z} + AR_{1Z} + \frac{e}{e+f} \times AR_{2Z} \tag{3.117}$$

Therefore the overall equivalent farm size becomes:

$$Aq = max\{Aq_{S:D}; Aq_{M:J}\} \tag{3.118}$$

From Figure 3.9, the values of the overlap coefficients are:

$a$ = 21.427, (from non-overlapping zone 1 late cassava tillage period)

$a+b$ = 43.571, (from zone 2 cassava tillage period)

$c$ = 22.142, (from non-overlapping zone 2 cassava tillage period)

$b+c$ = 44.286, (from zone 2 total cassava tillage period)

$e$ = 65.714, (from zone 1 rice tillage period)

$e + d$ = 87.14 (from zone 1 early cassava tillage period)

$e+f$ = 76.429 (from zone 2 (early) rice tillage period)

The adequate field capacity selection is based on the bigger of the farm sizes from Equations 3.112 or 3.117.

The window period for tractorized tillage of the non-flooded (ie $Z_1$) locations is mid March to mid June for rice, while for cassava it is bimodal; mid March to mid July and September to November. The tractorized tillage period for rice cropping can be carried out for the zone 2 study locations within April to June. As explained earlier second season (late) rice is regarded as non feasible in this study and therefore not considered. The operations overlap coefficients *a*, *b*, *c, d, e* and *f* were evaluated from the Figure 3.9 and the highest equivalent farm sizes were determined from these coefficients based on Equations 3.112 to 3.118.

### 3.13 Determining the adequate tillage machinery capacity required

The machinery capacities selected for the highest studied farm size under the actual field soil draught variables was selected as the final tillage machinery capacity. This final tillage machinery capacity selected was further corrected for the loss of field processing time to machinery transportation requirements to yield the actual tillage machinery capacity required ($C_{eR}$). Equation 3.119 was used to incorporate the time losses to machinery transport by adjusting the selected machinery capacity to accommodate completion of the field processing within the anticipated time.

$$C_{eR}=\frac{A}{\left(\frac{A}{C_e}-h_t\right)} \tag{3.119}$$

The implement sizes available in the market or the multiples and combinations of them are finally chosen to satisfy the adjusted implement capacity. The adequacy of the selected available machinery capacities in processing the given pool farms within the available hours ($h_{AV}$) were also crosschecked. Equation 3.120 was used to verify this adequacy given the time losses to machinery transportation also.

$$C_{eQ}=\frac{A}{h_{AV}} \tag{3.120}$$

The parameters used in evaluating the equivalent farm sizes are shown in Table 3.8. The total sum of each crop's serviced farms in each studied town is shown in the table, as well as the total of the serviced farms planted with the two crops in each town. The distances of the towns from the hiring outfit base and the towns' prevailing soil types are also shown in the table.

The tractor hourly transport fuel cost was evaluated as

$$fl_t = \frac{\Pi_t \sigma}{H} \qquad (3.121)$$

The tillage machinery is transported in a lifted position and the required power was evaluated like that of drawn non soil-engaging implements. The drawbar power requirement for suchimplements evaluated in accordance to the formula given by Kepner *et al* (2003) and can be converted to its equivalent PTO power ($\Pi_t$) as in Equation 3.122.

$$\Pi_t = \frac{F_N \times R_R \times S}{3.6 \times 0.96 E} \qquad (3.122)$$

where:

$F_N$ = static vertical force on the tractor drive wheels, kN

$R_R$ = rolling resistance on the tractor drive wheels, kN

Table 3.8: Study field sizes, distances from machinery hire base and soil types

| Location/ (LGA)/ *Zone* | Soil Type (*Surrogate Location*) | Soil Type For Draught Estimation | Indicated Farm Size (ha)^ Cassava Early | Cassava Late | Cassava Total | Rice | Location Total | Distance From Base (Awkuzu Oyi LGA) (km)* | Surrogate Location Used |
|---|---|---|---|---|---|---|---|---|---|
| Igbariam (An. E.) *1Z* | (*Nteje*) Sandy clay loam | Clay loam | 19.18 | 14.32 | 33.5 | 10 | 43.7 | 16 | None |
| Achalla (Awka N.) *1Z* | (*Awka*) Sandy loam | Sandy loam | 22.04 | 16.46 | 38.5 | 0 | 38.5 | 12 | None |
| Ugbene (Awka N.) *1Z* | (*Awka*) Loamy sand | Sandy loam | 36.9 | 27.55 | 64.45 | 0 | 64.45 | 33 | Ebenebe (Awka N.) |
| Anambra West *2Z* | Clay | Clay Loam | 6.01 | 4.49 | 10.5 | 45.5 | 56 | 13 | None |
| Omasi (Ayamelum) *2Z* | Silty Loam | Loam | 13.74 | 10.26 | 24 | 71 | 95 | 30 | None |
| Omor (Ayamelum) *2Z* | (*Umueje*) Clay loam | Clay Loam | 14.28 | 10.67 | 24.95 | 99 | 123.95 | 30 | None |
| Umunze (Orumba S.) *1Z* | (*Nawfija*) Loamy sand | Sandy Loam | 13.17 | 9.83 | 23 | 11 | 34 | 45 | Nawfija |
| Omogho (Orumba N.) *1Z* | (*Nawfija*) Loamy Sand | Sandy Loam | 17.75 | 13.25 | 31 | 104 | 135 | 38 | Ufuma |
| Ukpor | (*Nnewi*) | Sandy Loam | 18.32 | 13.68 | 32 | 9.5 | 25.0 | 36 | None |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (Nnewi S.) *1Z* | Loamy Sand | | | | | | | | |
| Ihiala (Ihiala) *1Z* | Silty Loam | Loam | 22.33 | 16.67 | 39 | 0 | 39.0 | 45 | None |

Sources: ^ASADAP (2016), Nwabuike (2017)
*http://www.latlong.net/

$S$ = forward travel speed of the tractor, km/hr

$0.96$ = conversion factor between drawbar power to PTO power, kN

$E$ = tractive efficiency, dimensionless.

**3.7.5 Statistical analysis of the predicted machinery cost and minimum-cost width**

The field capacities selected with the developed models were converted to their equivalent machine widths for comparison with the widths selected by the Hunt-Wilson model. The difference in the tillage machine widths obtained from the developed models and their corresponding machinery cost per hectare were tested statistically to show if they differ significantly from the ones from the Hunt-Wilson model. When farm size is varied, the implement widths and costs from the 3 model are compared with the basal widths and corresponding costs. The null hypothesis ($H_o$) was 'there is no significant difference in the samples tested'. See Equation 3.123. ANOVA statistical analysis tested the differences in sample means by testing the differences in variances. 0.05 level of

$$H_0 = w_{meanL} = w_{meanZ} = w_{meanH} \quad (3.123)$$

where:

$w_{meanL}=$¿ mean of implement widths obtained with operation labour cost-included model

$w_{meanZ}=$¿ mean of implement widths obtained with operation labour cost-excluded model

$w_{meanZ}=$¿ mean of implement widths selected with operation labour cost-included model

significance was used in the test Fs determination, and this corresponds to a 95 % confidence level. $H_o$ was rejected if the F-test value is higher than the F-critical. For the chosen 95 % confidence level of significance, a p-value of <0.05 means that $H_o$ should be rejected as that does not prove statistically that all the samples are from the same population.

For more than 2 groups of data ANOVA can show if there is a significant difference between all the groups but cannot indicate which pair of the groups the difference emanate from. Tukeys pairwise test show whether there is a significant difference as well as show which pairs of data have the difference in a single test. If the Tukeys statistics Q-test value is higher than the Q-critical the pair is seen as significantly different (Bluman, 2004). The ratio of the obtained width to farm size was employed for ANOVA statistical analysis so as to bring the obtained width variables to a common basis for mean determination and thereby, a reliable ANOVA testing. Also the ratio of the annual machinery cost per hectare was used as the common basis for ANOVA testing. The Q statistic is synonymous with the F statistic and the test value was obtained as

$$Q=\frac{\acute{X}_L-\acute{X}_S}{\sqrt{\frac{MS_{error}}{n}}} \qquad (4.124)$$

where:

$\acute{X}_L$ = the larger mean of the two samples being compared,

$\acute{X}_S$ = the smaller mean of the two samples being compared,

$MS_{error}$= the mean square error.

$n$ = total number the samples being tested, (Bluman, 2004).

The annual machinery cost predicted by the models was evaluated based on locally available implements' local operation speeds, field efficiencies and their local market prices.

### 3.14 Minimizing total machinery transport distance

In developing the model for minimizing total machinery transport distance the following assumptions were made:

-A single server multiple-customer situation exists.

-The distance to any of the farm or the base from any farm is known.

-All the farms are ready for operation within the required period.

-The farms can be visited in any order.

-The machine leaves the base and does not return until all the farms are processed.

-A farm that has been processed will not be visited again.

5 hypothetical small farms and 1 very small one varying 1.9 ha to 19.9 ha in size were pooled together. The small farms sizes and their inter-farm distances are shown in Table 3.9. Their distances from the machinery base are also shown in the same table. The shortest route

Table 3.9: Sizes and inter-farm transport distances of the small farms in km

| Source / Destination ($k/j$) | Farm Size (ha) | Inter-locations Distance (km) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Machinery Base (1) | Farm 1 (2) | Farm 2 (3) | Farm 3 (4) | Farm 4 (5) | Farm 5 (6) | Farm 7 (7) |
| Machinery Base (1) | na | 0 | 2.82 | 2.47 | 1.29 | 1.34 | 2.06 | 1.66 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Farm 1 (2) | 1.9 | 2.82 | 0 | 0.78 | 3.87 | 3.38 | 1.91 | 1.24 |
| Farm 2 (3) | 19.2 | 2.47 | 0.78 | 0 | 3.35 | 2.77 | 1.14 | 1.24 |
| Farm 3 (4) | 19.5 | 1.29 | 3.87 | 3.35 | 0 | 0.78 | 2.53 | 2.84 |
| Farm 4 (5) | 19.7 | 1.34 | 3.38 | 2.77 | 0.78 | 0 | 1.83 | 2..53 |
| Farm 5 (6) | 19.8 | 2.06 | 1.91 | 1.14 | 2.53 | 1.83 | 0 | 1.73 |
| Farm 6 (7) | 19.9 | 1.66 | 1.24 | 1.24 | 2.84 | 2.53 | 1.73 | 0 |

through the scattered *m* farms from a single machinery base was formulated as the LP transportation model in Equation 3.125.

$$Minimize\ D = \sum_{k,j=1}^{m+1} C_{kj} D_{kj} \qquad \forall\ defined\ arcs\ k, j \qquad (3.125),$$

subject to the flow conservation constraint and the non-negativity constraint in Equations 3.126 and 3.127.

$D_{kj}$ = length of path $k, j$

$C_{kj}$ = amount of flow from farm $k$ to farm $j$

$$= \begin{cases} 1, if\ arc(k, j)\ is\ on\ the\ shortest\ route \\ \text{¿}\ 0, otherwise \end{cases}$$

$$\begin{pmatrix} External\ input \\ into\ node\ j \end{pmatrix} + \sum_{k=1}^{m} C_{kj} = \begin{pmatrix} External\ output \\ \text{¿}\ node\ j \end{pmatrix} + \sum_{k=1}^{m} C_{kl}\ ;\ \forall\ defined\ arcs\ k, j \qquad (3.126)$$

$$D_{kj} \geq 0 \qquad (3.127)$$

$$k \neq j \qquad (3.128)$$

where *k* is the $k^{th}$ source, *j* is the $j^{th}$ destination and *l* is the next flow destination from *j*. Since the machinery will be transported from the base through the *m* farms and back to the base, there will be *m+1* sources and *m+1* destinations.

The Dijkstra's Algorithm (Taha, 2007) was employed for the solution, and follows the steps outlined below.

'Let $u_k$ be the shortest distance from the source node 1 to node *k*., and define $D_{kj}(\geq 0)$ as the length of arc (*k,j* ). …the algorithm defines the label for an immediately succeeding node as

$$[u_j, k] = [u_k + D_{kj}, k], D_{kj} \geq 0\text{'} \qquad (3.129).$$

The starting node is labelled ¿, which signifies that the node has no predecessor.

The Dijkstra's Algorithm assigns either a temporary or permanent status to each node label. A temporary label is modified when a shorter route to a node is found. A permanent status is assigned a temporary label if no better route can be found.

'**Step 0**: Label the source node (node 1) with the *permanent* label ¿ Set $k=1$.

**Step *k***: **(a)** Compute the *temporary* labels for $\left[u_k + D_{kj}, k\right]$ for each node *j* that can be reached from node *k*, provided *j* is not *permanently labelled*. If node *j* is already labelled with $\left[u_j, l\right]$ through another node *k* and if $u_k + D_{kj} < u_j$ replace $\left[u_j, l\right]$ with $\left[u_k + D_{kj}, k\right]$.

**(b)** If all the nodes have *permanent* labels stop. Otherwise select the label $\left[u_r, l\right]$ having the shortest distance (¿ $u_r$) among all the temporary labels (break ties arbitrarily). Set *k* = *r* and repeat step *k*.'

The iterations for solving the Dijkstra Algorithm can be generated in TORA (Temporary Organized Routing Algorithm) computer modeling platform (Taha, 2007). From the SOLVE/ MODIFY menu, select Solve problem – Iterations – Dijkstra algorithm, see Appendix D1. The farms matrix of the nodes flow constraint parameters extracted from the TORA model is shown in Figure 3.10 and Appendix D. The flow parameter $C_{kj}$ is denoted as $X$ in TORA in accordance with TORA notation.

| | | N1 | N2 | N3 | N4 | N5 | N6 | N7 | N8 | N9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | Min. | *C 17* | *C 14* | *C 45* | *C 47* | *C 56* | *C 63* | *C 23* | *C 27* |
| N1 | Min. | | 1.66 | 1.29 | 0.78 | 2.84 | 1.83 | 1.14 | 0.78 | 1.24 |
| N2 | *C 17* | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N3 | *C 14* | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N4 | *C 45* | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N5 | *C 47* | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 |
| N6 | *C 56* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 |
| N7 | *C 63* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 |
| N8 | *C 23* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 |
| N9 | *C 27* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |

Figure 3.10: Flow constraint model for Dijkstra Algorithm in TORA model

# CHAPTER FOUR

# RESULT AND DISCUSSION

To reduce wordiness the models names are reported as notations namely: L- for the variant developed in the study with operation labour cost considered, Z- for the variant that did not consider operation labour cost and H- for the Hunt-Wilson model. The effect of the model variables on the tillage machinery size selected and the annual machinery costs incurred was reported based on 420 ha farm size when parameters other than farm size were varied. The models results were evaluated in this study at the following operation speed and field efficiencies: 5.3 km/hr and 0.65 for plough, 6.4 km/hr and 0.69 for harrow and 4.5 km/hr and 0.66 for ridger.

## 4.1 Machinery Costs

The fixed cost factor (γ) employed in the model was estimated from the fixed cost factors parameters (see Equation 4.1) and shown in Table 4.1. Interest rate used was 6.56 %, and lump shelter, insurance and taxes rate utilized was 7%. The economic life employed for the

$$\gamma = 100\left[\frac{0.9}{L} + 0.55 \times 0.065 + 0.07\right] \qquad (4.1)$$

machinery depreciation in the study (see Table 4.1) was based on the experience of the Ministry of Agriculture, Mechanization, Processing and Export, Anambra State Nigeria. 10 years was employed for Massey Ferguson Tractors and 6 years for Mahindra tractors and other tractors in that class. It can be seen from Table 4.1 that the Mahindra class tractor of 48.5 kW sold for ₦3.5m as against ₦5.5m for a Massey Ferguson (MF) tractor of the same size. The Mahindra class tractor however had a ₦10,824.74 annual depreciation per kW which is higher than the ₦10,206.18 per kW for MF 425 tractor having the same size. This demonstrates that the cheapest initial investment-cost option is not always the least-cost option and the high production cost disadvantage that capital poverty leads investors into. Small-scale investors, especially those in capital-poor-developing countries suffer this disadvantage more. This shows the necessity of doing a proper economic analysis of investments and production equipment alternatives.

The tillage implements annual depreciation per machine size did not all corroborate with this inference. The cheaper 3-Bottom plough had a higher annual depreciation of ₦208,333.33/m (₦604,838.70 hr/ha) than the costlier 4-Bottom plough with a lower annual depreciation of ₦181,250.00/m (₦530,487.80 hr/ha), supporting the inference. The 20-Disc Harrow annual

Table 4.1: Some local cost factors / parameters related to the model

| Fixed Cost Parameters | | | | |
|---|---|---|---|---|
| Machine | Purchase Price P (₦m) | Economic Life $\Gamma$ (Years) | Price/ PTO Power OR Price/Capacity | Annual Depreciation Per Machine Size |
| Tractors | | | | |
| MF 425 | 5.5 | 10 | ₦113,402.06/kW | ₦10,206.18/kW |
| MF 435 | 6.0 | 10 | ₦111,731.84/kW | ₦10,055.86/kW |
| MF 440 | 8.0 | 10 | ₦130,932.89/kW | ₦11,789,39/kW |
| MF 470 | 12.5 | 10 | ₦130,932.89/kW | ₦11,789,39/kW |
| Mahindra 406D, Swaraj 780 | 3.5 | 6 | ₦72,164.94/kW | ₦10,824.74/kW |
| Implements | | | | |
| 3-BottomPlough | 1.25 | 6 | ₦1388888.88 /m<br>₦4032258.00 hr/ha | ₦208,333.33 /m<br>₦604,838.70 hr/ha |
| 4-Bottom Plough | 1.45 | 6 | ₦1,208333.33/m<br>₦3,536585.53hr/ha | ₦181,250.00 /m<br>₦530,487.80 hr/ha |
| 20-Disc Harrow | 1.31 | 6 | ₦770588.23 /m<br>₦1744991.47 hr/ha | ₦115,588.23 /m<br>₦262,000.00 hr/ha |
| 24-DiscHarrow | 1.65 | 6 | ₦785714.28 /m<br>₦1779244.30 hr/ha | ₦117,857.14 /m<br>₦266,129.03 hr/ha |
| 4-Disc Ridger | 1.255 | 6 | ₦865517 /m<br>₦2200828 hr/ha | ₦94,123.00 /m<br>₦176,062.47 hr/ha |
| Fixed Cost Factors ^ (%) | | | | |
| Total Fixed Costs Factor γ | | MF Tractors<br>Other Machinery | 19.61<br>24.61 | Not Applicable |

^ Values are percentages of 2016 equipment purchase prices.

depreciation was ₦115,588.23/m (₦262,000.00 hr/ha) and that of the 24-Disc Harrow was ₦117,857.14/m (₦266,129.03 hr/ha), contrary to the inference. As for the Disc Ridger, only the 4-Disc Ridger with ₦94,123.00 /m (₦176,062.47 hr/ha)was available in the local market and could not afford such comparison for this study. Thus each cost situation should be treated on its own merits.

### 4.1.1 Machinery operations parameters

Other parameters relevant to the annual machinery cost model collected in the study are presented in Table 4.2. The tillage operations carried out in some of the studied farms gave the operations parameters shown in Table 4.2. The tillage depth sand the operation speeds were: 18.5 cm and 5.3 km/hr for ploughing, 12.5 cm and 6.4 km/hr for harrowing and 19.8 cm and 4.5 km/hr for ridging. Their field efficiencies were 0.65, 0.69 and 0.66 for ploughing, harrowing and ridging operations respectively while the field capacities were 0.310 ha/hr, 0.7507 ha/hr and 0.5346 ha/hr in the same order. These operation parameters were close to the ones reported by Oduma *et al* (2015) from their field experimentation in Ebonyi State,

Table 4.2: Field tillage operations parameters

| Machinery /Parameter | Haulage | Plough | Harrow | Ridger |
|---|---|---|---|---|
| Working Width (m) | Na | 0.9 | 1.7 | 1.8 |
| Tillage Depth (cm) | Na | 18.5 | 12.5 | 19.8 |
| Working Speed (km/hr) | Na | 5.3 | 6.4 | 4.5 |
| Field Efficiency (decimal) | Na | 0.65 | 0.69 | 0.66 |
| Field Capacity (ha/hr) | Na | 0.3100 | 0.7507 | 0.5346 |
| Size of Tractor Used (kW) | 48.5 | 48.5 | 61.1 | 61.1 |
| Field Size Processed (ha) | | 126 | 556.8 | 97 |
| Annual Field Operations Hours (hr) | | 406.45 | 741.71 | 170.12 |
| Annual Haulage/ Machinery Transport Hours (hr) | 70 | 10.86 | 12.29 | 11.83 |
| Percentage of Tractor Hours Used for Operations (%) | 14.36 | 83.41 | 79.25 | 18.18 |
| Percentage of Tractor Hours Used for Machine Transport (%) | | 2.23 | 1.31 | 1.26 |

south eastern Nigeria. Their experimental results were 75.73 % efficiency for ploughing operation at 5.54 km/hr speed and 24.1 cm depth, 82.11 % efficiency for harrowing at 6.66 km/hr and 22.7 cm, and 77.92 % efficiency for ridging at 5.98 km/hr and 25.7 cm.

For this study the machinery transport hours were evaluated as 10.86 for ploughs, 12.29 for harrows and 11.83 for ridgers for the annual machinery transport distance of 596 km. The annual haulage operations hours were 70 hours. Haulage and ploughing operations were powered by the 48.5 kW tractors and used 14.36 % and 83.41 % of the tractor hours respectively while the plough machinery transportation took the remaining 2.23 %. The harrowing and ridging operations on the other hand were carried out with the 61.1 kW tractors. Their annual tractor use hours percentage were 79.25 % and 18.18 %, while their machinery transportation constituted 1.31 % and 1.26 % of the tractor use hours respectively.

### 4.1.2 Effect of field soil factors on annual machinery cost and selected machine size

The effect of the studied farms' soil texture draught factors on tillage power requirement is reported for the ploughing, harrowing and ridging operations.

I) Effect of soil type on required plough power and plough's power loading on tractor: The effect of the soil texture class on the required power for ploughing operation is shown in Table 4.3. The percentage power load of the ploughing operation on a 48.5 kW tractor is also

Table 4.3 Predicted plough width and machinery costs per hectare for varying soil types

| Field Location Type | Field Soil Class | Required Tillage Power (kW) | % Power Loading (%) | Selected Plough Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| A | Clay Loam | 27.40 | 58.8 | 0.9988 | 0.5588 | 1.7275 | 8965.36 | 10253.14 | 8059.75 |
| B | Sandy Loam | 11.58 | 24.9 | 0.7837 | 0.2235 | 1.2738 | 7611.54 | 13713.98 | 6485.23 |
| C | Loam | 13.13 | 28.2 | 0.8534 | 0.3386 | 1.4627 | 8055.41 | 11185.36 | 6749.45 |

shown in Table 4.3. At constant ploughing speed (5.3 km/hr) and depth (18.5 cm), the fields with similar soil types from different locations required the same plough power as can be seen in the table. They also exerted the same percentage power loading on any given tractor size, as shown in Figure 4.1B. Thus fields in locations with type A (clay loam) soil; as in Igbariam, Anambra West and Omor required 27.40 kW ploughing power. This translated to a 58.8 % power loading on a 48.5 kW nominal power (ie 46.6 kW PTO power) tractor. Type B (sandy loam) soils as in Achalla, Ugbene, Umunze, Omogho and Ukpor required 11.58 kW for ploughing which requires 24.9 % of a 48.5 kW tractor power (ie a 24.98% power loading). The type C loam soils- such as in Omasi and Ihiala required 13.13 kW tractor power, which translated to 28.2 % power loading on a 48.5 kW tractor.

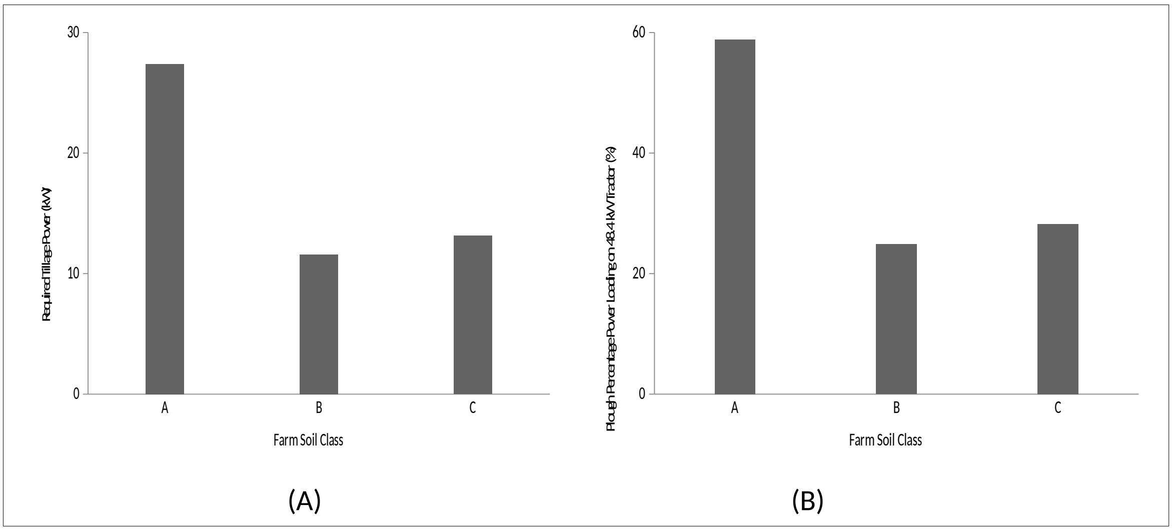



Figure 4.1: (A) Required plough power and percentage power load (B) on a 48.5 kW tractor for the studied farm soil types

II) Effect of farm soil type on selected plough size and plough machinery cost: The minimum-cost plough width selected with the models and the corresponding annual machinery cost for a 420 ha farm was considered for each studied location. The result is shown in Table 4.3 and Figure 4.2. A plough width of 0.9988 m was derived from the capacity selected by the developed L- model for the studied locations having type A *ie* clay loam soil. The developed Z- model gave 0.5588 m, and the H- model selected 1.7275 m for such soil type. Type B- sandy loam soil gave plough widths of 0.7837 m, 0.2235 m and

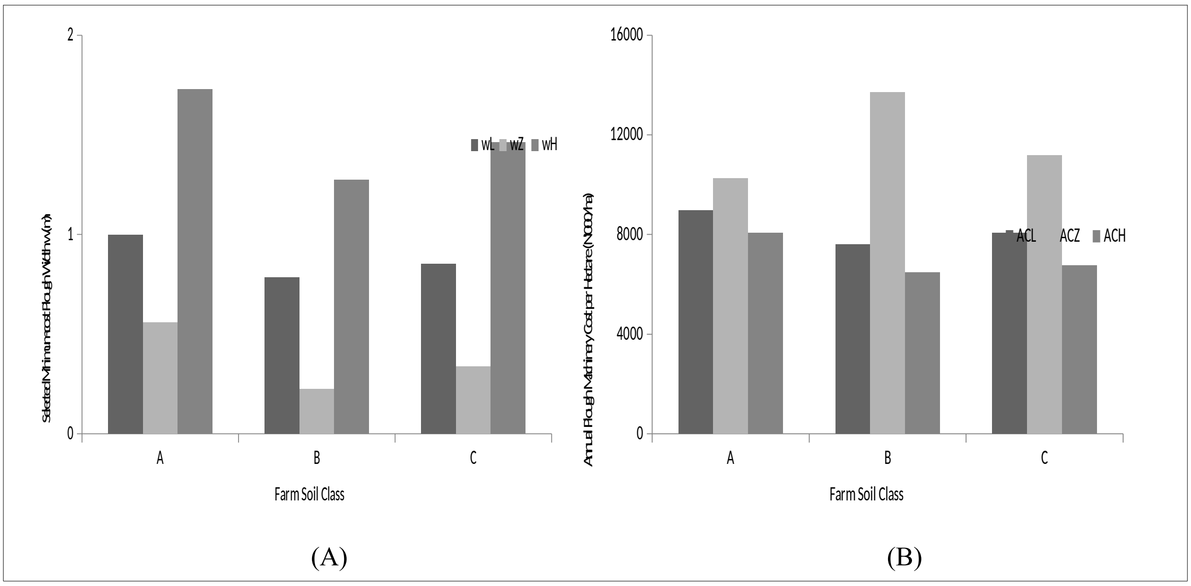



Figure 4.2: Selected minimum-cost plough width (A) and annual plough machinery cost per hectare (B) for a 420 ha farm in the concerned soil types

1.2738 m with L-, Z- and H- models respectively. Type C- loam soils gave 0.8534 m, 0.3386 m and 1.4627 m with the 3 models in the same order. The foregoing shows that when fuel, tractor and implement prices remain constant, soil draught factors are the most influential model parameters in tillage equipment capacity selection for a given farm size.

The annual plough machinery costs obtained for each of the studied locations soil types for a 420 ha farm size are shown in Table 4.3 and Figure 4.2. The plough machinery cost per hectare was ₦8,965.36 for the clay loam type A soils based on L- model cost. It was ₦10,253.14 based on the Z- model and ₦8,059.75 based on the H- model. Type B- sandy loam soils had annual machinery cost per hectare of ₦7,611.54, ₦13,713.98 and ₦6,485.23 with the L-, Z- and H- models, respectively. For the type C- loam soils of Omasi and Ihiala, the corresponding annual plough machinery cost was ₦8,055.41, ₦11,185.36 and ₦6,749.45 with the L-, Z- and H- models respectively. The obtained results show that soil draught factors affect the annual machinery cost predicted by the studied tillage cost equations.

III) Effect of soil type on required harrow power and harrow power loading on tractor: The effect of the soil texture class on the required power for harrowing operation is shown in Table 4.4. The percentage power load of the ploughing operation on a 61.1 kW tractor is also

Table 4.4 Predicted harrow width and machinery costs per hectare for varying soil types

| Field | Field | Required | % Power | Selected Harrow Width | Annual Machinery Cost |
|---|---|---|---|---|---|

| Location Type | Soil Class | Tillage Power (kW) | Loading (%) | *w* (m) | | | per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $w_L$ | $w_Z$ | $w_H$ | $AC_{wL}$ | $AC_{wZ}$ | $AC_{wH}$ |
| A | Clay Loam | 46.07 | 78.5 | 2.3641 | 1.7951 | 2.2804 | 5144.13 | 5150.65 | 4970.39 |
| B | Sandy Loam | 18.79 | 32.0 | 1.5649 | 0.7089 | 1.6774 | 4240.43 | 5213.43 | 3937.82 |
| C | Loam | 21.77 | 37.1 | 1.8003 | 1.0545 | 1.9128 | 4698.47 | 5039.59 | 4377.63 |

shown in Table 4.4. At constant harrowing speed (6.4 km/hr) and depth (12.5 cm), the fields with similar soil types from different locations required the same harrow power as can be seen in Table 4.4 and Figure 4.3A. They exerted the same percentage power loading on any given tractor size, as shown in Figure 4.3B. Thus fields in locations with type A (clay loam) soil; as in Igbariam, Anambra West and Omor required 46.07 kW harrowing power. This translated to a 78.5 % power loading on a 61.1 kW nominal power (*ie* 58.7 kW PTO power) tractor. Type B (sandy loam) soils as in Achalla, Ugbene, Umunze, Omogho and Ukpor required 18.79 kW for harrowing which requires 32 % of a 61.1 kW tractor power. The type C loam soils- such as in Omasi and Ihiala required 21.77 kW tractor power, which translated to 37.1 % power loading on a 61.1 kW tractor.

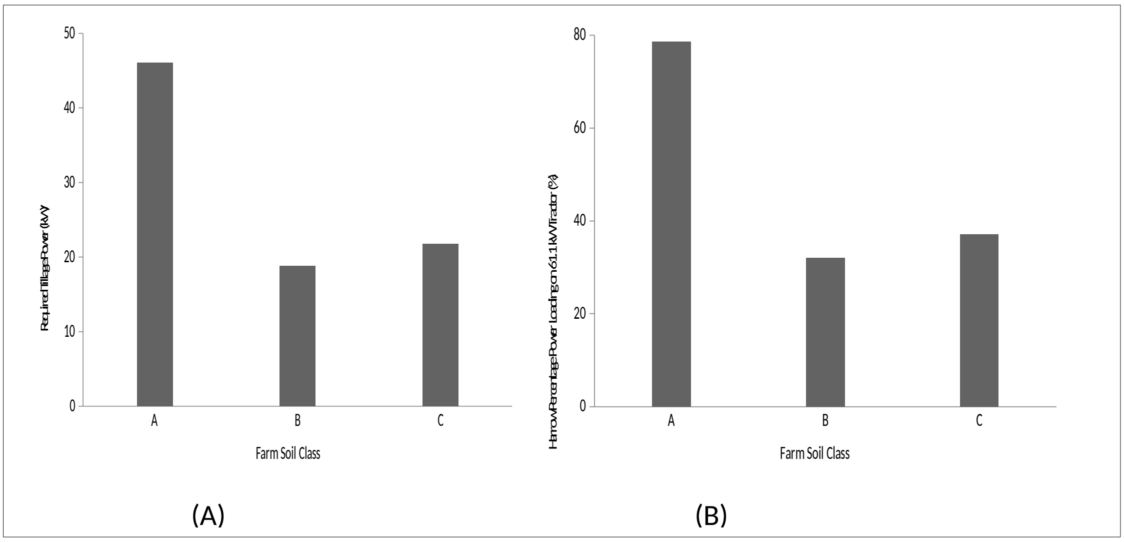



Figure 4.3: Required harrow power (A) and percentage power load (B) on a 61.1 kW tractor for the studied farm soil types

IV) Effect of farm soil type on selected harrow size and harrow machinery cost: The minimum-cost harrow width selected with the models and the corresponding annual machinery cost for a 420 ha farm was considered for each studied location. The result is shown in Table 4.4 and Figure 4.4A. A harrow width of 2.3641 m was obtained with the developed L- model for the studied locations having type A *ie* clay loam soil. The developed Z- model gave 1.7951 m, and the H- model selected 2.2804 m for such soil type. Type B- sandy loam soil gave harrow widths of 1.5649 m, 0.7089 m and 1.6774 m with

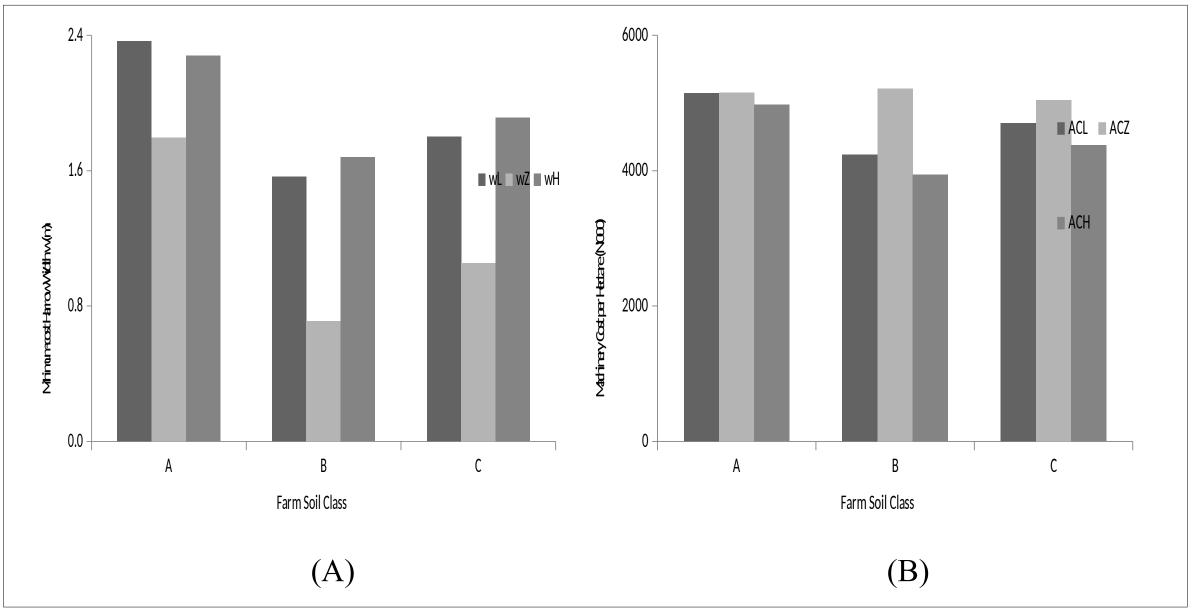



Figure 4.4: Selected minimum-cost harrow width (A) and annual harrow machinery cost per hectare (B) for a 420 ha farm in the studied soil types

the L-, Z- and H- models respectively. Type C- loam soils gave 1.8003 m, 1.0545 m and 1.9128 m with the 3 models in the same order. The foregoing shows that when fuel, tractor and implement prices remain constant, soil draught factors are the most influential model parameters in tillage equipment capacity selection for a given farm size.

The annual harrow machinery costs obtained for each of the studied locations soil types for a 420 ha farm size are shown in Table 4.4 and Figure 4.4B. The harrow machinery cost per hectare was ₦7,225.88 for the clay loam type A soils based on L- model cost. It was ₦7,850.78 based on the Z- model and ₦6,885.03 based on the H- model. Type B- sandy loam soils had annual machinery cost per hectare of ₦6,556.83, ₦9,172.56 and ₦6,179.97 with the L-, Z- and H- models, respectively. For the type C- loam soils of Omasi and Ihiala, the corresponding annual harrow machinery cost was ₦6,877.73, ₦8,214.08 and ₦6,475.74 with the L-, Z- and H- models respectively. The obtained results show that soil draught factors affect the annual machinery cost predicted by the studied tillage cost equations.

V) Effect of soil type on required ridger power and ridger's power loading on tractor: The effect of the soil texture class on the required power for ridging operation is shown in Table 4.5. The percentage power load of the ridging operation on a 61.1 kW tractor is also shown in Table 4.5. At constant ridging speed (4.5 km/hr) and depth (19.8 cm), the fields with similar soil types from different locations required the same ridger power as can be seen

Table 4.5 Predicted ridger width and machinery costs per hectare for varying soil types

| Field Location Type | Field Soil Class | Required Tillage Power (kW) | % Power Loading (%) | Selected Ridger Width *w* (m) | | | Annual Machinery Cost per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $w_L$ | $w_Z$ | $w_H$ | $AC_{wL}$ | $AC_{wZ}$ | $AC_{wH}$ |
| A | Clay Loam | 47.03 | 80.2 | 2.0124 | 1.1964 | 2.3563 | 7225.88 | 7850.78 | 6885.03 |
| B | Sandy Loam | 20.37 | 34.7 | 1.5847 | 0.5490 | 1.8178 | 6556.83 | 9172.56 | 6179.97 |
| C | Loam | 22.78 | 38.8 | 1.7548 | 0.8191 | 2.0771 | 6877.73 | 8214.08 | 6475.74 |

in Table 4.3 and Figure 4.5A. They exerted the same percentage power loading on any given tractor size, as shown in Figure 4.5B. Thus fields in locations with type A (clay loam) soil; as in Igbariam, Anambra West and Omor required 47.03 kW ridging power. This translated to a 80.2 % power loading on a 61.1 kW nominal power (ie 58.7 kW PTO power) tractor. Type B (sandy loam) soils as in Achalla, Ugbene, Umunze, Omogho and Ukpor required 20.37 kW for ploughing which translated to 34.7 % of the 61.1 kW tractor power. The type C loam soils- such as in Omasi and Ihiala required 22.78 kW, which translated to 38.8 % power loading on a 61.1 kW tractor.

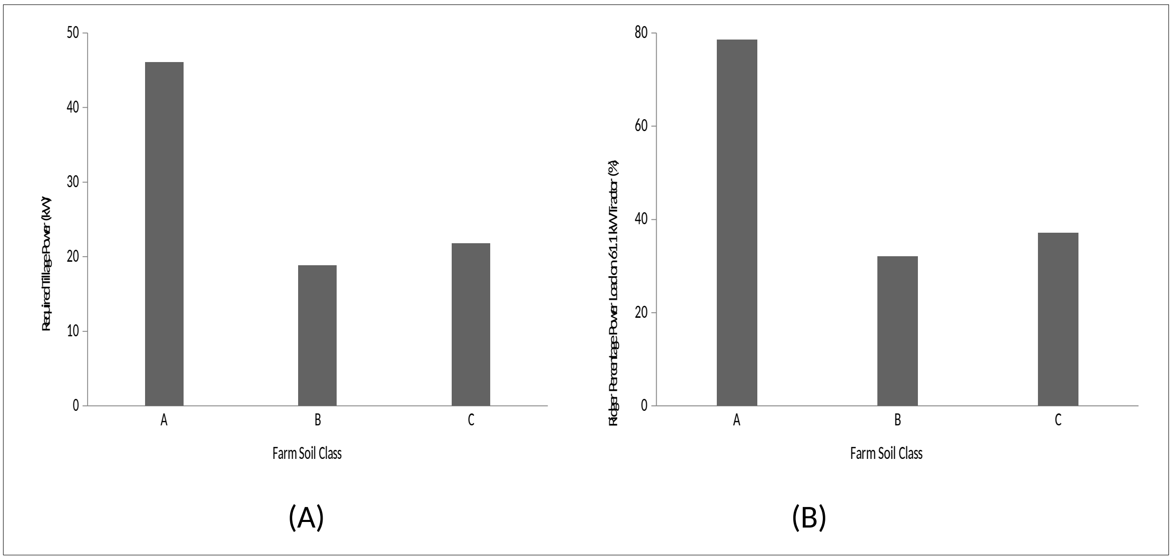



Figure 4.5: Required ridger power (A) and percentage power load (B) on a 61.1 kW tractor for the studied farm soil types

VI) Effect of farm soil type on selected ridger size and plough machinery cost: The minimum-cost plough width selected with the models and the corresponding annual machinery cost for a 420 ha farm was evaluated for each studied location. The result is shown in Table 4.5 and Figure 4.6A. A ridger width of 2.0124 m was obtained with the L- model for the studied locations having type A (ie clay loam) soil. The Z- model gave 1.2964 m, and the H- model selected 2.3563 m for such soil type. Type B- sandy loam soil gave ridger widths of

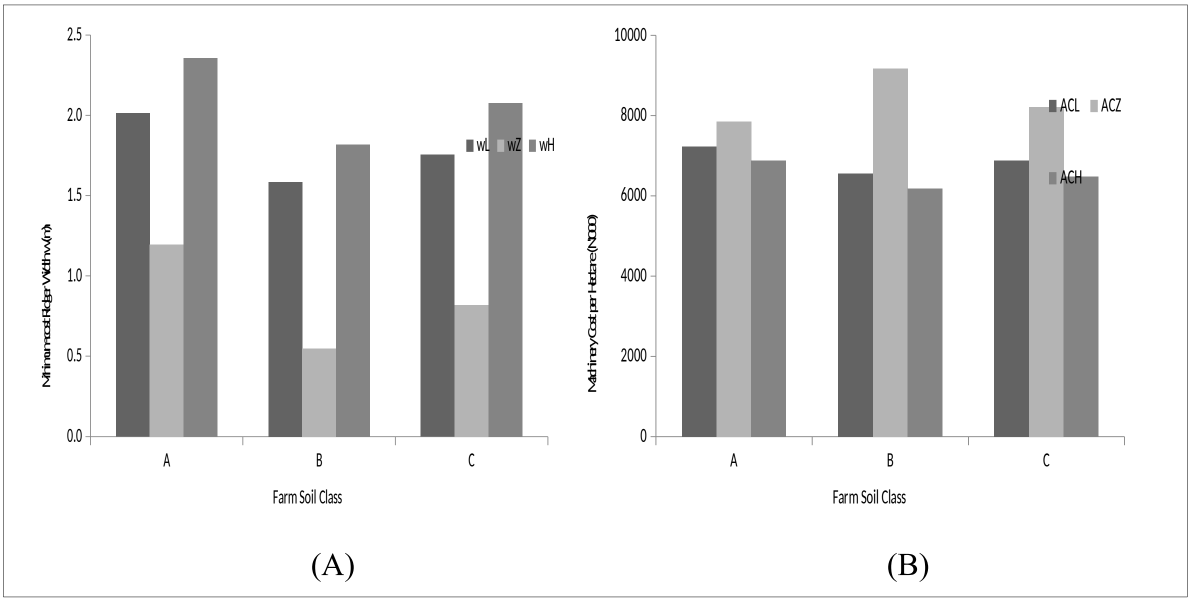



Figure 4.6: Selected minimum-cost ridger width (A) and annual ridger machinery cost per hectare (B) for a 420 ha farm in the studied soil types

1.5847 m, 0.5490 m and 1.8178 m with L-, Z- and H- models respectively. Type C- loam soils gave 1.7548 m, 0.8191 m and 2.0771 m with the 3 models in the same order. The foregoing shows that when fuel, tractor and implement prices remain constant, soil draught factors are the most influential model parameters in tillage equipment capacity selection for a given farm size.

The annual ridger machinery costs obtained for each of the studied locations soil types for a 420 ha farm size are shown in Table 4.5 and Figure 4.6B. The ridger machinery cost per hectare was ₦7,225.88 for the clay loam type A soils based on L- model cost. It was ₦7,850.78 based on the Z- model and ₦6,885.03 based on the H- model. Type B- sandy loam soils had annual machinery cost per hectare of ₦6,556.83, ₦9,172.56 and ₦6,179.97 with the L-, Z- and H- models respectively. For the type C- loam soils of Omasi and Ihiala, the corresponding annual ridger machinery cost was ₦6.877.73, ₦8,214.08 and ₦6,475.74 with the L-, Z- and H- models respectively. The obtained results show that soil draught factors affect the annual machinery cost predicted by the studied tillage cost models.

### 4.1.3 Effect of labour cost on annual machinery cost and selected machine size

The effect of changing labour cost on the minimum-cost tillage machine width selected with the models and the corresponding annual machinery cost was considered for a fixed farm size.

I) 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 per hectare changes in a 420 ha farm is shown in Table 4.6. The predicted minimum-cost width is also shown in Figure 4.7A, while the corresponding plough machinery cost per hectare is in Figure 4.7B. A plough width of 1.6663 m was derived from the capacity selected by the L-

Table 4.6: Predicted plough widths and machinery costs for varying labour rates

| Labour Rate $L$ (₦/hr) | Selected Plough Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 550.00 | 1.6663 | 0.8650 | 1.2738 | 6165.73 | 6709.88 | 6292.70 |
| 700.00 | 1.8059 | 0.8650 | 1.2738 | 6392.60 | 7213.28 | 6634.52 |
| 850.00 | 1.9327 | 0.8650 | 1.2738 | 6598.44 | 7716.67 | 6976.34 |
| 1000.00 | 2.0495 | 0.8650 | 1.2738 | 6788.20 | 8220.07 | 7318.16 |

model for ₦550.00 wages per hectare. The developed Z- model gave 0. 8650 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 Z- and H-models widths remained unchanged for labour rate changes.

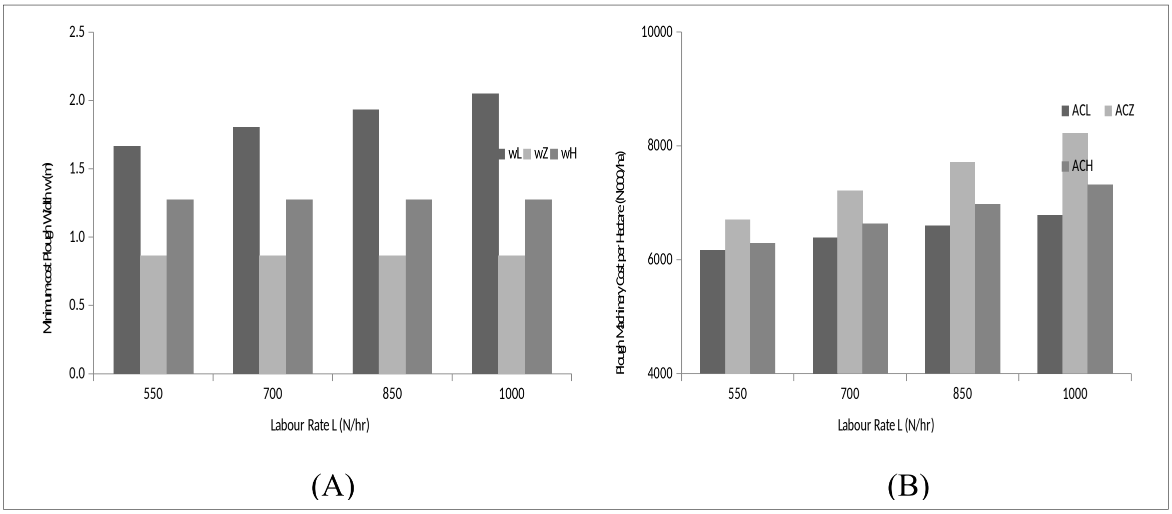



Figure 4.7: Selected minimum-cost plough width (A) and annual plough machinery cost per hectare (B) for varying labour rates

The plough machinery cost per hectare was ₦6,165.73 for ₦550.00 labour rate based on L- model cost. It was ₦6,709.88 based on the Z- model and ₦6,292.70 with the H- model for the same labour rate. The ₦700.00 labour rate gave annual machinery cost per hectare of ₦6,392.60, ₦7,213.28 and ₦6,634.52 with the L-, Z- and H- models, respectively. For the ₦850.00 labour rate, the corresponding annual plough machinery cost was ₦6,598.44,

₦7,716.67 and ₦6,976.34 with the L-, Z- and H- models respectively. For the ₦1,000.00 labour rate, the corresponding annual plough machinery cost was ₦6,788.20, ₦8,220.07 and ₦7,318.16 with the L-, Z- and H- models respectively. The obtained results showed that labour cost affect the annual plough machinery cost predicted by the tillage machinery models and the plough sizes predicted by the L- model.

II) Effect of changing labour cost on harrow machine size and machinery cost: The predicted annual harrow machinery cost per hectare and the minimum-cost width obtained when the labour rate per hectare changes for a 420 ha farm is shown in Table 4.7 and Figure 4.8A. A harrow width of 1.5086 m was derived from the capacity selected by the developed L- model for ₦550.00 wages per hectare. The developed Z- model gave 0. 8111 m, and the H- model

Table 4.7: Predicted harrow widths and machinery costs for varying labour rates

| Labour Rate (₦/hr) | Selected Harrow Width *w* (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 550.00 | 1.5086 | 0.8111 | 1.7536 | 4643.60 | 4980.56 | 4659.28 |
| 700.00 | 1.6319 | 0.8111 | 1.7536 | 4855.31 | 5399.36 | 4852.98 |
| 850.00 | 1.7438 | 0.8111 | 1.7536 | 5047.61 | 5818.16 | 5046.68 |
| 1000.00 | 1.8470 | 0.8111 | 1.7536 | 5225.03 | 6236.95 | 5240.38 |

selected 1.7536 m for the same labour rate. For ₦700.00, ₦850.00 and ₦1,000.00, labour rates the harrow widths were 1.6319 m, 1.7438 m and 1.8470 m respectively with the L-model. The Z- and H-models widths remained unchanged for changes in labour rate.

The harrow machinery cost per hectare was ₦4,643.60 for ₦550.00 labour rate based on the L- model width. It was ₦4,980.56 based on the Z- model and ₦4,659.28 based on the H-model for the same labour rate. The ₦700.00 labour rate gave annual harrow machinery cost per hectare of ₦4,855.31, ₦5,399.36 and ₦4,852.98 with the L-, Z- and H- models, respectively. For the ₦850.00 labour rate, the corresponding annual harrow machinery cost

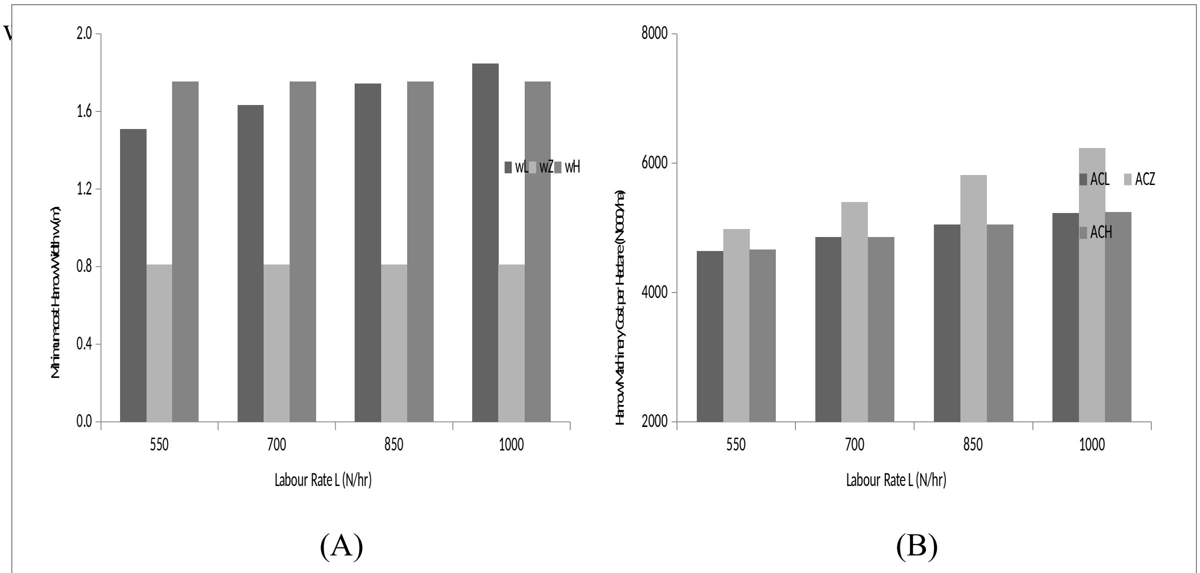


Figure 4.8: Selected minimum-cost harrow width (A) and annual harrow machinery cost per hectare (B) for varying labour rates

₦1,000.00 labour rate, the corresponding annual harrow machinery cost was ₦5,225.03, ₦6,236.95 and ₦5,240.38 with the L-, Z- and H- models respectively. The obtained results showed that labour cost affect the annual harrow machinery cost predicted by the tillage machinery models and the harrow sizes predicted by the L- model.

III) Effect of changing labour cost on ridger machine size and machinery cost: The predicted annual ridger machinery cost per hectare and the minimum-cost width obtained when the labour rate per hectare changes for a 420 ha farm is shown in Table 4.8. The minimum-cost

Table 4.8: Predicted ridger widths and machinery costs for varying labour rates

| Labour Rate (₦/hr) | Selected Ridger Width *w* (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 550.00 | 1.4428 | 0.5490 | 1.8178 | 6500.30 | 8206.65 | 6396.45 |
| 700.00 | 1.5847 | 0.5490 | 1.8178 | 6764.97 | 9126.67 | 6674.28 |
| 850.00 | 1.7127 | 0.5490 | 1.8178 | 7003.64 | 10046.70 | 6952.11 |
| 1000.00 | 1.8302 | 0.5490 | 1.8178 | 7222.75 | 10966.73 | 7229.94 |

ridger width is also shown in Figure 4.9A and the annual ridger machinery cost per hectare in Figure 4.9B. A ridger width of 1.4428 m was derived from the capacity selected by the L- model for ₦550.00 wages per hectare. The developed Z- model gave 0. 5490 m, and the H- model selected 1.8178 m for the same labour rate. For ₦700.00, ₦850.00 and ₦1,000.00, labour rates the plough widths were 1.5847 m, 1.7127 m and 1.8302 m respectively with the L- model. The Z- and H-models widths remained unchanged for changes in labour rate.

The plough machinery cost per hectare was ₦6,500.30 for ₦550.00 labour rate based on L- model cost. It was ₦8,206.65 based on the Z- model and ₦6,396.45 based on the H- model for the same labour rate. The ₦700.00 labour rate gave annual ridger machinery cost per hectare of ₦6,764.97, ₦9,126.67 and ₦6,674.28 with the L-, Z- and H- models, respectively. For the ₦850.00 labour rate, the corresponding annual ridger machinery cost was ₦7,003.64,

₦10,046.70 and ₦6,952.11 with the L-, Z- and H- models respectively. For the ₦1,000.00 labour rate, the corresponding annual ridger machinery cost was ₦7,222.75, ₦10.966.73 and ₦7,229.94 with the L-, Z- and H- models respectively. The obtained results showed that labour cost affect the annual ridger machinery cost predicted by the tillage machinery models and the ridger sizes predicted by the L- model.

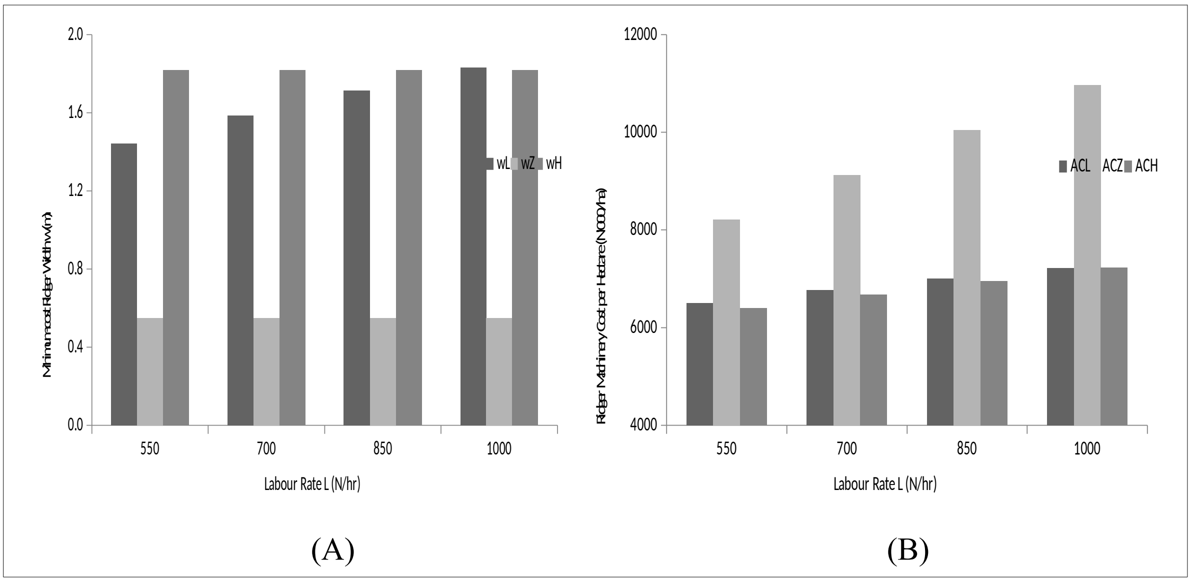



Figure 4.9: Selected minimum-cost ridger width (A) and annual ridger machinery cost per hectare (B) for varying labour rates

Generally the tillage machine width predicted by the L- model increased with increasing labour rate. In this way the labour use hours will decrease thereby limiting the increase in the labour cost that would have otherwise resulted from the labour rate increase. Increased machine size and cost will however lead to increased machine fixed cost, fuel consumption and required tractor size. This agrees with the findings of Srivastava *et al* (2006) that increasing the field machine size inreases the machinery cost but reduces labour cost. The Z- and H- models could not respond to the change in the labour rate. This can be attributed to the lack of consideration of the labour cost in the development of the Z- and H- models. The machinery cost per hectare corresponding to the macine widths obtained with each of the 3 models increased with increasing labour rate. The Z- model cost was the highest at each labour rate for all the tillage implements. The L- model gave the lowest cost for all the machinery at the ₦1,000.00 labour rate and for the plough machinery at all the labour rates. The H- model cost was the lowest for the harrow and ridger machinery at the lower rate.

**4.1.4 Models' circumvention of arbitrary machine capacity input in the width selection**

The effect of the change in the arbitrary prior field capacity value on the selectd machine width was reported in this subsection. The effect was presented and discussed for the plough, harrow and ridger machinery widths predicted for a fixed farm size of 420 ha.

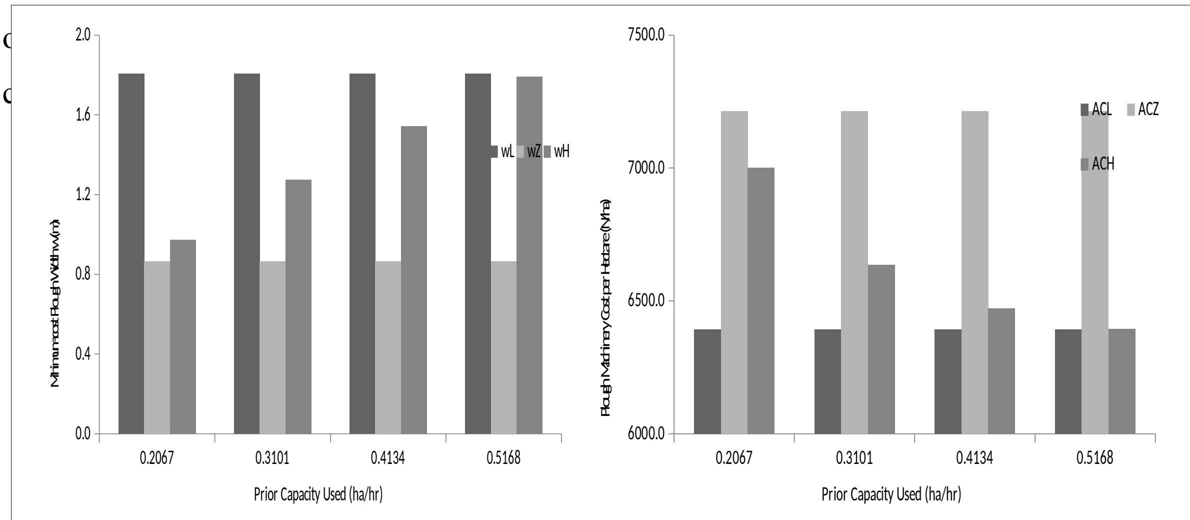
I) Effect of chosen prior field capacity change on predicted plough width and machinery cost: The predicted minimum-cost width and the corresponding annual plough machinery cost per hectare for changing prior field capacity for a 420 ha farm is shown in Table 4.9. The minimum-cost plough width is also shown in Figure 4.10A and the annual plough machinery

Table 4.9: Predicted plough widths and machinery costs for varying chosen prior capacities

| Prior Capacity used (ha/hr) | Equivalent Working Width $w$ (m) | Selected Plough Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|
| | | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 0.2067 | 0.6 | 1.8059 | 0.8650 | 0.9716 | 6392.60 | 7213.28 | 7001.08 |
| 0.3101 | 0.9 | 1.8059 | 0.8650 | 1.2738 | 6392.60 | 7213.28 | 6634.52 |
| 0.4134 | 1.2 | 1.8059 | 0.8650 | 1.5438 | 6392.60 | 7213.28 | 6471.26 |
| 0.5168 | 1.5 | 1.8059 | 0.8650 | 1.7923 | 6392.60 | 7213.28 | 6395.31 |

cost per hectare in Figure 4.10B. A plough width of 0.9716 m was predicted by the H- model for 0.2067 ha/hr prior plough capacity input. For 0.3101 ha/hr, 0.4134 ha/hr and 0.5168 ha/hr prior capacities input the selected plough widths were 1.2738 m, 1.5438 m and 1.7923 m respectively with the same H- model. These plough capacities corresponded to plough working widths of 0.6 m, 0.9 m, 1.2 m and 1.5 m respectively at the plough speed of 5.3 km/hr and field efficiency of 0.65 used. The L- and Z- models-predicted plough widths were 1.8059 m and 0.8650 m respectively, and remained unchanged for changes in prior plough capacity input.

The incurred plough machinery cost per hectare was ₦7,001.08, ₦6,634.52, ₦6,471.26, and ₦6,395.31 for the widths predicted with the H- model for the listed prior capacities in the same order. The cost per hectare was ₦6,392.60 based on the L- model and ₦7,213.28 based




(A) (B)

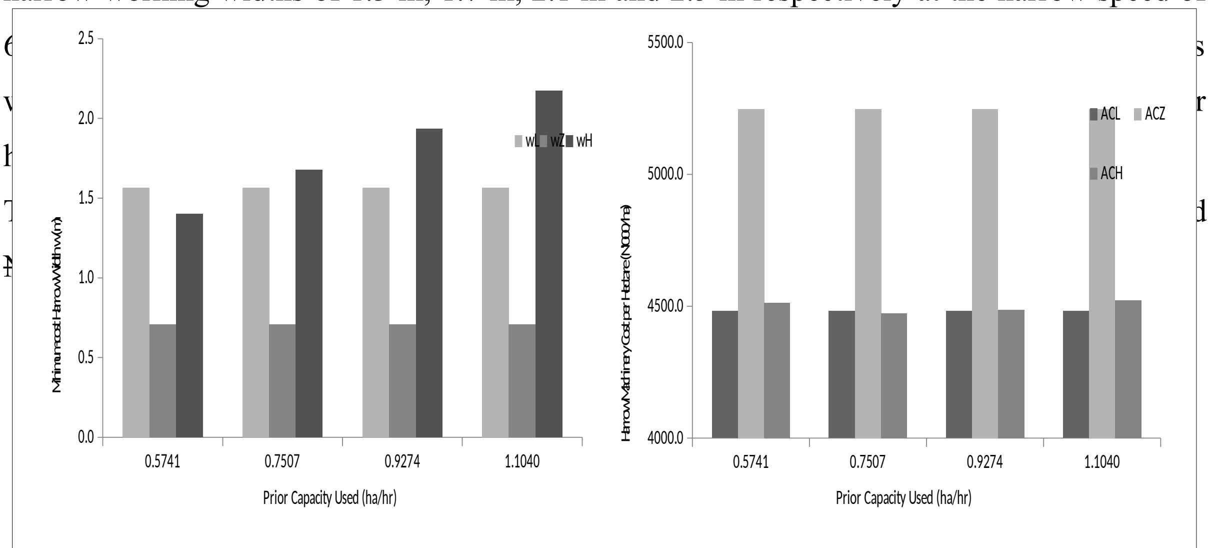
Figure 4.10: Selected minimum-cost plough width (A) and annual plough machinery cost per hectare (B) for varying chosen prior capacities

II) Effect of chosen prior field capacity change on predicted harrow width and machinery cost: The predicted annual harrow machinery cost per hectare and the minimum-cost width obtained when the labour rate per hectare changes for a 420 ha farm is shown in Table 4.10. The minimum-cost harrow width is also shown in Figure 4.11A and the annual harrow machinerycost per hectare in Figure 4.11B. A harrow width of 1.4016 m was predicted by the H- model for 0.5741 ha/hr prior harrow capacity input. For 0.7507 ha/hr, 0.9274 ha/hr and 1.1040 ha/hr prior capacities input the selected harrow widths were 1.6774 m, 1.9327 m

Table 4.10: Predicted harrow widths and machinery costs for varying chosen prior capacities

| Prior Capacity used (ha/hr) | Equivalent Working Width *w* (m) | Selected Harrow Width *w* (m) | | | Annual Machinery Cost per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|
| | | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 0.5741 | 1.3 | 1.5649 | 0.7089 | 1.4016 | 4481.92 | 5247.12 | 4512.60 |
| 0.7507 | 1.7 | 1.5649 | 0.7089 | 1.6774 | 4481.92 | 5247.12 | 4474.15 |
| 0.9274 | 2.1 | 1.5649 | 0.7089 | 1.9327 | 4481.92 | 5247.12 | 4485.85 |
| 1.1040 | 2.5 | 1.5649 | 0.7089 | 2.1726 | 4481.92 | 5247.12 | 4523.60 |

and 2.1726 m respectively with the same H- model. These harrow capacities corresponded to harrow working widths of 1.3 m, 1.7 m, 2.1 m and 2.5 m respectively at the harrow speed of




(A) (B)

Figure 4.11: Selected minimum-cost harrow width (A) and annual harrow machinery cost per hectare (B) for varying chosen capacities

same order. The cost per hectare was ₦4,481.92 based on the L- model and ₦5,247.12 based on the Z- model for the 0.5741 ha/hr prior capacity and remained unchanged for the other capacities.

III) Effect of chosen prior field capacity change on predicted ridger width and machinery cost: The predicted annual ridger machinery cost per hectare and the minimum-cost width obtained when the labour rate per hectare changes for a 420 ha farm is shown in Table 4.11. The minimum-cost ridger width is also shown in Figure 4.11A and the annual ridger machinery cost per hectare in Figure 4.11B. A ridger width of 1.1449 m was predicted by the H- model for 0.2673 ha/hr prior ridger capacity input. For 0.5346 ha/hr, 0.8019 ha/hr and 1.0692 ha/hr prior capacities input the selected ridger widths were 1.8178 m, 2.3826 m and 2.8869 m respectively with the same H- model. These ridger capacities corresponded to ridger working widths of 0.9 m, 1.8 m, 2.7 m and 3.6 m respectively at the ridger speed of4.5 km/hr and field efficiency of 0.66 used. The L- and Z- models-predicted ridger widths were 1.5847 m and 0.5490 m respectively, and remained unchanged for changes in prior ridger capacity input.

Table 4.11: Predicted ridger widths and machinery costs for varying chosen prior capacities

| Prior Capacity used (ha/hr) | Equivalent Working Width $w$ (m) | Selected Ridger Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦) | | |
|---|---|---|---|---|---|---|---|
| | | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| 0.2673 | 0.9 | 1.5847 | 0.5490 | 1.1449 | 6764.97 | 9126.67 | 7147.54 |
| 0.5346 | 1.8 | 1.5847 | 0.5490 | 1.8178 | 6764.97 | 9126.67 | 6674.28 |
| 0.8019 | 2.7 | 1.5847 | 0.5490 | 2.3826 | 6764.97 | 9126.67 | 6609.31 |
| 1.0692 | 3.6 | 1.5847 | 0.5490 | 2.8869 | 6764.97 | 9126.67 | 6652.93 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

The incurred ridger machinery cost per hectare was ₦7,147.54, ₦6,674.28, ₦6,609.31 and ₦6,652.93 for the widths predicted with the H- model for the listed prior capacities in the same order. The cost per hectare was ₦6,764.97 based on the L- model and ₦9,126.67 based on the Z- model for the 0.2673 ha/hr prior capacity and remained unchanged for the other capacities.

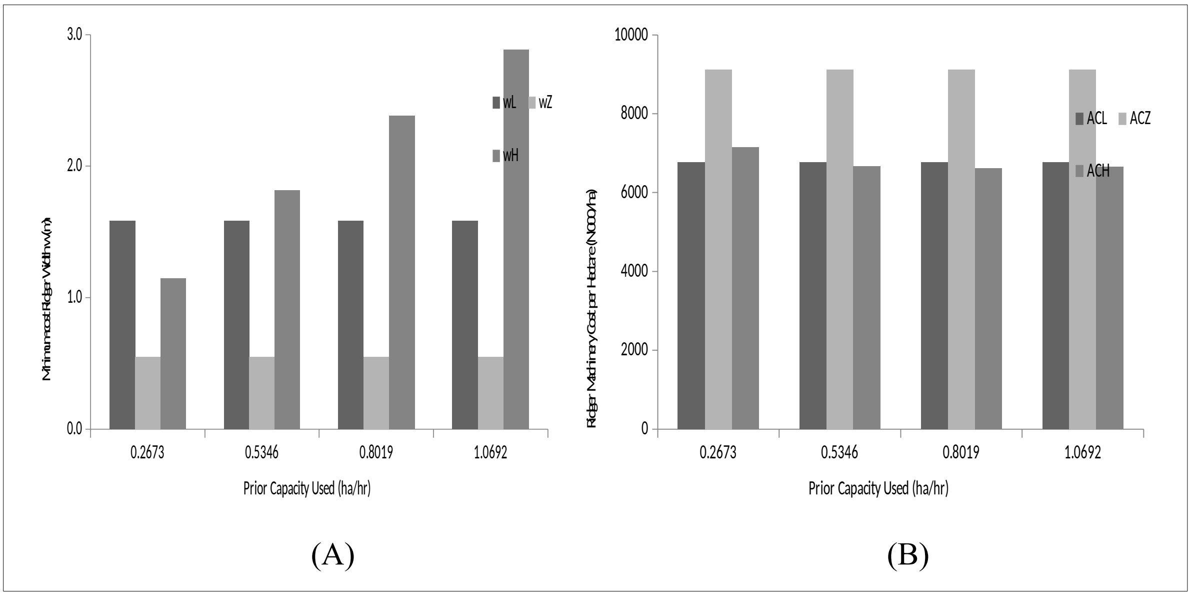



Figure 4.12: Selected minimum-cost ridger width (A) and annual ridger machinery cost per hectare (B) for varying chosen capacities

Generally the obtained results showed that the chosen prior tillage capacity affected the predicted tillage width for the H- model and that the choice of a proper prior capacity is needed to realize cost minimization with this model. The choice of a prior tillage capacity input was not needed for the L- and Z- models developed in the study. This shows that the developed models were more objective and less dependent on the user's experience.

### 4.2 Models Behaviour under Farm Size Variations

The effect of farm size and fuel price variations on the selected size of tillage machinery and their corresponding annual tillage machinery costs on heterogeneous soil-type pool farms were studied. The results are presented and discussed hereunder.

#### 4.2.1 Disc plough size and cost under farm size variations

For fragmented scattered farms, the disc plough widths derived from the developed minimum-cost models in the study for varying pool farm sizes are presented in Table 4.12 The plot of the plough widths for varying pool farm sizes is shown in Figure 4.12. It could be seen that a plough width ($w$) of 0.5481 m, 0.9740 m, 2.1009 m and 2.5997 m was derived from the minimum-cost plough capacity selected with the L- model for pool farm sizes ($A$) of 45, 145, 420 and 675 hectares respectively. Plough widths of 0.2251 m, 0.4242 m, 1.5880 m and 2.0579 m were obtained for the listed farm sizes in that order with the Z- model. The least-cost plough widths selected by the H- model are shown in Table 4.12 and plotted on Figure 4.13. They were 0.8186 m, 1.0201m, 1.5896 m and 1.7587 m for the same listed farm sizes in that order.

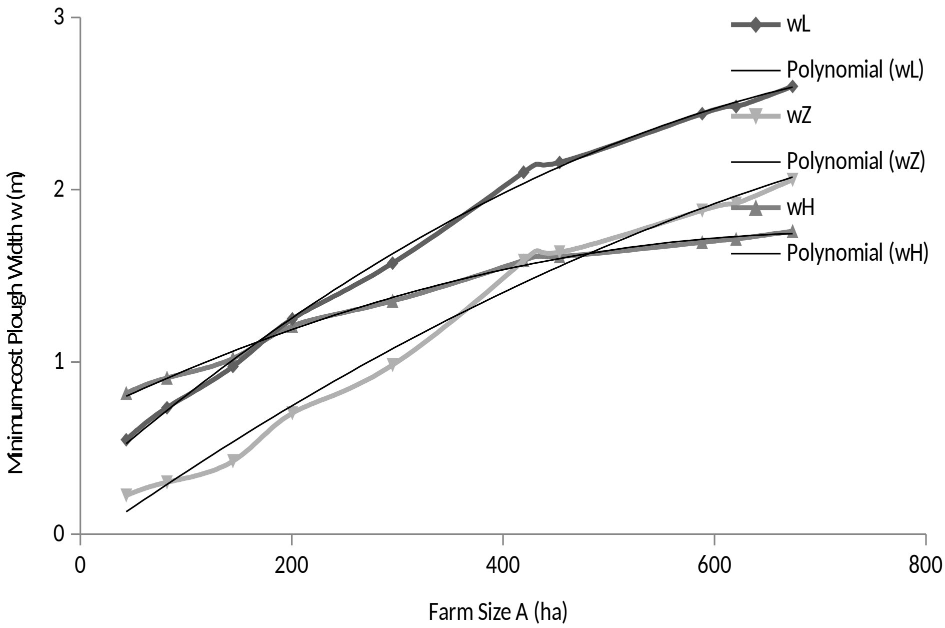



Figure 4.13: Plough width predictions by the various models for different farm sizes

Table 4.12: The disc plough sizes and minimum cost predictions of the various models under the different pool farm sizes

| Farm Area $A$ (ha) | Cum. Transpt Distnce $D$ (km) | Minimum-cost Plough Width | | | | | |
|---|---|---|---|---|---|---|---|
| | | Width $w$ (m) | | | Width to Farm Size Ratio | | |
| | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |
| 45 | 32 | 0.5481 | 0.2251 | 0.8186 | 0.0126 | 0.0052 | 0.0188 |
| 82 | 56 | 0.7343 | 0.3013 | 0.9071 | 0.0090 | 0.0037 | 0.0111 |
| 145 | 122 | 0.9740 | 0.4242 | 1.0201 | 0.0067 | 0.0029 | 0.0071 |
| 200 | 148 | 1.2491 | 0.7022 | 1.2081 | 0.0062 | 0.0035 | 0.0060 |
| 295 | 208 | 1.5733 | 0.9826 | 1.3539 | 0.0053 | 0.0033 | 0.0046 |
| 420 | 268 | 2.1009 | 1.5880 | 1.5896 | 0.0050 | 0.0038 | 0.0038 |
| 453 | 358 | 2.1582 | 1.6367 | 1.6124 | 0.0048 | 0.0036 | 0.0036 |
| 588 | 434 | 2.4411 | 1.8797 | 1.6943 | 0.0041 | 0.0032 | 0.0029 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 620 | 506 | 2.4825 | 1.9204 | 1.7133 | 0.0040 | 0.0031 | 0.0028 |
| 675 | 596 | 2.5997 | 2.0579 | 1.7587 | 0.0039 | 0.0031 | 0.0026 |
| | | | | | | | |
| Farm Area $A$ (ha) | Cum. Transpt Distnce $D$ (km) | Annual Plough Machinery Cost per Hectare | | | | | |
| | | Machinery Alone | | | Machinery and Transport | | |
| | | $AC_L$ | $AC_Z$ | $AC_H$ | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 32 | 12485.44 | 16470.60 | 12378.38 | 14631.99 | 18572.06 | 15266.59 |
| 82 | 56 | 10002.47 | 12994.49 | 9884.03 | 11775.47 | 14712.39 | 12352.44 |
| 145 | 122 | 8480.44 | 10452.75 | 8471.28 | 10477.10 | 12364.81 | 11338.81 |
| 200 | 148 | 8344.88 | 9062.20 | 8385.45 | 10064.84 | 10710.40 | 10882.50 |
| 295 | 208 | 7621.26 | 7981.46 | 7710.79 | 9228.29 | 9516.68 | 10070.45 |
| 420 | 268 | 7611.25 | 7650.97 | 7708.13 | 9053.37 | 9039.01 | 9850.51 |
| 453 | 358 | 7489.00 | 7523.10 | 7585.63 | 9253.16 | 9219.65 | 10217.12 |
| 588 | 434 | 7028.27 | 7051.76 | 7154.24 | 8667.58 | 8624.65 | 9610.63 |
| 620 | 506 | 6974.23 | 6991.91 | 7095.78 | 8780.49 | 8724.89 | 9807.31 |
| 675 | 596 | 6892.56 | 6891.91 | 7010.44 | 8844.86 | 8768.33 | 9948.93 |

Selection of higher plough widths was favoured for bigger pool farm sizes by the 3 models. It can be seen that the least-cost plough width selected by the H- model was higher than the widths obtained from the developed models for farm sizes lower than 145 ha. Also the plough width obtained for the L- model was higher than those of the H- model for each of the given farm sizes. It must be noted that the choice of the prior capacity affected the least-cost width selected by the H- model. The 1.2738 m obtained with the 0.3101 prior capacity used will become 1.7923 if a 0.5168 ha/hr capacity is used as previously shown in Table 4.9. The dependence of the selected width on the user's arbitrary capacity choice has been cited as a weakness in the H- model that this study is addressing.

The prediction of the plough width obtained for the 3 models with the farm size followed a 2nd order polynomial trend. The L- model trendline equation was as shown in Equation 4.2, and had an $R^2$ value of 0.998.

$$w_L = -3\times10^{-6}A^2 + 0.0054A + 0.2985 \quad (4.2)$$

For the Z- model trendline was as shown in Equation 4.3, and had an $R^2$ value of 0.9876.

$$w_Z = -2\times10^{-6}A^2 + 0.0044A + 0.057 \quad (4.3)$$

The H- model trendline equation was as shown in Equation 4.4, and had an $R^2$ value of 0.996.

$$w_H = -2\times10^{-6}A^2 + 0.003A + 0.6755 \quad (4.4)$$

Prediction of the plough width from a 2nd order polynomial expression of the farm size was most precise (99.8 % accuracy) for the L- model least precise (98.76 % accuracy) with the Z-model. The prediction accuracy for the H- model was 99.6 %.

The ratio of the minimum-cost plough width to their respective farm sizes for the 3 models are shown in Table 4.12. The ratio varied from 0.0039 to 0.0126, 0.0031 to 0.0031 and 0.0026 to 0.0188 for the L- model, the Z- model and the H- model respectively. For the 3 models, the ratio was highest for the smallest farm size and reduced as the farm size increased. Table 4.13 shows the ANOVA table of the statistical analysis of width-to-farm

Table 4.13: ANOVA table for statistical test on the developed models' and Hunt-Wilson model's plough widths-to-farm size ratio

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 4.89E-05 | 2 | 2.45E-05 | 2.161627 | 0.134651 | 3.354131 |
| Within Groups | 0.000306 | 27 | 1.13E-05 | | | |
| Total | 0.000354 | 29 | | | | |

size ratio for the 3 models at the 0.05 level of significance. The test F value of 2.1616 was lower than the F-critical of 3.3541, showing that the widths predicted by the developed models were not significantly different from the H- model widths for the farm sizes in question. Also the 0.1346 p-value obtained in the ANOVA test is greater than the 0.05 p-value for 95 % confidence level. This shows that the developed models predicted plough widths acceptably as does the H- model for the given farm sizes.

The annual plough machinery costs per hectare for varying farm sizes for the 3 models are also shown in Table 4.12, and plotted against varying farm sizes in Figure 4.14. The cost was ₦16,578.54, ₦10,670.67, ₦9,238.50 and ₦8,145.70 for the farm sizes (*A*) of 45 ha, 145 ha, 420 ha and 675 ha respectively for the L- model width. The annual plough machinery cost per hectare corresponding to the Z- model width was ₦18,151.45, ₦11,406.64, ₦8,880.93 and ₦7,883.90 for the same the listed farm sizes in that same order. For the H-model width it was ₦12,378.38, ₦8,471.28, ₦7,708.13 and ₦7,010.44 for the same the listed farm sizes in

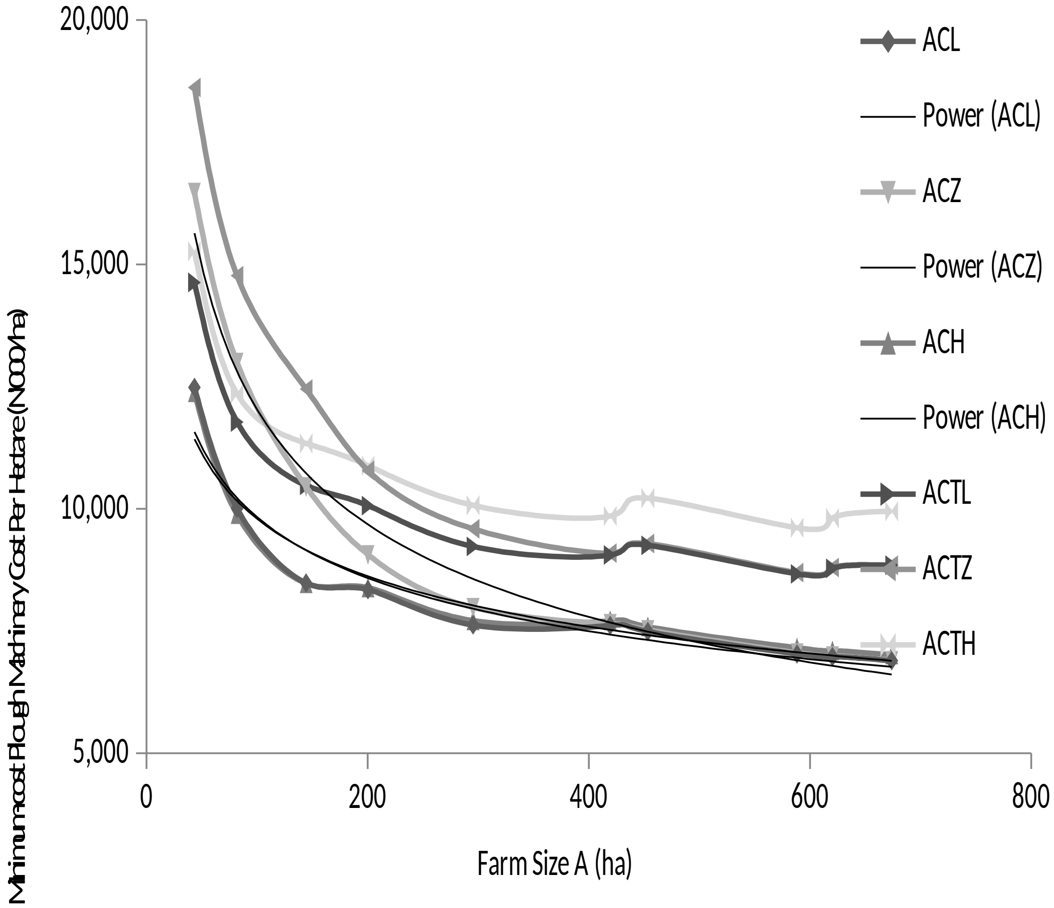



Figure 4.14: Annual plough cost per hectare for varying farm sizes as predicted by the different models

that same order.

The incurred plough machinery cost per hectare for the 3 models with the farm size was predicted as a power function of the farm size. The L- model trendline equation was as shown in Equation 4.5, and had an $R^2$ value of 0.9482.

$$AC_L = 24232\, A^{-0.196} \qquad (4.5)$$

For the Z- model trendline was as shown in Equation 4.6, and had an $R^2$ value of 0.9797.

$$AC_Z = 51192\, A^{-0.314} \qquad (4.6)$$

The H- model trendline was as shown in Equation 4.7, and had an $R^2$ value of 0.9389.

$$AC_H = 22916\, A^{-0.185} \qquad (4.7)$$

Prediction of the corresponding plough machinery cost in terms of the farm size with a power model was most precise (approximately 98 % accuracy) for the Z- model and least precise (93.9 % accuracy) for the H- model. The prediction accuracy for the L- model was 94.8 %.

It was observed that the plough machinery cost per hectare for the Z- model width was the highest of the 3 models' at farm sizes below 420 ha. Thereafter it became lower than the H-model cost. At 675 ha, it became lower than the L- model cost also by only 65 kobo. The cost for the H- model width was lower than that of the L- model's width for farm sizes of 145 ha and less. Thereafter it was higher than the L- model cost.

The ANOVA table of the statistical test on the plough machinery costs per hectare for the 3 models at a 0.05 level of significance is shown in Table 4.14. The test F value of 0.622 was lower than the 3.351 F-critical value. Also the-value of 0.5443 obtained in the ANOVA test is greater than the 0.05 p-value for 95 % confidence level. This showed that the annual plough

Table 4.14: ANOVA table for statistical test on the plough machinery costs per hectare from the developed models and Hunt-Wilson model widths

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 6563038.108 | 2 | 3281519.054 | 0.622003 | 0.544385 | 3.354131 |
| Within Groups | 142444651.8 | 27 | 5275727.845 | | | |
| Total | 149007689.9 | 29 | | | | |

machinery costs incurred per hectare with the widths from the developed models' were not significantly different from that incurred with the plough width from the Hunt-Wilsons model.

The annual plough machinery and transport cost per hectare at the serviced-field distances also are shown in Table 4.12. The plot of the costs against varying farm sizes is also shown in Figure 4.14. The annual plough machinery and transport cost as is expected was higher than the ordinary annual plough machinery cost. It was ₦14,631.99, ₦10,477.10, ₦9,053.37 and ₦8,768.33 for farm sizes of 45 ha, 145 ha, 420 ha and 675 ha respectively with the L- model width. The cost for the Z- model width was ₦18,572.06, ₦12,364.81, ₦9,039.01 and ₦8,768.33 for the same listed farm sizes in that same order. For the H- model it was ₦15,266.59, ₦11,338.81, ₦9,850.51 and ₦9,948.93 for the same the listed farm sizes, in that same order.

Of the 3 models, the machinery and transport cost per hectare for the H- model width was the highest for farm sizes higher than 145 ha. The cost for the L- model width was the lowest for farm sizes lower than 420 ha, after which it became higher than the Z- model costs. The cost for the Z- model width was higher than the cost for H- model width for farm sizes of 145 ha and below. The higher cost of transporting bigger size plough selected by the H- model could have given rise to the observed higher machinery and transport cost per hectare.

The plough machinery costs for the 3 models tended towards close values for each indicated farm size for farm sizes of 420 ha and above. The plough machinery and transport costs for the 3 models were closest in value at above 145 ha farm size, up to 420 ha. They were farther away in values at other farm sizes. The plough machinery costs per hectare for the 3 models were continually decreasing with increasing farm size, showing that the mechanization of large farms is more economical than that of small farms. Najafi and Torabi Dastgerduei (2015), Rasouli *et al* (2009) and Onwualu *et al* (2006) have reported fragmented and scattered holdings as among the constraints to agricultural mechanization.

The decrease in the plough machinery and transport costs with increasing farm size was irregular after 420 ha farm size increase, probably due to the comparative irregular increase in the cumulative machinery travel distance. The detailed consideration of the tractor cost influence on minimum-cost machinery width determination could have led to the developed models' slightly reduced cost per hectare of compared to the Hunt-Wilson model at higher farm sizes. It must be noted that the choice of the prior capacity affected the least-cost width selected by the H- model. The 1.2738 m obtained with the 0.3101 prior capacity used will become 1.7923 if a 0.5168 ha/hr capacity is used as previously shown in Table 4.9. The dependence of the selected width on the user's arbitrary capacity choice has been cited as a weakness in the H- model that this study is addressing.

### 4.2.2 Disc harrow size and cost under farm size variations

The disc harrow widths derived from the minimum-cost harrow capacities selected for varying pool farm sizes with the developed models for such fragmented scattered farms are shown in Table 4.15 and also plotted in Figure 4.15. A harrow width ($w$) of 0.4780 m, 0.8576 m, 1.8473 m and 2.3230 m was derived from the minimum-cost harrow capacity selected with the L- model for farm sizes ($A$) of 45 ha, 145 ha, 420 ha and 675 ha respectively. A harrow width of 0.1862 m, 0.3526 m, 1.3353 m and 1.7567 m was obtained for the listed farm sizes in that order with the Z- model. The H- model harrow widths selected for various farm sizes are shown in Table 4.15 and also plotted on Figure 4.15. They were 1.0917 m, 1.3610 m, 2.1083 m and 2.3333 m for the same listed farm sizes in that order. The models favoured the selection of higher harrow widths for bigger pool farm sizes.

Table 4.15: The disc harrow sizes and minimum cost predictions of the various models under the different pool farm sizes

| Farm Area A (ha) | Cum. Transpt Distnc | Minimum-cost Harrow Width | | | | | |
|---|---|---|---|---|---|---|---|
| | | Width $w$ (m) | | | Width to Farm Size Ratio | | |
| | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |

| | e D (km) | | | | | | |
|---|---|---|---|---|---|---|---|
| 45 | 32 | 0.4780 | 0.1862 | 1.0917 | 0.0110 | 0.0043 | 0.0251 |
| 82 | 56 | 0.6440 | 0.2498 | 1.2114 | 0.0079 | 0.0030 | 0.0148 |
| 145 | 122 | 0.8576 | 0.3526 | 1.3610 | 0.0059 | 0.0024 | 0.0094 |
| 200 | 148 | 1.0996 | 0.5875 | 1.6100 | 0.0055 | 0.0029 | 0.0080 |
| 295 | 208 | 1.3844 | 0.8192 | 1.7977 | 0.0047 | 0.0028 | 0.0061 |
| 420 | 268 | 1.8473 | 1.3353 | 2.1083 | 0.0044 | 0.0032 | 0.0050 |
| 453 | 358 | 1.9063 | 1.3822 | 2.1398 | 0.0042 | 0.0030 | 0.0047 |
| 588 | 434 | 2.1654 | 1.5938 | 2.2472 | 0.0037 | 0.0027 | 0.0038 |
| 620 | 506 | 2.2115 | 1.6351 | 2.2736 | 0.0036 | 0.0026 | 0.0037 |
| 675 | 596 | 2.3230 | 1.7567 | 2.3333 | 0.0034 | 0.0026 | 0.0035 |
| | | | | | | | |
| Farm Area $A$ (ha) | Cum. Transpt Distnce $D$ (km) | Annual Harrow Machinery Cost per Hectare | | | | | |
| | | Machinery Alone | | | Machinery and Transport | | |
| | | $AC_L$ | $AC_Z$ | $AC_H$ | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 32 | 9771.98 | 13464.90 | 11072.28 | 11877.01 | 15549.61 | 13831.89 |
| 82 | 56 | 7614.64 | 10396.97 | 8063.43 | 9380.41 | 12137.46 | 10440.76 |
| 145 | 122 | 6272.84 | 8103.97 | 6425.08 | 8288.48 | 10079.95 | 9203.04 |
| 200 | 148 | 6044.16 | 6688.41 | 6214.00 | 7784.34 | 8393.81 | 8629.31 |
| 295 | 208 | 5408.93 | 5731.55 | 5508.72 | 7039.93 | 7326.42 | 7789.73 |
| 420 | 268 | 5310.84 | 5330.20 | 5385.43 | 6777.08 | 6767.32 | 7451.06 |
| 453 | 358 | 5203.95 | 5219.31 | 5270.68 | 7000.45 | 6979.07 | 7809.00 |
| 588 | 434 | 4825.41 | 4832.82 | 4864.91 | 6496.17 | 6466.56 | 7232.39 |
| 620 | 506 | 4774.58 | 4777.43 | 4811.49 | 6616.54 | 6578.20 | 7424.87 |
| 675 | 596 | 4699.21 | 4686.89 | 4731.57 | 6691.10 | 6635.12 | 7562.47 |

The 3 models predicted the harrow width with a 2nd order polynomial expression of the farm size. The L- model trendline was as shown in Equation 4.8 with an $R^2$ value of 0.998.

$$w_L = -2\times10^{-6}A^2 + 0.0046A + 0.2649 \tag{4.8}$$

For the Z- model trendline was as shown in Equation 4.9, and had an $R^2$ value of 0.988.

$$w_Z = -1\times10^{-6}A^2 + 0.0036A + 0.0478 \tag{4.9}$$

The H- model trendline equation was as shown in Equation 4.10, and had an $R^2$ value of 0.9961.

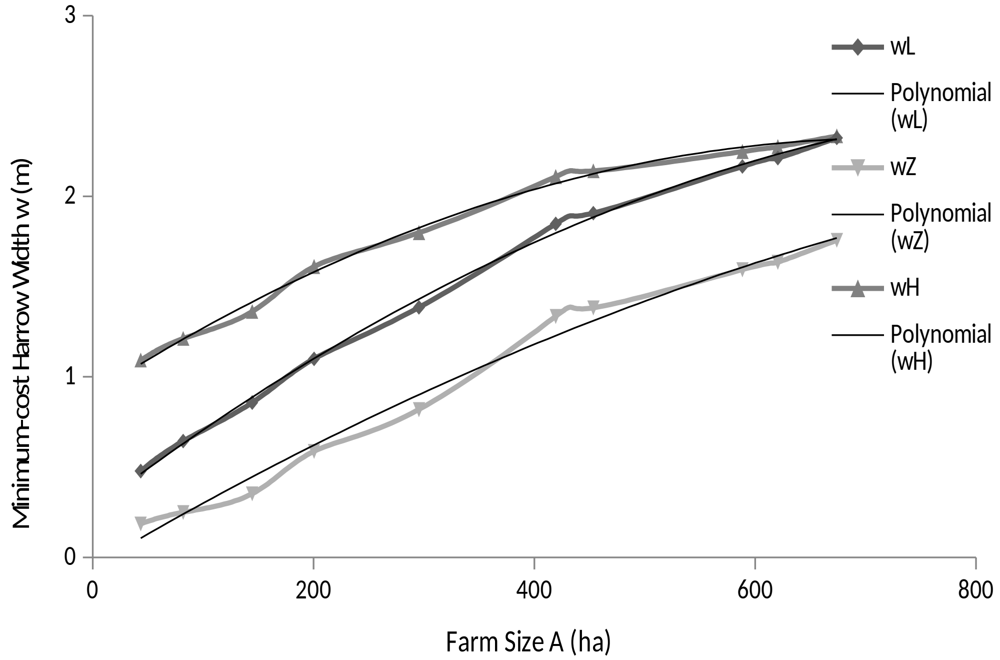



Figure 4.15: Harrow width predictions by the various models for different farm sizes.

$$w_H = -3 \times 10^{-6} A^2 + 0.0039 A + 0.9057 \quad (4.10)$$

Prediction of the harrow width from a 2nd order polynomial expression of the farm size was most precise (99.83 % accuracy) for the L- model least precise (98.8 % accuracy) with the Z- model. The prediction accuracy for the H- model was 99.61 %.

The ratio of the minimum-cost harrow width to their respective farm sizes for the 3 models are shown in Table 4.15. The ratio varied from 0.0034 to 0.0110, 0.0024 to 0.043 and 0.0035 to 0.0251 for the L- model, the Z- model and the H- model respectively. The ratio was highest for the smallest farm size and reduced as the farm size reduced for the models. For the H- model, the lowest ratio was observed for the 145 ha farm size.

Table 4.16 shows the ANOVA of the statistical analysis of width-to-farm size ratio for the 3 models at the 0.05 level of significance. The ANOVA F-test of 4.255 was higher than the 3.354 F-critical. Also the 0.0247 p-value obtained in the ANOVA test is below the 0.05 p-value for 95 % confidence level. This showed that the harrow widths predicted by the developed models were significantly different from the H- model harrow widths.

The F-critical for the pair-wise comparison of the L- and Z- models with the H- model widths was 4.4138. The test Q (*ie* F) value of 2.253 for the L- model was lower than the F-critical of 4.4138. Also the 0.2658 p-value obtained in the pair-wise comparison ANOVA test of the models widths-per-hectare is above the 0.05 p-value for 95 % confidence level. This shows that the widths predicted by the L- model were not significantly different from the H- model widths at the studied farm sizes. It could therefore be inferred that the L- model predicts plough widths acceptably well as does the H- model for the given farm sizes. For the Z- model the test Q (*ie* F) value was 4.128 and was lower than the 4.4138 F-critical. The 0.0187 p-value obtained in the pairwise test for the model widths-per-hectare is less than the 0.05 p-value for 95 % confidence level. It could not thus be conclusively inferred at 95 % level of

Table 4.16: ANOVA table for the comparison of the developed models' and Hunt-Wilson model's harrow widths-to-farm size ratios

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.000149 | 2 | 7.43E-05 | 4.25545 | 0.024747 | 3.354131 |
| Within Groups | 0.000472 | 27 | 1.75E-05 | | | |
| | | | | | | |
| Total | 0.00062 | 29 | | | | |

Tukey's pairwise comparisons: Q \ p(same) *F crit* = 4.4138

| Between Groups | $wR_L$ | $wR_Z$ | $wR_H$ |
|---|---|---|---|
| $wR_L$ | | 0.3935 | 0.2658 |
| $wR_Z$ | 1.875 | | 0.0187 |
| $wR_H$ | 2.253 | 4.128 | |

confidence whether their widths differed significantly. However the pairwise ANOVA retest at 0.01 level of significance showed that the 6.3364 F-test is lower than the prevailing F-critical of 8.2854. The p-value was 0.0215 which was lower than the 0.01 p-value showing that the Z- and H- models-predicted widths do not have significant difference at 99 % confidence level.

The annual harrow machinery cost per hectare corresponding to such harrow widths are also shown in Table 4.15 and also plotted in Figure 4.16. The cost was ₦12,796.66, ₦7,906.98, ₦6,523.14 and ₦5,647.97 for the same sizes (*A*) of 45 ha, 145 ha, 420 ha and 675 ha farms respectively with the L- model width. For the Z- model the cost was ₦14,642.97, ₦8,775.90, ₦6,206.48 and ₦5,404.37 for the same listed farm sizes, in that same order. For the H- model it was ₦11,072.28, ₦6,425.08, ₦5,385.43 and ₦4,731.57 for the same listed farm sizes, in that same order.

The incurred plough machinery cost per hectare for the 3 models with the farm size was predicted as a power function of the farm size. The L- model trendline equation was as shown in Equation 4.11, and had an $R^2$ value of 0.9657.

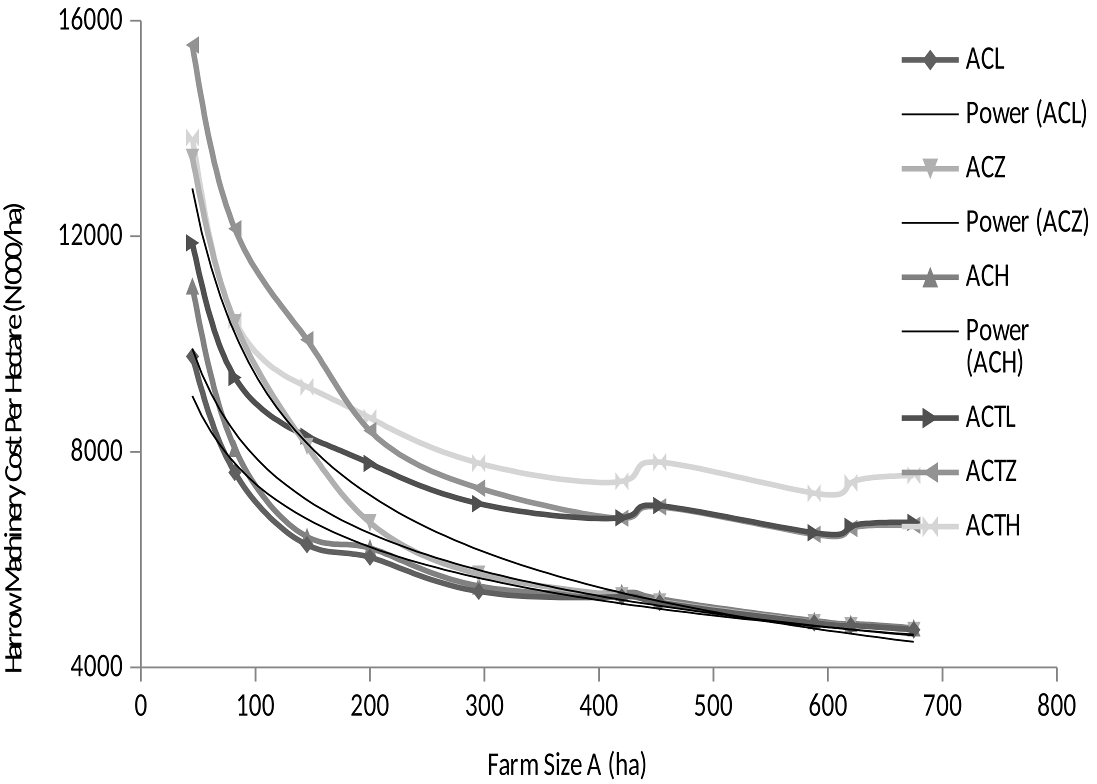



Figure 4.16: Annual harrow cost per hectare for varying farm sizes as predicted by the different models

$$AC_L = 23308\, A^{-0.249} \quad (4.11)$$

For the Z- model trendline was as shown in Equation 4.12, and had an $R^2$ value of 0.9855.

$$AC_Z = 57027\, A^{-0.391} \quad (4.12)$$

The H- model trendline equation was as shown in Equation 4.13, and had an $R^2$ value of 0.9519.

$$AC_H = 29235\, A^{-0.284} \quad (4.13)$$

Prediction of the corresponding plough machinery cost in terms of the farm size with a power model was most precise (98.55 % accuracy) for the Z- model and least precise (95.19 % accuracy) for the H- model. The prediction accuracy for the L- model was 96.57 %.

Table 4.17: ANOVA table for statistical test on the developed models' and Hunt-Wilson model's harrow machinery cost per hectare

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 4662087.004 | 2 | 2331043.502 | 0.465483 | 0.63277 | 3.354131 |
| Within Groups | 135210436.5 | 27 | 5007793.946 | | | |

| | | |
|---|---|---|
| Total | 139872523.6 | 29 |

Table 4.17 shows the ANOVA table of the statistical analysis of the harrow machinery costs per hectare for the 3 models at a 0.05 level of significance. The test F value of 1.0715 was ₦6,523.14 and ₦5,647.97 for the same sizes ($A$) of 45 ha, 145 ha, 420 ha and 675 ha farms ₦6,523.14 and ₦5,647.97 for the same sizes ($A$) of 45 ha, 145 ha, 420 ha and 675 ha farms not significantly different from the ones from the Hunt-Wilson model widths at the studied farm sizes. Also the p-value of 0.3565 obtained in the test is greater than the 0.05 p-value for 95 % confidence level, showing that the developed models plough machinery costs and the Hunt-Wilsons model's costs are not significantly different.

The annual harrow machinery and transport costs per hectare at the serviced-field distances are also shown in Table 4.15, and their plots against varying farm sizes shown in Figure 4.16. The annual harrow machinery and transport cost per hectare as is expected was higher than the ordinary annual harrow machinery cost per hectare. It varied from ₦14,901.69 for a 45 ha pool farm, to ₦9,922.62, ₦7,989.38 and ₦7,639.86 for pool farm sizes of 145 ha, 420 ha and 675 ha, in that order, for the L- model width. The cost for the Z- model width, was ₦16,727.68, ₦10,751.89, ₦7,643.60 and ₦7,352.59 for the same listed pool farm sizes in that same order. For the H- model it was ₦13,831.89, ₦9,203.04, ₦7,451.06 and ₦7,562.47 for the same listed farm sizes, in that same order.

### 4.2.3 Disc ridger size and cost under farm size variations

The disc ridger widths derived from the minimum-cost ridger capacities selected with the developed models for varying pool farm sizes are shown in Table 4.18. The plots of these ridger widths against varying farm sizes are shown in Figures 4.17. A ridger width ($w$) of 0.4794 m, 0.8813 m, 1.7660 m and 2.2728 m was derived from the minimum-cost ridger capacity selected with the L- model for farm sizes ($A$) of 45 ha, 145 ha, 420 ha and 675 ha respectively. A ridger width of 0.1241 m, 0.2554 m, 0.9498 m and 1.2728 m was obtained for the listed farm sizes in that order with the Z- model. The H- model least-cost ridger widths are shown in Table 4.18 and plotted on Figure 4.17. They were 1.1106 m, 1.4144 m, 2.1901 m and 2.4417 m for the same listed farm sizes in that order. The models favoured the selection of higher ridger widths for bigger pool farm sizes for the 3 models.

The 3 models predicted the ridger width with a 2nd order polynomial expression of the farm size. The L- model trendline was as shown in Equation 4.8 with an $R^2$ value of 0.9996.

$$w_L = -2 \times 10^{-6} A^2 + 0.004 A + 0.304 \qquad (4.14)$$

For the Z- model trendline was as shown in Equation 4.15, and had an $R^2$ value of 0.9919.

Table 4.18: The disc ridger sizes and minimum cost predictions of the various models under the different pool farm sizes

| Farm Area A (ha) | Cum. Transpt Distnce D (km) | Minimum-cost Ridger Width | | | | | |
|---|---|---|---|---|---|---|---|
| | | Width $w$ (m) | | | Width to Farm Size Ratio | | |
| | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |
| 45 | 32 | 0.4794 | 0.1241 | 1.1106 | 0.0110 | 0.0029 | 0.0255 |
| 82 | 56 | 0.6567 | 0.1742 | 1.2447 | 0.0080 | 0.0021 | 0.0152 |
| 145 | 122 | 0.8813 | 0.2554 | 1.4144 | 0.0061 | 0.0018 | 0.0098 |
| 200 | 148 | 1.0958 | 0.4140 | 1.6618 | 0.0055 | 0.0021 | 0.0083 |
| 295 | 208 | 1.3776 | 0.5978 | 1.8784 | 0.0047 | 0.0020 | 0.0064 |
| 420 | 268 | 1.7660 | 0.9480 | 2.1901 | 0.0042 | 0.0023 | 0.0052 |
| 453 | 358 | 1.8349 | 0.9904 | 2.2239 | 0.0040 | 0.0022 | 0.0049 |
| 588 | 434 | 2.1027 | 1.1635 | 2.3476 | 0.0036 | 0.0020 | 0.0040 |
| 620 | 506 | 2.1596 | 1.2029 | 2.3754 | 0.0035 | 0.0019 | 0.0038 |
| 675 | 596 | 2.2728 | 1.3041 | 2.4417 | 0.0034 | 0.0019 | 0.0036 |

| Farm Area $A$ (ha) | Cum. Transpt Distnce $D$ (km) | Annual Ridger Machinery Cost per Hectare | | | | | |
|---|---|---|---|---|---|---|---|
| | | Machinery Alone | | | Machinery and Transport | | |
| | | $AC_L$ | $AC_Z$ | $AC_H$ | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 32 | 12572.58 | 25179.19 | 12389.83 | 15348.65 | 27955.26 | 15760.25 |
| 82 | 56 | 10206.60 | 19082.23 | 9812.90 | 12602.40 | 21478.03 | 12767.44 |
| 145 | 122 | 8705.09 | 14471.34 | 8373.45 | 11506.21 | 17272.46 | 11876.48 |
| 200 | 148 | 8280.45 | 11199.44 | 8068.64 | 10708.12 | 13627.11 | 11123.83 |
| 295 | 208 | 7573.07 | 9319.12 | 7433.26 | 9860.66 | 11606.71 | 10330.80 |
| 420 | 268 | 7312.15 | 8102.72 | 7245.37 | 9374.88 | 10165.45 | 9876.89 |
| 453 | 358 | 7191.51 | 7939.61 | 7131.52 | 9725.64 | 10473.73 | 10370.50 |
| 588 | 434 | 6813.88 | 7420.16 | 6780.74 | 9173.98 | 9780.25 | 9806.21 |
| 620 | 506 | 6749.23 | 7326.91 | 6721.66 | 9353.63 | 9931.31 | 10063.55 |
| 675 | 596 | 6657.42 | 7155.16 | 6639.53 | 9476.29 | 9974.02 | 10262.56 |

$$w_Z = -8\times 10^{-7} A^2 + 0.0025 A + 0.0372 \quad (4.15)$$

The H- model trendline equation was as shown in Equation 4.16, and had an $R^2$ value of 0.9974.

$$w_H = -3\times 10^{-6} A^2 + 0.0041 A + 0.9203 \quad (4.16)$$

Prediction of the ridger width with a quadratic expression of the farm size was most precise (99.96 % accuracy) for the L- model least precise (99.19 % accuracy) with the Z- model. The prediction accuracy for the H- model was 99.61 %.

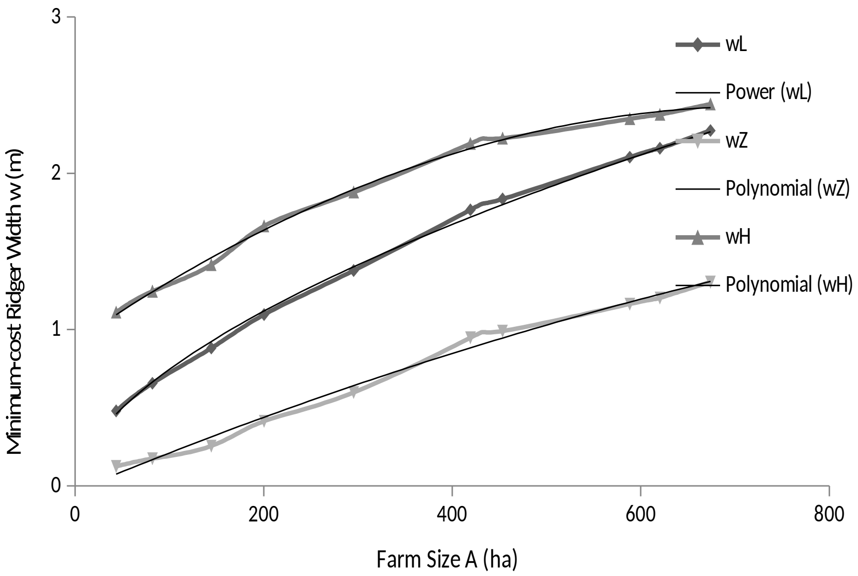



Figure 4.17: Ridger width predictions by the various models for different farm sizes

The ratio of the minimum-cost ridger width to their respective farm sizes for the studied farm sizes, for the 3 models are shown in Table 4.18. The ratio varied from 0.0034 to 0.0110, 0.0018 to 0.0029 and 0.0036 to 0.0255 for the L- model, the Z- model and the H- model respectively. The ratio was highest for the smallest farm size and reduced as the farm size increased for the L- model and the H- models. For the Z- model, the ratio change was irregular at 145 ha farm size where the ratio had its lowest value.

Table 4.19 shows the ANOVA table of the statistical analysis of width-to-farm size ratio for the 3 models at the 0.05 level of significance. The ANOVA F-test of 5.9887 was higher than

Table 4.19: ANOVA table for statistical test on the obtained ridger widths-to-farm size ratio with the developed models and Hunt-Wilson model

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.000215 | 2 | 0.000108 | 5.988757 | 0.007038 | 3.354131 |
| Within Groups | 0.000485 | 27 | 1.8E-05 | | | |
| | | | | | | |
| Total | 0.0007 | 29 | | | | |

Tukey's pairwise comparisons: Q \ p(same) — *F crit* = 4.4138

| Between Groups | $wR_L$ | $wR_Z$ | $wR_H$ |
|---|---|---|---|
| $wR_L$ | | 0.2120 | 0.2139 |
| $wR_Z$ | 2.449 | | 0.0051 |
| $wR_H$ | 2.442 | 4.891 | |

the 3.354 F-critical, showing that the ridger widths predicted by one or both of the developed models were significantly different than the H- model ridger widths. Also the 0.00703 p-value obtained in the ANOVA test is below the 0.05 p-value for 95 % confidence level. This shows that the ridger widths from the various models are unlikely to be same. The F-critical for the pairwise ANOVA test for each of the developed models widths comparison with the H- model widths was 4.4138. The 2.442 test Q (*ie* F) for the L- model widths comparison with the H- model widths was lower than the F-critical of 4.4138. Also the p- value of 0.2139 was above the 0.05 p-value for 95 % confidence level. This shows that the widths predicted by the model were not significantly different from the H- model widths at the concerned farm sizes. It was thus inferred that the model predicts ridger widths acceptably as does the H- model for the given farm sizes. For the Z- model the test Q (*ie* F) value was 4.891, and was higher than the 4.4138 F-critical. Also the 0.0051 p-value obtained in the test was less than the 0.05 p-value for the 95 % confidence level. It was thus inferred that their widths differed significantly.

Figure 4.18 shows the annual ridger machinery cost per hectare corresponding to ridger widths obtained with the 3 models as seen in Table 4.18. It was ₦12,572.58, ₦8,705.09, ₦7,312.15 and ₦6,657.42 for a 45 ha, 145 ha, 420 ha and 675 ha pool farms respectively with the L- model widths. For the Z- model it was ₦25,179.19, ₦14,471.34, ₦8,102.72 and ₦7,155.16 for the same pool farms in the same order. The cost for the H- model was ₦12,389.83, ₦8,373.45, ₦7,245.37 and ₦6,639.53 for the same farm sizes in the same order. The incurred plough machinery cost per hectare for the widths predicted by the 3 models from the farm size followed a power function trend. The L- model trendline equation was as shown in Equation 4.17, and had an $R^2$ value of 0.9778.

$$AC_L = 27125\,A^{-0.219} \qquad (4.17)$$

For the Z- model trendline was as shown in Equation 4.18, and had an $R^2$ value of 0.9588.

$$AC_Z = 57027\,A^{-0.208} \qquad (4.18)$$

The H- model trendline equation was as shown in Equation 4.19, and had an $R^2$ value of 0.9883.

$$AC_H = 148769\,A^{-0.475} \qquad (4.19)$$

Prediction of the corresponding plough machinery cost in terms of the farm size with a power model was most precise (98.83 % accuracy) for the H- model and least precise (95.58 % accuracy) for the Z- model. The prediction accuracy for the L- model was 97.78 %.

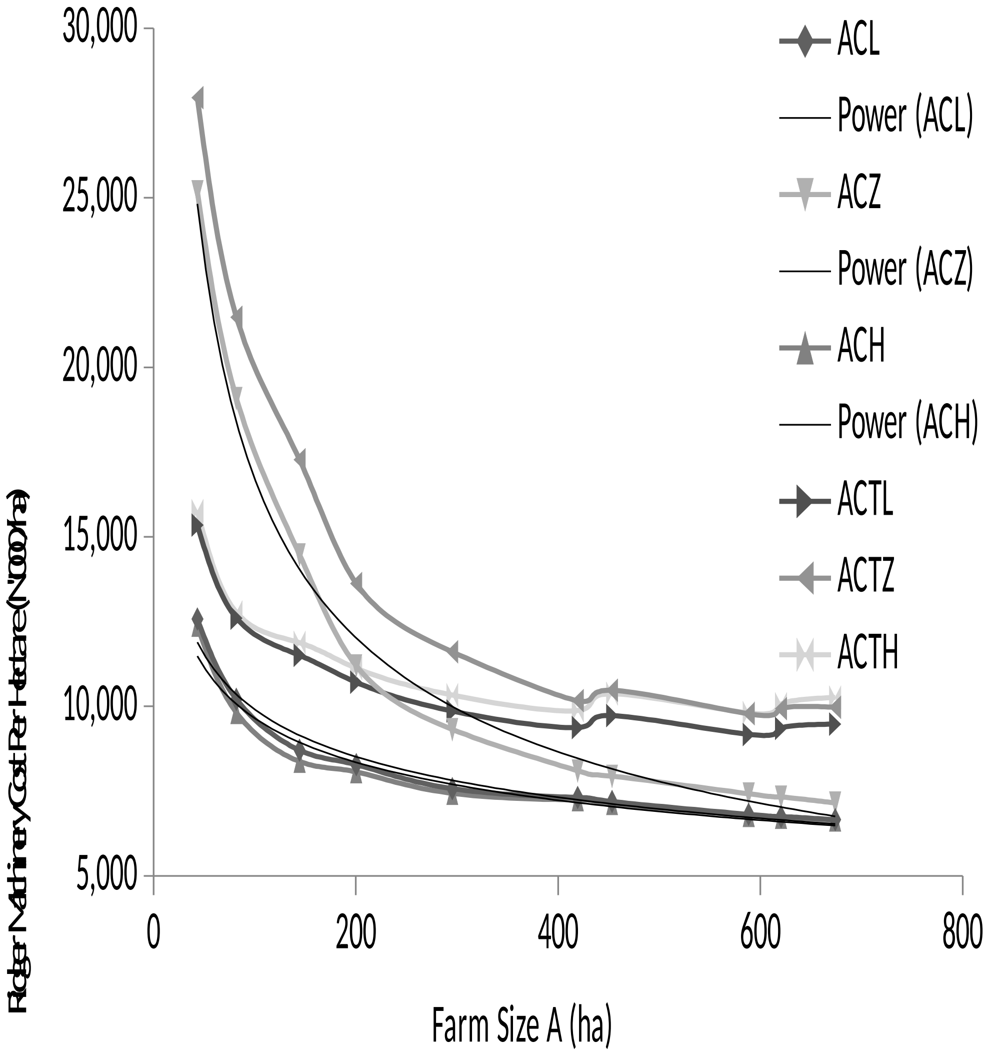



Figure 4.18: Annual ridger cost per hectare for varying farm sizes as predicted by the different models

Table 4.20 shows the ANOVA table of the statistical analysis of the ridger machinery costs per hectare for the 3 models at a 0.05 level of significance. The test F value of 3.113 was lower than the 3.3541 F-critical value. Also the p-value of approximately 0.0607 obtained in the ANOVA test is greater than the 0.05 p-value for 95 % confidence level. This showed that the costs from the developed models were not significantly different from the H- model costs at the studied farm sizes.

The annual ridger machinery and transport cost per unit farm size corresponding to the 3 models minimum-cost widths for the concerned farm sizes are also shown in Table 4.18 and plotted on Figure 4.18. The annual ridger machinery and transport cost per hectare as is expected was higher than the plain annual ridger machinery cost per hectare. It was

Table 4.20: ANOVA table for statistical test on ridger machinery cost per hectare from the developed models and Hunt-Wilson model

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 85867424.19 | 2 | 42933712.09 | 2.92543 | 0.07079 | 3.35413 |
| Within Groups | 396252390.5 | 27 | 14676014.46 | | | |
| | | | | | | |
| Total | 482119814.7 | 29 | | | | |

₦15,348.65, ₦11,506.21, ₦9,374.88 and ₦9,476.29 for pool farm sizes of 144.45 ha, 419.4 ha and 673.9 ha, in that order, for the L- model width. The cost for the Z- model width, was ₦27,955.26, ₦17,272.46, ₦10,165.45 and ₦9,974.02 for the same listed pool farm sizes in that same order. For the H- model width, the cost was ₦15,760.25, ₦11,876.48, ₦9,876.89 and ₦10,262.56 for the same listed pool farm sizes in that same order.

The ridger machinery cost per hectare and its machinery and transport cost corresponding to the Z- model ridger widths was higher than that for the L- model widths for all farm sizes studied. Above this farm size it was lower. The H- model width yielded the lowest ridger machinery costs per hectare for any studied farm size. Its ridger machinery and transport costs were higher than the L- model costs for any studied farm size, but lower than the Z- model cost for farm sizes less than 590 ha. The Z- model costs were lower at 590 ha and higher farm sizes studied.

The foregoing shows that the annual tillage machinery cost ($AC_g$) and the minimum-cost tillage capacity ($C_e$) models are sensitive to farm size variation, while the machinery transport cost-incorporated annual machinery cost ($AC_T$) model is additionally sensitive to the machinery transport distance. The 3 models favoured the selection of higher tillage machinery widths for increasing farm sizes. Generally, the Hunt-Wilson least-cost widths selected were higher than the minimum-cost widths obtained with the L- and Z- models. Hunt-Wilson (2015) reported that the assumption that tractor cost is independent of implement size leads to erroneous large tillage machinery width selection. A more thorough consideration of tractor cost contribution in minimum-cost width selection may thus be expected to yield lower machinery sizes.

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. This agrees with the well known fact that the mechanization of larger farms is more economical than that of the smaller ones. Adama *et al* (2009) have proposed Centres for

Community Farms (CCF) programme for pooling contiguous fragmented farm lands together into bigger ones. This is aimed at making the mechanization of the pool farms more economically feasible. The present study attempts the extension of such mechanization problem-solution approach to non-contiguous fragmented farms. The high annual machinery cost per hectare for mechanizing the non-contiguous small farms could be reduced by increasing the hectarage processed for the same inter-plot distances.

The total annual machinery cost was increased with the machinery transport cost incorporation. This seemed to agree with Larsén (2008) report that machinery- and labour-sharing farms had larger farm lands and value of total output, and on the average, higher farm and machinery efficiencies; with equally higher capital costs. Lai *et al* (2015) showed that consolidating farms of about 0.31 ha on the average into 1 ha farms increases machinery use by about 10 %. The annual tillage machinery transport cost per hectare also was comparatively smaller as the pool farm size increased. Both the annual tillage machinery cost per hectare and the tillage machinery and transport cost per hectare tended toward very close values at farm sizes higher than 420 ha. When compared to the plain annual tillage machinery cost per hectare, the annual tillage machinery and transport could be seen as non-prohibitive to mechanizing fragmented scattered farm pool.

The ₦14,000.00 machinery hiring charge on clients by the Ministry of Agriculture Anambra State Nigeria was rarely recovered even for the studied costs until the total combined area processed approached 145 ha for ploughing and harrowing operations. For ridging operation, the farm size had to exceed the 145 ha before the involved cost was recovered with the charge. Ajah (2014) reported that small scale farmers in Abuja attributed high machinery hiring cost as an impediment to using tractorized tillage operations and spent an average of ₦11,543.00; (₦800.00 - ₦35,000.00 in range) on such tillage machinery hiring from private NGO's/cooperative and government owned hiring services operators. The sizes of such farms covered by a unit machinery size were however not given.

The costs per hectare observed in the study under the given conditions suggest that mechanizing far-flung fragmented farms is not cost effective until the pool farm size approaches 145 ha. The developed models selected lower harrow and ridger machine widths than the H- model for all the studied farm sizes and lower plough sizes for farm sizes of 145 ha and below. However the corresponding annual machinery costs for the developed models were not necessarily lower than the Hunt-Wilson (2015) model cost. This suggests that using the models developed in the study may favour cheaper farm implements acquisition for our capital-poor small-scale farmers. The lower implement sizes selected will translate to reduced machinery acquisition cost.

This is more so since pooling enough lump farm size is naturally difficult and financing the tillage machinery acquisition a financial bottleneck to the poor farmers. The annual machinery cost per hectare for the developed models machine width were higher than the for the Hunt-Wilson model's. This was in contrast to the higher implement purchase price inherent in the tillage implements selected by the Hunt-Wilson model. The annual machinery and transport cost per hectare for the L- models machine width was lower than the Hunt-Wilson model's own, however for each of the farm size. The Z- models machinery and transport cost per hectare was lower than the H- model's at farm sizes above 145 ha for the plough and harrow. It was higher for lower farm sizes. For the ridger, it was lower for farm sizes above 420 ha. The decrease in the machinery and transport cost per hectare with farm size increase was irregular beyond 420 ha farm size. The irregularity could be as a result of the irregular variation of the machinery transport distance. This shows the necessity of considering all the components involved in machine costing and the need of cost modelling in machine selection decisions.

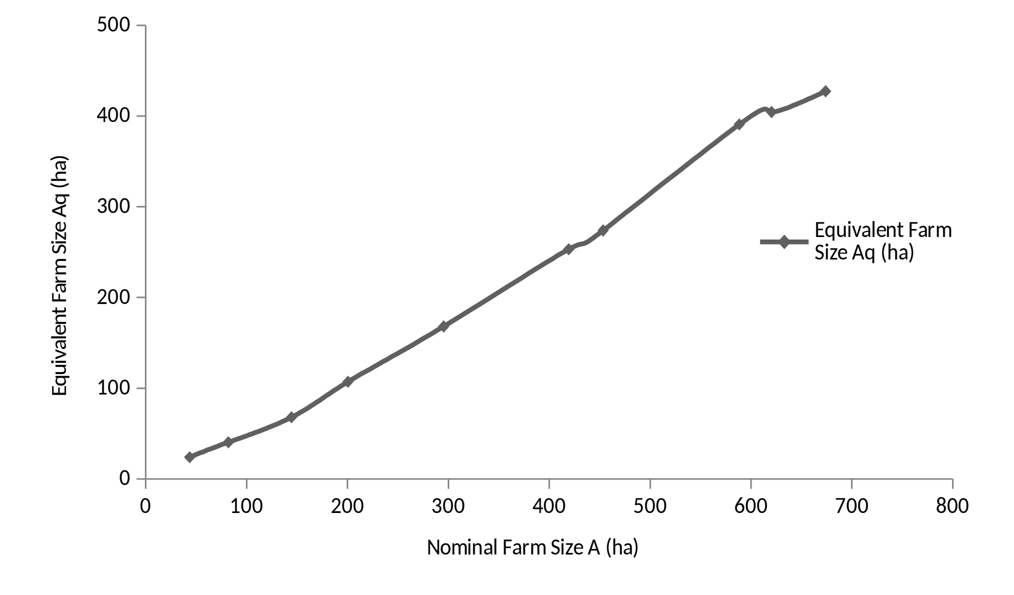
### 4.3.1 Equivalent pool farm size for overlapping operations timing farms

The previous sections assumed coinciding field operations. The effect of non-coinciding field processing period window on size of field machines selected was considered in this section. Key cassava and rice producing local government areas (LGAs) of Anambra State, Nigeria were mentioned earlier on during the model formulation. The overlap in the period of tractorized tillage operations for rice and cassava in the studied locations of the state was shown during the model development, (see Figure 3.9). Tillage operations for rainfed cassava cropping must be done within November and December for the zone 2 ($_{2Z}$) locations studied; Anambra West and Ayamelum LGAs ecological zones. This is done to ensure that the tubers are matured enough for harvest within June and July of the second following year since the cassava cultivars grown take 18 months from planting to maturity.

The June-July target harvest date arises because the annual flooding of these areas. It does not permit cassava harvest beyond this period as the tubers will rot when the farms are submerged. The other local governments studied; Awka North, Anambra East, Ayamelum, Dunukofia, Ihiala, Nnewi South, Ogbaru, Oyi, Orumba North and Orumba South do not experience the annual flooding. They do not suffer such restriction on cassava harvest and by extension the planting dates. However year-round tractorized tillage cannot be guaranteed in these zones as the early rains are needed to soften the ground enough for practicable tillage

(Onyeokoro, 2016 and Chigbo, 2016) without excessive draught. Equally, excessive slip and sinking of the tractor occur when the ground becomes too soft (Chigbo, 2016) on account of excessive soil moisture making tractorized tillage not feasible.

The window period for tractorized tillage of the non-flooded zone 1 ($_{1z}$) locations is mid March to mid June for rice, while for cassava it is bimodal; mid March to mid July and September to November. The tractorized tillage period for rice cropping can be carried out for the zone 2 study locations within April to June. Equivalent farm sizes ($A_q$) were derived from the studied nominal farm sizes ($A$). Equation 3.115 takes advantage of the non conciding timing the pool farms operation to evaluate the smaller $A_q$ the machinery selection can be based on instead of the corresponding larger $A$. The derived $A_q$ and their corresponding $A$ are shown in Table 4.21. The plot of the derived $A_q$ for varying $A$ values are shown in Figure 4.19. The $A_q$ varied irregularly with $A$ variation as can be seen in the figure. $A$ values of 45 ha, 145 ha, 420 ha and 675 ha yielded $A_q$ values of 25, 70, 255 and 430 hectares respectively. ANOVA was performed on the width-to-farm size ratio of both farm size types so as to have a common basis for the statistical analysis. The test F of 109.098 was higher than the 4.4138 F-critical, and the 4.55E-9 p value was less than the p-value for 95 %




| ANOVA | F- test | 109.0987 |
|---|---|---|
| F- crit = 4.4138 at p = 0.05 | p-value | 4.55E-9 |

Figure 4.19: Equivalent farm sizes for nominal pool farm sizes

Table 4.21: Minimum-cost disc plough sizes for differing equivalent pool farm sizes

| Farm | Equivlt | Cum. | Equivalent Farm Size-Based Minimum-cost Plough Width |
|---|---|---|---|

| Area A (ha) | Farm Area $A_q$ (ha) | Transpt Distnce D (km) | Width $w$ (m) | | | Variation (%) | | | Width-to-Farm Size Ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $w_{qL}$ | $w_{qZ}$ | $w_{qH}$ | $w\%_{qL}$ | $w\%_{qZ}$ | $w\%_{qH}$ | $wR_{qL}$ | $wR_Z$ | $wR_H$ |
| 45 | 24 | 32 | 0.3806 | 0.1241 | 0.6763 | 30.56 | 44.87 | 17.38 | 0.0110 | 0.0029 | 0.0255 |
| 82 | 40 | 56 | 0.4845 | 0.1563 | 0.7362 | 34.02 | 48.12 | 18.84 | 0.0080 | 0.0021 | 0.0152 |
| 145 | 70 | 122 | 0.6243 | 0.2103 | 0.8158 | 35.90 | 50.42 | 20.03 | 0.0061 | 0.0018 | 0.0098 |
| 200 | 110 | 148 | 0.8546 | 0.4051 | 1.0124 | 31.58 | 42.31 | 16.20 | 0.0055 | 0.0021 | 0.0083 |
| 295 | 170 | 208 | 1.1029 | 0.5857 | 1.1458 | 29.90 | 40.39 | 15.37 | 0.0047 | 0.0020 | 0.0064 |
| 420 | 255 | 268 | 1.5046 | 1.0021 | 1.3685 | 28.38 | 36.90 | 13.91 | 0.0042 | 0.0023 | 0.0052 |
| 453 | 275 | 358 | 1.5452 | 1.0312 | 1.3878 | 28.40 | 37.00 | 13.93 | 0.0040 | 0.0022 | 0.0049 |
| 588 | 390 | 434 | 1.8339 | 1.2459 | 1.4821 | 24.87 | 33.72 | 12.52 | 0.0036 | 0.0020 | 0.0040 |
| 620 | 405 | 506 | 1.8467 | 1.2585 | 1.4935 | 25.61 | 34.47 | 12.83 | 0.0035 | 0.0019 | 0.0038 |
| 675 | 430 | 596 | 1.8964 | 1.3135 | 1.5203 | 27.05 | 36.17 | 13.56 | 0.0034 | 0.0019 | 0.0036 |
| Average Variation | | | | | | 29.63 | 40.44 | 15.46 | | | |

| Farm Area $A$ (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce $D$ (km) | Nominal Farm Size-Based Minimum-cost Plough Width | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Width $w$ (m) | | | Width-to-Farm Size Ratio | | |
| | | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |
| 45 | 24 | 32 | 0.5481 | 0.2251 | 0.8186 | 0.0126 | 0.0052 | 0.0188 |
| 82 | 40 | 56 | 0.7343 | 0.3013 | 0.9071 | 0.0090 | 0.0037 | 0.0111 |
| 145 | 70 | 122 | 0.9740 | 0.4242 | 1.0201 | 0.0067 | 0.0029 | 0.0071 |
| 200 | 110 | 148 | 1.2491 | 0.7022 | 1.2081 | 0.0062 | 0.0035 | 0.0060 |
| 295 | 170 | 208 | 1.5733 | 0.9826 | 1.3539 | 0.0053 | 0.0033 | 0.0046 |
| 420 | 255 | 268 | 2.1009 | 1.5880 | 1.5896 | 0.0050 | 0.0038 | 0.0038 |
| 453 | 275 | 358 | 2.1582 | 1.6367 | 1.6124 | 0.0048 | 0.0036 | 0.0036 |
| 588 | 390 | 434 | 2.4411 | 1.8797 | 1.6943 | 0.0041 | 0.0032 | 0.0029 |
| 620 | 405 | 506 | 2.4825 | 1.9204 | 1.7133 | 0.0040 | 0.0031 | 0.0028 |
| 675 | 430 | 596 | 2.5997 | 2.0579 | 1.7587 | 0.0039 | 0.0031 | 0.0026 |

confidence level. This showed that the two sets of farm sizes are significantly different. Selecting the equipment size on the basis of these smaller $A_q$ rather than the bigger $A$ resulted in smaller implement capacity as will be discussed shortly. This also meant higher machinery annual use, leading to better recovery of the machinery fixed cost, as suitable field operation period is spread out over an adequate comparatively longer duration. The new tillage machine widths ($w_q$) obtained with the 3 models for the $A_q$ and the $w$ for the corresponding nominal farm size ($A$) are presented and discussed in the succeeding sections for the 3 implements treated in this study.

### 4.3.2 Plough size and cost for overlapping operations timing pool farms

The plough widths ($w_q$) derived from the minimum-cost plough capacities selected by the developed models for varying ($A_q$) are shown in Table 4.21 and are also plotted in Figure 4.20A. The widths ($w$) obtained with the 3 models for the corresponding ($A$) are represented

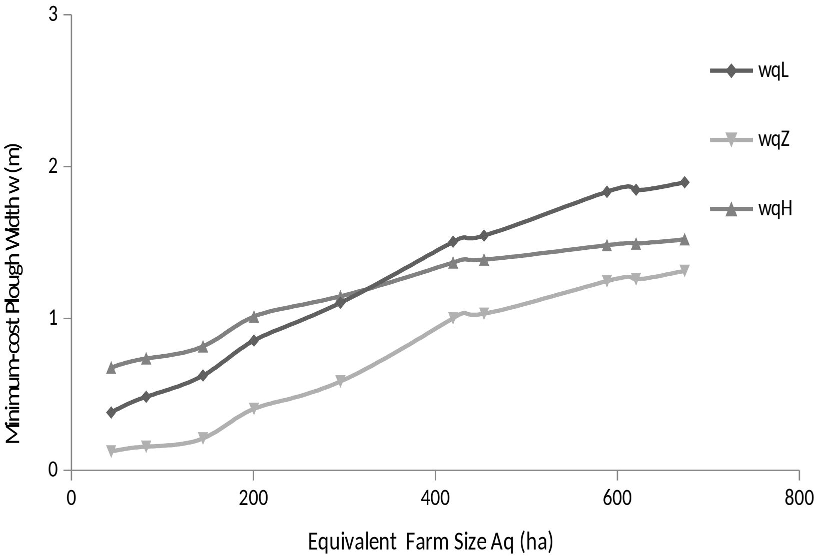



Figure 4.20A: Minimum-cost plough width for equivalent farm size

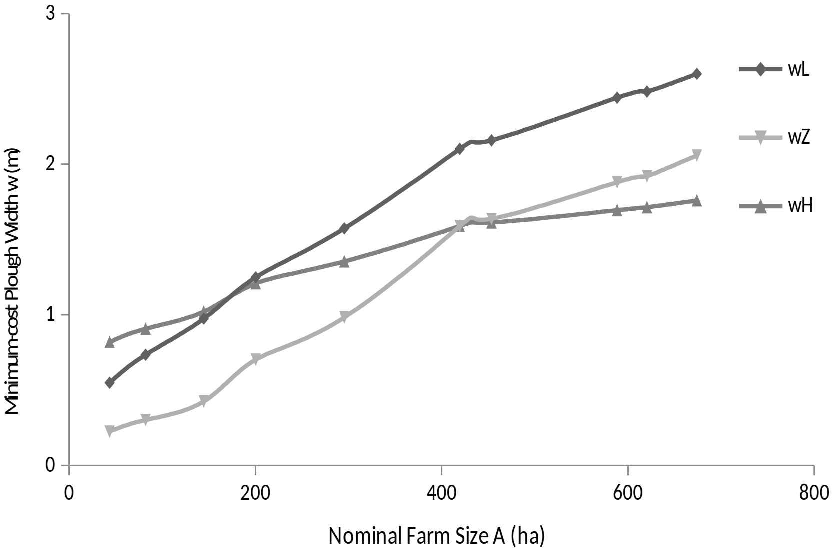



Figure 4.20B: Minimum-cost plough width for nominal farm size

in the table and in Figure 4.20B for easier comparison. On the basis of ($A_q$) a plough width of 0.3806 m, 0.6243 m, 1.5046 m and 1.8964 m were obtained for $A_q$ of 25 ha, 70 ha, 255 ha and 430 ha in that order with the L- model. These $A_q$ correspond to $A$ of 45 ha, 145 ha, 420 ha and 675 ha respectively. The selected widths contrasted with the plough widths of 0.5481 m, 0.9740 m, 2.1009 m and 2.5997 m obtained for the $A$ in that order with the same model.

The ANOVA F-value and p- value of the per hectare ratio of the 2 widths types derived with the L-model can be seen in Table 4.22. The F-test value of 3.2626 was lower than the 4.4138 F-critical. The p-value was 0.8762, which is higher than the 0.05 p-value for 95 % confidence level. This showed that there was no significant difference between the plough widths from both farm sizes types.

Table 4.22: ANOVA F- and p- values for comparison of equivalent and nominal farm sizes plough widths and corresponding costs

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| F-crit = 4.4138 at p = 0.05 | Width / Cost per Hectare Groups Compared | | | | | |
| | $wR_L : wR_{qL}$ | $wR_Z : wR_{qZ}$ | $wR_H : wR_{qH}$ | $AC_L : AC_{qL}$ | $AC_Z : AC_{qZ}$ | $AC_H : AC_{qH}$ |
| *F-test* | 3.262604 | 37.94716 | 0.25649 | 39.23409 | 10.24568 | 43.04752 |
| Test- p | 0.087626 | 8.13E-6 | 0.61868 | 6.6E-6 | 0.004953 | 3.65E-6 |

The Z- model width was 0.1241 m, 0.2103 m, 1.0021 m and 1.3135 m for the same $Aq$ values in that order. In contrast, plough widths of 0.2251 m, 0.4242 m, 1.5880 m and 2.0579 m were obtained for the corresponding $A$ in that same order with the same model. The ANOVA for the per hectare ratios of the 2 sets of widths obtained with the Z- model is shown in Table 4.22. The F-test value of 37.9471 was higher than the 4.4138 F-critical. The 8.13E-6 p-value is less than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between the plough widths selected for both farm sizes types.

The least-cost plough widths ($w_q$) selected by the H- model for varying ($A_q$) are shown in Table 4.21 and also plotted in Figure 4.20A. For the corresponding $A$, the least-cost plough widths ($w$) selected with the H- model are also shown in Table 4.21 and also plotted in Figure 4.20B. The plough width ($w_q$) was 0.6763 m, 0.8158 m, 1.3685 m and 1.5203 m for the same listed $A_q$ in that same order. The width ($w$) was 0.8186 m, 1.0201m, 1.5896 m and 1.7587 m for the corresponding $A$ in the same order.

The ANOVA for the per-hectare ratio of the 2 sets of widths obtained with the H-model is shown in Table 4.22. The F-test value of 0.2564 was lower than the 4.4138 F-critical. The 0.6186 p-value was higher than the 0.05 p-value for 95 % confidence level. This showed that there was no significant difference between the plough widths selected for both farm size types. The plough width ($w$) obtained for each nominal farm size ($A$) was higher than the width ($w_q$) for its equivalent farm size ($A_q$). The trend of the variation of the plough width with changes in the equivalent farm size ($A_q$) was similar to its variation for the corresponding nominal farm size ($A$) changes.

The difference in the minimum-cost plough widths for the $A_q$ type and the $A$ type ($w_q$ and $w$ respectively) for each of the 3 models are also shown in Table 4.21. The difference in the L-model widths was 30.56 %, 35.90, 28.38 % and 27.05 % for the 45 ha, 145 ha, 420 ha and 675 ha farm size respectively. The average variation was 29.63 %. For the Z- model the difference was 44.87 %, 50.42 %, 36.90 % and 36.17 % for the same farm sizes in the same order. The average variation was 40.44 %. The H- model the difference was 17.38 %, 20.03 %, 13.91 % and 13.56 % for the same farm sizes in the same order. The average variation was 15.46 %.

The annual plough machinery costs per hectare corresponding to these minimum-cost plough widths ($w_q$) obtained for the $A_q$ with the 3 models are shown in Table 4.23. The costs are plotted against varying $A$ in Figure 4.21A. The costs incurred with the 3 models on the basis of the corresponding $A$ widths are also shown in the table and plotted in Figure 4.21B for comparison. The annual plough machinery cost per hectare was ₦8,108.41, ₦4,812.59, ₦5,003.53 and ₦4,651.20 for the $A_q$ of 25, 70, 255 and 430 hectares respectively with the L-model plough width. These were lower than the per hectare plough machinery costs of ₦12,485.44, ₦8,480.44, ₦7,611.25 and ₦6,892.56 predicted for the corresponding plough widths obtained on the $A$ basis in the same order. The ANOVA of the 2 sets of costs from the L- model as can be seen in Table 4.22, gave an F-test value of 39.2340 which is higher than the 4.4138 F-critical. The 6.6E-6 p-value is less than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between the plough machinery costs incurred for the widths from both farm size types selected by this model.

The annual plough machinery cost per hectare was ₦13,131.85, ₦7,276.35, ₦5,154.61 and ₦4,741.27 for the same $A_q$ in that same order with the Z- model plough width. These were lower than the plough machinery costs per hectare of ₦16,470.60, ₦10,452.75, ₦7,523.10 and ₦6,891.91 predicted for the plough widths on the basis of the corresponding $A$ in the same order. The ANOVA of the 2 sets of costs from the Z- model is shown in Table 4.22. The F- test value of 10.2456 is higher than the 4.4138 F-critical. The 0.0049 p-value is less than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between

Table 4.23: Disc plough cost per hectare for different equivalent pool farm sizes

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Equivalent Farm Size Based Plough Machinery Cost per Hectare (₦/ha) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | | Machinery and Transport |
| | | | $AC_{qL}$ | $AC_{qZ}$ | $AC_{qH}$ | Variation (%) | |

| | | | | | | $AC\%_{qL}$ | $AC\%_{qZ}$ | $AC\%_{qH}$ | $AC_{TqL}$ | $AC_{TqZ}$ | $AC_{TqH}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 24 | 32 | 8108.41 | 13131.85 | 8043.44 | 35.06 | 20.27 | 35.02 | 8932.44 | 13959.35 | 9509.16 |
| 82 | 40 | 56 | 5979.02 | 9571.89 | 5856.46 | 40.22 | 26.34 | 40.75 | 6522.99 | 10119.95 | 6998.24 |
| 145 | 70 | 122 | 4812.59 | 7276.35 | 4725.73 | 43.25 | 30.39 | 44.21 | 5287.20 | 7757.27 | 5943.08 |
| 200 | 110 | 148 | 5140.61 | 6101.71 | 5117.54 | 38.40 | 32.67 | 38.97 | 5527.02 | 6493.96 | 6159.04 |
| 295 | 170 | 208 | 4838.77 | 5405.58 | 4853.14 | 36.51 | 32.27 | 37.06 | 5171.28 | 5744.36 | 5815.05 |
| 420 | 255 | 268 | 5003.53 | 5154.61 | 5046.60 | 34.26 | 32.63 | 34.53 | 5284.61 | 5440.98 | 5905.84 |
| 453 | 275 | 358 | 4918.61 | 5061.41 | 4962.36 | 34.32 | 32.72 | 34.58 | 5247.61 | 5397.08 | 6006.56 |
| 588 | 390 | 434 | 4919.02 | 5040.72 | 4996.17 | 30.01 | 28.52 | 30.16 | 5214.33 | 5342.97 | 5964.22 |
| 620 | 405 | 506 | 4814.22 | 4926.92 | 4885.81 | 30.97 | 29.53 | 31.14 | 5134.18 | 5254.54 | 5949.99 |
| 675 | 430 | 596 | 4651.20 | 4741.27 | 4718.15 | 32.52 | 31.21 | 32.70 | 4991.13 | 5089.39 | 5866.19 |
| | | | Average Variation | | | 35.55 | 29.65 | 35.91 | | | |

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Nominal Farm Size Based Plough Machinery Cost per Hectare (₦/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | | Machinery and Transport | | |
| | | | $AC_L$ | $AC_Z$ | $AC_H$ | | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 24 | 32 | 12485.44 | 16470.60 | 12378.38 | | 14631.99 | 18572.06 | 15266.59 |
| 82 | 40 | 56 | 10002.47 | 12994.49 | 9884.03 | | 11775.47 | 14712.39 | 12352.44 |
| 145 | 70 | 122 | 8480.44 | 10452.75 | 8471.28 | | 10477.10 | 12364.81 | 11338.81 |
| 200 | 110 | 148 | 8344.88 | 9062.20 | 8385.45 | | 10064.84 | 10710.40 | 10882.50 |
| 295 | 170 | 208 | 7621.26 | 7981.46 | 7710.79 | | 9228.29 | 9516.68 | 10070.45 |
| 420 | 255 | 268 | 7611.25 | 7650.97 | 7708.13 | | 9053.37 | 9039.01 | 9850.51 |
| 453 | 275 | 358 | 7489.00 | 7523.10 | 7585.63 | | 9253.16 | 9219.65 | 10217.12 |
| 588 | 390 | 434 | 7028.27 | 7051.76 | 7154.24 | | 8667.58 | 8624.65 | 9610.63 |
| 620 | 405 | 506 | 6974.23 | 6991.91 | 7095.78 | | 8780.49 | 8724.89 | 9807.31 |
| 675 | 430 | 596 | 6892.56 | 6891.91 | 7010.44 | | 8844.86 | 8768.33 | 9948.93 |

the plough machinery costs incurred for the widths from both farm size types selected by this model.

The annual plough machinery cost per hectare for the H- model width was ₦8,043.44, ₦4,225.73, ₦5,046.60 and ₦4,718.15 for the same listed $A_q$, in that same order. The costs were lower than the ₦12,378.38, ₦8,471.28, ₦7,708.13 and ₦7,010.44 corresponding to the $A$ plough widths ($w$) in the same order. The ANOVA result for the 2 sets of costs as can be

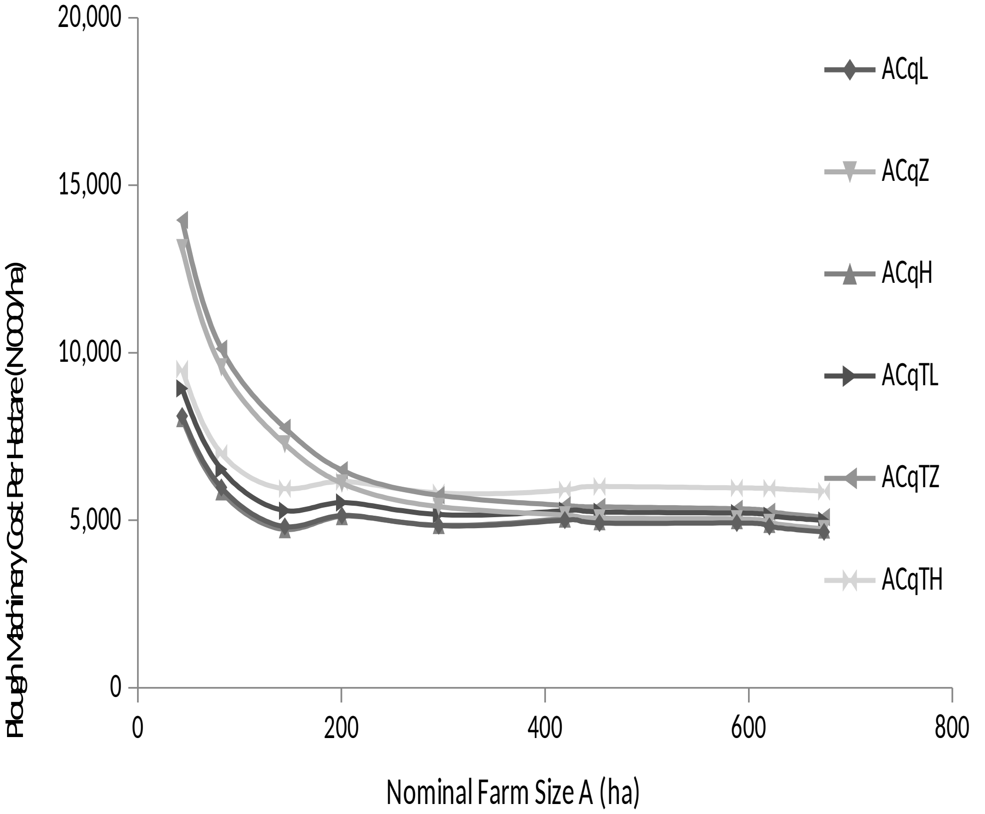



Figure 4.21A: Annual plough machinery cost per hectare for equivalent farm size $A_q$ type

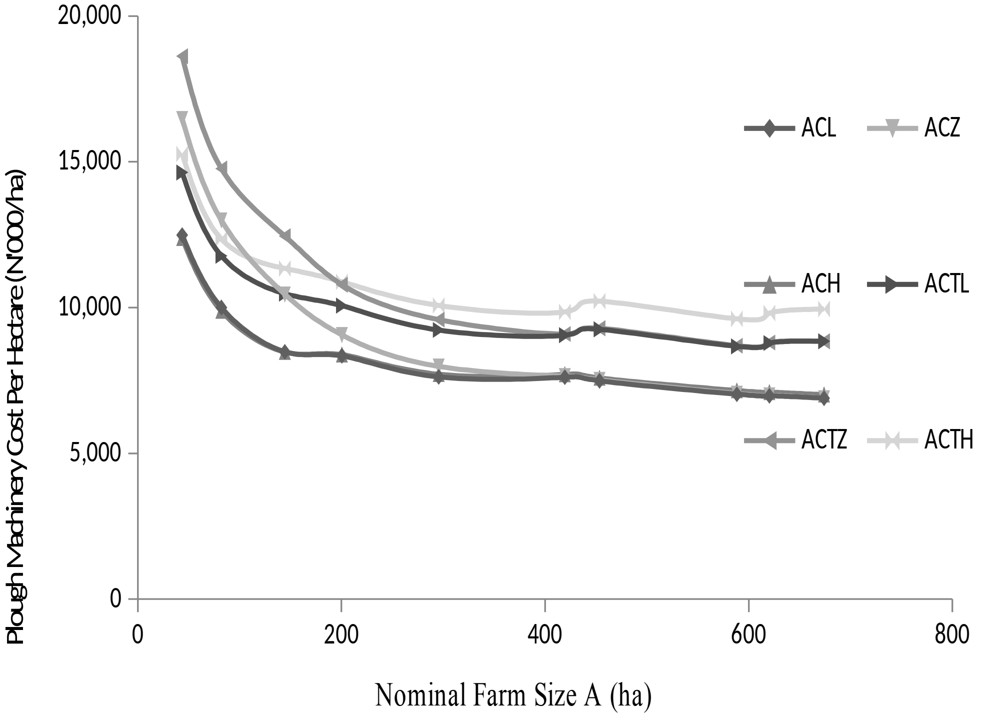



Figure 4.21B: Annual plough machinery cost per hectare for nominal farm size $A$ type

seen in Table 4.22, gave an F-test value of 43.0475 which is higher than the 4.4138 F-critical. The 3.65E-6 p-value is less than the 0.05 p-value for 95 % confidence level. This shows that there was a significant difference between the plough machinery costs incurred for the widths from both farm size types selected by this model.

The percentage difference of the plough machinery cost per hectare for the $A_q$ type from the $A$ type for each of the 3 models are shown in Table 4.23. The L- model costs difference was 35.06 %, 43.25 %, 34.26 % and 32.52 % for the 45 ha, 145 ha, 420 ha and 675 ha farm size respectively. The average variation was 35.55 %. For the Z- model the difference was 20.27 %, 30.39 %, 32.63 % and 31.21 % for the same farm sizes in the same order. The average variation was 29.65 %. The H- model the difference was 35.02 %, 44.21 %, 34.53 % and 32.70 % for the same farm sizes in the same order. The average variation was 35.91 %.

The annual plough machinery and transport costs per hectare at the serviced-field distances corresponding to the minimum-cost plough widths from the 3 models are also shown in Table 4.23 for the 2 farm sizes types. The plots of the costs against varying $A$ are also shown in Figures 4.21A and 4.21B for the 2 farm sizes types $A_q$ and $A$ respectively. The annual plough machinery and transport cost per hectare for $A_q$ was as expected higher than the annual plough machinery cost per hectare. It was however less than the plough machinery and transport cost per hectare for the corresponding $A$. The cost was ₦8,932.44, ₦5,287.20, ₦5,284.61 and ₦4,991.13 for the widths obtained for equivalent farm sizes of 25 ha, 70 ha, 255 ha and 430 ha $A_q$ respectively with the L- model. The cost for the Z- model width, was ₦13,959.35, ₦7,757.27, ₦5,440.98 and ₦5,089.39 for the same listed $A_q$ in that same order. For the H- model, the cost per hectare was ₦9,509.16, ₦5,943.08, ₦5,905.84 and ₦5,866.19 for the same listed $A_q$ in that same order.

The cost per hectare for the 3 models had very close values for each $A_q$ as from 255 ha and above. This $A_q$ corresponded to $A$ 420 ha and above. The plough width chosen with any of the models for any nominal farm size was always higher than that for its $A_q$. The L- model gave a higher plough widths and a lower machinery cost per hectare than the Z- model. The irregular trend of the variation of the costs per hectare could have resulted from the irregular variation of $A_q$ for the $A$ changes. The H- model gave highest plough width of all the 3 models at each studied equivalent farm size. However its corresponding machinery cost per hectare was lower than the L- model and Z- model costs at less than 420 ha and 255 ha $A_q$ respectively. It became higher at higher $A_q$.

### 4.3.3 Harrow size and costs for overlapping operations timing pool farms

The harrow widths ($w_q$) derived from the minimum-cost harrow capacities selected by the developed models for varying $A_q$ are shown in Table 4.24. They are also plotted in Figure 4.22A against the nominal farm size $A$. The widths ($w$) obtained with the 3 models for the

Table 4.24: Minimum-cost disc harrow sizes for differing equivalent pool farm sizes

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Equivalent Farm Size-Based Minimum-cost Harrow Width | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Width $w$ (m) | | | Variation (%) | | | Width-to-Farm Size Ratio | | |
| | | | $w_{qL}$ | $w_{qZ}$ | $w_{qH}$ | $w\%_{qL}$ | $w\%_{qZ}$ | $w\%_{qH}$ | $wR_{qL}$ | $wR_{qZ}$ | $wR_{qH}$ |
| 45 | 24 | 32 | 0.3334 | 0.1027 | 0.9098 | 30.00 | 44.19 | 16.73 | 0.0077 | 0.0024 | 0.0209 |
| 82 | 40 | 56 | 0.4267 | 0.1297 | 0.9946 | 34.18 | 46.67 | 18.24 | 0.0052 | 0.0016 | 0.0121 |
| 145 | 70 | 122 | 0.5521 | 0.1749 | 1.1021 | 35.59 | 50.00 | 19.15 | 0.0038 | 0.0012 | 0.0076 |
| 200 | 110 | 148 | 0.7552 | 0.3391 | 1.3602 | 30.91 | 41.38 | 15.00 | 0.0038 | 0.0017 | 0.0068 |
| 295 | 170 | 208 | 0.9747 | 0.4882 | 1.5315 | 29.79 | 39.29 | 14.75 | 0.0033 | 0.0017 | 0.0052 |
| 420 | 255 | 268 | 1.3286 | 0.8428 | 1.8234 | 27.27 | 37.50 | 14.00 | 0.0032 | 0.0020 | 0.0043 |
| 453 | 275 | 358 | 1.3708 | 0.8710 | 1.8508 | 28.57 | 36.67 | 12.77 | 0.0030 | 0.0019 | 0.0041 |
| 588 | 390 | 434 | 1.6336 | 1.0565 | 1.9738 | 24.32 | 33.33 | 10.53 | 0.0028 | 0.0018 | 0.0034 |
| 620 | 405 | 506 | 1.6521 | 1.0717 | 1.9908 | 25.00 | 34.62 | 13.51 | 0.0027 | 0.0017 | 0.0032 |
| 675 | 430 | 596 | 1.7025 | 1.1220 | 2.0275 | 26.47 | 34.62 | 14.29 | 0.0025 | 0.0017 | 0.0030 |
| | | | | | Average Variation | 29.21 | 39.82 | 14.90 | | | |

| Farm Area $A$ (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce $D$ (km) | Nominal Farm Size-Based Minimum-cost Harrow Width | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Width $w$ (m) | | | Width-to-Farm Size Ratio | | |
| | | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |
| 45 | 24 | 32 | 0.4780 | 0.1862 | 1.0917 | 0.0110 | 0.0043 | 0.0251 |
| 82 | 40 | 56 | 0.6440 | 0.2498 | 1.2114 | 0.0079 | 0.0030 | 0.0148 |
| 145 | 70 | 122 | 0.8576 | 0.3526 | 1.3610 | 0.0059 | 0.0024 | 0.0094 |
| 200 | 110 | 148 | 1.0996 | 0.5875 | 1.6100 | 0.0055 | 0.0029 | 0.0080 |
| 295 | 170 | 208 | 1.3844 | 0.8192 | 1.7977 | 0.0047 | 0.0028 | 0.0061 |
| 420 | 255 | 268 | 1.8473 | 1.3353 | 2.1083 | 0.0044 | 0.0032 | 0.0050 |
| 453 | 275 | 358 | 1.9063 | 1.3822 | 2.1398 | 0.0042 | 0.0030 | 0.0047 |
| 588 | 390 | 434 | 2.1654 | 1.5938 | 2.2472 | 0.0037 | 0.0027 | 0.0038 |
| 620 | 405 | 506 | 2.2115 | 1.6351 | 2.2736 | 0.0036 | 0.0026 | 0.0037 |
| 675 | 430 | 596 | 2.3230 | 1.7567 | 2.3333 | 0.0034 | 0.0026 | 0.0035 |

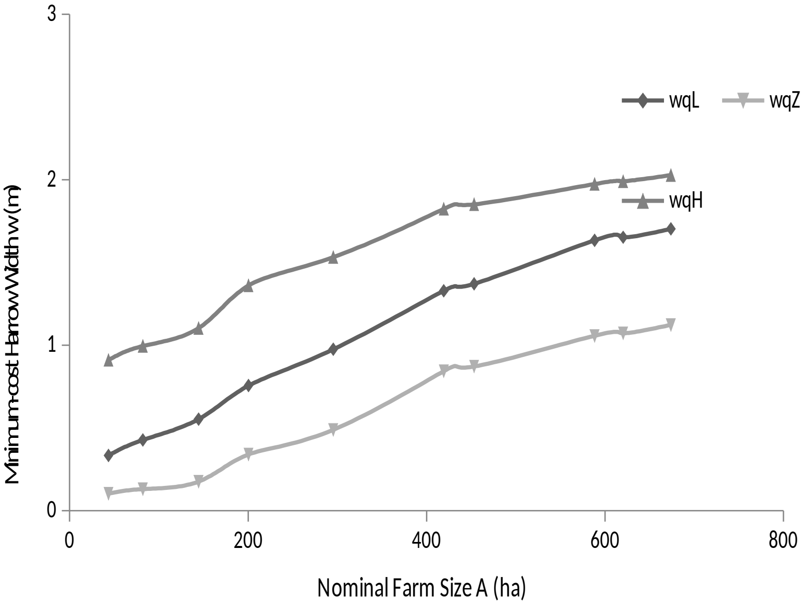



Figure 4.22A: Predicted Minimum-cost harrow width for equivalent farm sizes

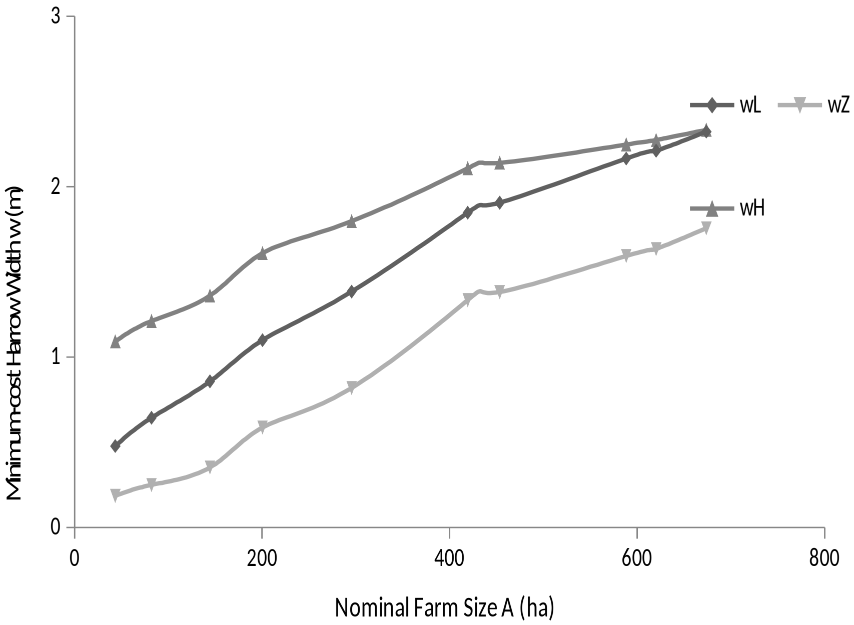



Figure 4.22B: Predicted Minimum-cost harrow width for nominal farm size

corresponding $A$ are also shown in the table and plotted in Figure 4.22B for comparison. A harrow width of 0.3334 m, 0.5521 m, 1.3286 m and 1.7025 m were obtained for $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model. The selected widths contrasted distinctly with the higher harrow widths of 0.4780 m, 0.8576 m, 1.8473 m and 2.3230 m for $A$ values of 45 ha, 145 ha, 420 ha and 675 ha, in the same order. The chosen harrow width for any nominal farm size was always higher than that for its corresponding $A_q$. The ANOVA result for the widths-per-hectare from the 2 sets of farm sizes is shown in Table 4.25 for each of the 3 models. The F-test value of 3.3028 for the L- model is lower than the 4.4138 F-critical. The test p-value of 0.0858 was higher than the 0.05 p-value for 95 % confidence level. It was inferred that the 2 sets of widths obtained with L- model were not significantly different.

Table 4.25 ANOVA F- and p- values for comparison of equivalent and nominal farm sizes harrow widths and corresponding costs

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| F-crit = 4.4138 at p = 0.05 | Width / Cost per Hectare Groups Compared | | | | | |
| | $wR_L : wR_{qL}$ | $wR_Z : wR_{qZ}$ | $wR_H : wR_{qH}$ | $AC_L : AC_{qL}$ | $AC_Z : AC_{qZ}$ | $AC_H : AC_{qH}$ |
| F-test | 3.30283 | 40.56723 | 0.23233 | 23.22407 | 5.141568 | 14.97643 |
| p-value | 0.08584 | 5.34E-6 | 0.63561 | 1.38E-4 | 0.035909 | 0.001122 |

The Z- model width was 0.1027 m, 0.1749 m, 0.8428 m and 1.1220 m for the same $A_q$ in that order. In contrast, harrow widths of 0.1862 m, 0.3526 m, 1.3353 m and 1.7567 m were obtained with the same model on the basis of $A$ corresponding to the listed $A_q$. The ANOVA result for the 2 sets of widths obtained with the Z- model gave an F-test value of 40.5672 which is higher than the 4.4138 F-critical. The 5.34E-6 p-value was lower than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between the harrow widths selected for both farm size types with the model.

The least-cost harrow widths selected by the H- model were 0.9098 m, 1.1021 m, 1.8234 m and 2.0275 m for the listed $A_q$ in that same order. This contrasted with the 1.0917 m, 1.3610 m, 2.1083 m and 2.3333 m for the corresponding $A$ in that same order. The ANOVA result for the 2 sets of widths obtained with the H- model as can be seen in Table 4.25, gave an F-test value of 0.2323 which is lower than the 4.4138 F-critical. The 0.6356 p-value was higher than the 0.05 p-value for 95 % confidence level. This means that the 2 sets of widths were unlikely to be significantly different. There was a significant difference between between the harrow widths selected for both farm size types with the L- and H- models but no significant difference for the widths from the Z- model.

The differences between the minimum-cost harrow widths for the $A_q$ type from the $A$ type for each of the 3 models are shown in Table 4.24. There was a 30 %, 35.59 %, 27.27 % and 26.47 % difference for the L- model widths for the 45 ha, 145 ha, 420 ha and 675 ha nominal size farm ($A$), respectively. The average variation was 29.21 %. For the Z- model the difference was 44.19 %, 50.00 %, 37.50 % and 34.62 % for the same farm sizes in the same order. The average variation was 39.82 %. The H- model the difference was 16.73 %, 19.15 %, 14 % and 14.29 % for the same farm sizes in the same order. The average variation was 14.90 %.

The annual harrow machinery costs per hectare corresponding to these minimum-cost harrow widths from the 3 models are shown in Table 4.26. These costs per hectare based on the equivalent farm size ($A_q$) are also plotted in Figure 4.23A against varying nominal pool farm sizes ($A$). The costs incurred with the 3 models for the corresponding nominal farm size $A$ are also shown in the table and plotted in Figure 4.23B for comparison. The harrow machinery cost per hectare was ₦6,541.76, ₦3,707.41 ₦3,573.34 and ₦3.234.82 for the $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model harrow width. The costs were lower than the corresponding $A$ harrow machinery costs per hectare of ₦9,771.98, ₦6,272.84, ₦5,310.84 and ₦4,699.21 incurred for the plough widths obtained with the same model in the same order. The ANOVA result for the 2 sets of costs as can be seen in Table 4.25, gave an F-test value of 23.2240 which is higher than the 4.4138 F-critical. Also the 1.38E-4 p-value is less than the 0.05 p-value for 95 % confidence level. It was inferred that the costs for the 2 sets of widths were very likely to be significantly different.

The annual harrow machinery cost per hectare corresponding to the Z- model width was ₦11244.01, ₦6,011.19, ₦3,700.24 and ₦3,308.21 for the same listed equivalent pool farm sizes, in that same order. The costs were lower than the corresponding $A$ plough machinery costs per hectare of ₦13,464.90, ₦8,103.97, ₦5,330.20 and ₦4,686.89 incurred for the plough widths obtained with the same model in the same order. The ANOVA result for the 2 sets of costs as can be seen in Table 4.25, gave an F-test of 5.1415 which is higher than the 4.4138 F-critical. The 0.0359 p-value is less than the 0.05 p-value for 95% confidence level, meaning that the costs for the 2 sets of widths were likely to be significantly different.

The annual harrow machinery cost per hectare for the H- model width was ₦7852.84, ₦3,939.71, ₦3,687.61 and ₦3,292.72 for the same $A_q$ in that same order. The costs were lower than the corresponding $A$ harrow machinery costs per hectare of ₦11,072.28, ₦6,425.08, ₦5,385.43 and ₦4,731.57 in the same order, obtained with the same model. The ANOVA result for the 2 sets of costs as can be seen in Table 4.25, gave an F-test value of 14.9764 which is higher than the 4.4138 F-critical. The 0.0011 p-value is less than the 0.05 p-value for 95% confidence level. This showed that there was a significant difference between the harrow machinery costs incurred for the selected widths from both farm size types with this model. The ANOVA of the harrow widths and costs showed significant differences between their between their nominal farm size ($A$) and the equivalent farm size ($A_q$) values for all the 3 models.

Table 4.26 also contains the difference of the harrow machinery costs per hectare for the 2 farm

Table 4.26: Disc harrow cost per hectare for different equivalent pool farm sizes

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Equivalent Farm Size-Based Harrow Machinery Cost per Hectare (₦/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | | | | Machinery and Transport | | |
| | | | | | | Variation (%) | | | | | |
| | | | $AC_{qL}$ | $AC_{qZ}$ | $AC_{qH}$ | $AC\%_{qL}$ | $AC\%_{qZ}$ | $AC\%_{qH}$ | $AC_{TqL}$ | $AC_{TqZ}$ | $AC_{TqH}$ |
| 45 | 24 | 32 | 6541.76 | 11244.01 | 7852.84 | 37.93 | 22.34 | 32.87 | 7371.58 | 12075.70 | 9285.72 |
| 82 | 40 | 56 | 4721.61 | 8085.82 | 5275.66 | 43.47 | 28.57 | 38.53 | 5302.85 | 8669.28 | 6417.87 |
| 145 | 70 | 122 | 3707.41 | 6011.19 | 3939.71 | 48.64 | 34.88 | 43.66 | 4256.97 | 6564.23 | 5184.86 |
| 200 | 110 | 148 | 3843.98 | 4724.25 | 4078.21 | 44.75 | 38.23 | 40.36 | 4300.89 | 5184.49 | 5146.22 |
| 295 | 170 | 208 | 3534.83 | 4058.02 | 3672.65 | 44.03 | 39.02 | 40.13 | 3940.58 | 4467.45 | 4663.61 |
| 420 | 255 | 268 | 3573.34 | 3700.24 | 3687.61 | 42.08 | 40.08 | 38.61 | 3925.08 | 4055.25 | 4574.23 |
| 453 | 275 | 358 | 3497.33 | 3617.30 | 3602.63 | 44.06 | 42.11 | 40.03 | 3916.35 | 4040.48 | 4683.08 |
| 588 | 390 | 434 | 3439.93 | 3540.51 | 3501.70 | 41.17 | 39.27 | 37.72 | 3821.92 | 3926.93 | 4504.21 |
| 620 | 405 | 506 | 3358.95 | 3451.89 | 3419.55 | 42.94 | 41.12 | 39.09 | 3775.67 | 3873.54 | 4522.68 |
| 675 | 430 | 596 | 3234.82 | 3308.21 | 3292.72 | 44.99 | 43.34 | 40.71 | 3680.81 | 3759.52 | 4483.69 |
| | | | Average Variation | | | 43.40 | 36.90 | 39.17 | | | |

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Nominal Farm Size-Based Harrow Machinery Cost per Hectare (₦/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | Machinery and Transport | | |
| | | | $AC_L$ | $AC_Z$ | $AC_H$ | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 24 | 32 | 9771.98 | 13464.90 | 11072.28 | 11877.01 | 15549.61 | 13831.89 |
| 82 | 40 | 56 | 7614.64 | 10396.97 | 8063.43 | 9380.41 | 12137.46 | 10440.76 |
| 145 | 70 | 122 | 6272.84 | 8103.97 | 6425.08 | 8288.48 | 10079.95 | 9203.04 |
| 200 | 110 | 148 | 6044.16 | 6688.41 | 6214.00 | 7784.34 | 8393.81 | 8629.31 |
| 295 | 170 | 208 | 5408.93 | 5731.55 | 5508.72 | 7039.93 | 7326.42 | 7789.73 |
| 420 | 255 | 268 | 5310.84 | 5330.20 | 5385.43 | 6777.08 | 6767.32 | 7451.06 |
| 453 | 275 | 358 | 5203.95 | 5219.31 | 5270.68 | 7000.45 | 6979.07 | 7809.00 |
| 588 | 390 | 434 | 4825.41 | 4832.82 | 4864.91 | 6496.17 | 6466.56 | 7232.39 |
| 620 | 405 | 506 | 4774.58 | 4777.43 | 4811.49 | 6616.54 | 6578.20 | 7424.87 |
| 675 | 430 | 596 | 4699.21 | 4686.89 | 4731.57 | 6691.10 | 6635.12 | 7562.47 |

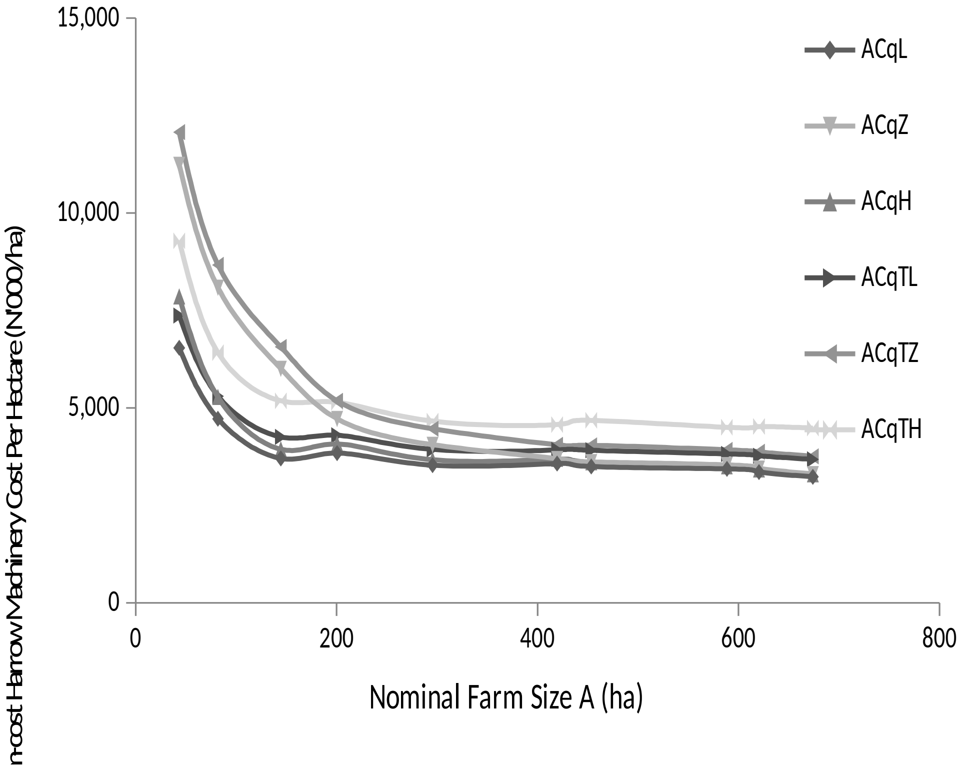



Figure 4.23A: Annual harrow machinery cost per hectare for equivalent farm size type

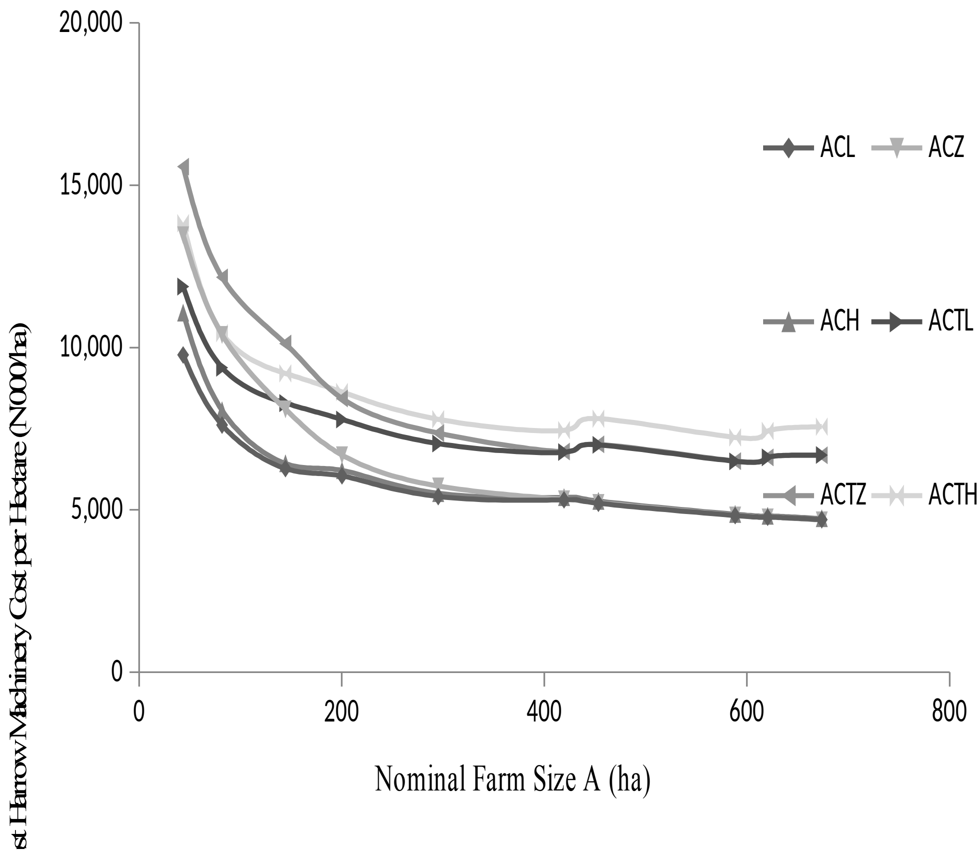



Figure 4.23B: Annual harrow machinery cost per hectare for nominal farm size type

sizes types $A$ and $A_q$ for each of the 3 models. The difference for the L- model costs was 37.93 %, 48.64 %, 42.08 % and 44.99 % for the 45 ha, 145 ha, 420 ha and 675 ha nominal size farm ($A$), respectively. The average variation was 43.40 %. For the Z- model the difference was 22.34 %, 34.88 %, 40.08 % and 43.34 % for the same farm sizes in the same order. The average variation was 36.90 %. The H- model the difference was 32.87 %, 43.66 %, 38.61 % and 40.71 % for the same farm sizes in the same order. The average variation was 39.17 %.

The annual harrow machinery and transport costs per hectare at the serviced-field distances corresponding to the minimum-cost harrow widths obtained for the $A_q$ from the 3 models are also shown in Table 4.26. The plot of the costs against varying $A$ is also shown in Figure 4.23A. The annual harrow machinery and transport cost per hectare as is expected was higher than the ordinary annual harrow machinery cost per hectare for any given $A_q$. It was ₦7,371.58, ₦4,256.97, ₦3,925.08 and ₦3,680.81 for $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model harrow width. The cost for the Z- model width was ₦12,075.70, ₦6,564.23, ₦4,055.25 and ₦3,759.52 for the same listed pool farm sizes in that same order. For the H- model the cost per hectare was ₦9,285.72, ₦5,184.86, ₦4,574.23 and ₦4,483.69 for the same listed pool farm sizes in that same order.

The harrow machinery cost per hectare incurred with the 3 models tended towards the one other for each given farm size for equivalent pool farm sizes of 255 ha and above. This corresponds to 420 ha nominal pool farm size and above. The L- model gave a higher harrow width and a lower machinery cost per hectare than the Z- model. The H- model gave highest harrow width of all the 3 models at each studied equivalent farm size. However its corresponding machinery cost per hectare was lower than the Z- model cost, but higher than the L- model. The H- model harrow machinery and transport cost per hectare was higher than theL- model cost for each farm size considered. It was also higher than the Z- model cost at nominal farm sizes ($A$) of 295 ha and above. Below this farm size it was lower. The cost variation was irregular for nominal farm sizes ($A$) of 295 ha and above.

### 4.3.4 Ridger size and cost for overlapping operations timing pool farms

The ridger widths derived from the minimum-cost ridger capacities ($C_e$) selected by the developed models and the least-cost ridger width selected with the H- model for varying $A_q$ are shown in Table 4.27. The widths are also plotted in Figure 4.24A. The widths obtained with the 3 models for the corresponding $A$ are also shown in the table and plotted in Figure 4.24B for comparison. The chosen ridger width for any $A$ was always higher than that for its

Table 4.27: Predicted minimum-cost disc ridger sizes for differing equivalent pool farm sizes

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Equivalent Farm Size-Based Minimum-cost Ridger Width | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Width $w$ (m) | | | Variation (%) | | | Width-to-Farm Size Ratio | | |
| | | | $w_{qL}$ | $w_{qZ}$ | $w_{qH}$ | $w\%_{qL}$ | $w\%_{qZ}$ | $w\%_{qH}$ | $wR_{qL}$ | $wR_{qZ}$ | $wR_{qH}$ |
| 45 | 24 | 32 | 0.3426 | 0.0684 | 0.9133 | 49.03 | 48.39 | 49.03 | 0.0079 | 0.0016 | 0.0210 |
| 82 | 40 | 56 | 0.4438 | 0.0898 | 1.0017 | 73.00 | 73.17 | 73.01 | 0.0054 | 0.0011 | 0.0122 |
| 145 | 70 | 122 | 0.5785 | 0.1256 | 1.1205 | 84.67 | 84.21 | 84.58 | 0.0040 | 0.0009 | 0.0078 |
| 200 | 110 | 148 | 0.7664 | 0.2365 | 1.3821 | 89.02 | 88.79 | 88.94 | 0.0038 | 0.0012 | 0.0069 |
| 295 | 170 | 208 | 0.9887 | 0.3546 | 1.5813 | 92.62 | 92.50 | 92.44 | 0.0033 | 0.0012 | 0.0054 |
| 420 | 255 | 268 | 1.2973 | 0.5952 | 1.8778 | 94.71 | 94.80 | 94.69 | 0.0031 | 0.0014 | 0.0045 |
| 453 | 275 | 358 | 1.3474 | 0.6209 | 1.9060 | 95.07 | 95.00 | 95.12 | 0.0030 | 0.0014 | 0.0042 |
| 588 | 390 | 434 | 1.6207 | 0.7712 | 2.0492 | 96.17 | 96.26 | 96.22 | 0.0028 | 0.0013 | 0.0035 |
| 620 | 405 | 506 | 1.6477 | 0.7876 | 2.0652 | 96.37 | 96.35 | 96.46 | 0.0027 | 0.0013 | 0.0033 |
| 675 | 430 | 596 | 1.7018 | 0.8304 | 2.1035 | 96.75 | 96.80 | 96.74 | 0.0025 | 0.0012 | 0.0031 |
| | | | | | Average Variation | 86.74 | 86.63 | 86.72 | | | |

| Farm Area $A$ (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce $D$ (km) | Nominal Farm Size-Based Minimum-cost Ridger Width | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Width $w$ (m) | | | Width-to-Farm Size Ratio | | |
| | | | $w_L$ | $w_Z$ | $w_H$ | $wR_L$ | $wR_Z$ | $wR_H$ |
| 45 | 24 | 32 | 0.4794 | 0.0684 | 0.9133 | 0.0155 | 0.0031 | 0.0412 |
| 82 | 40 | 56 | 0.6567 | 0.0898 | 1.0017 | 0.0200 | 0.0041 | 0.0452 |
| 145 | 70 | 122 | 0.8813 | 0.1256 | 1.1205 | 0.0261 | 0.0057 | 0.0506 |
| 200 | 110 | 148 | 1.0958 | 0.2365 | 1.3821 | 0.0346 | 0.0107 | 0.0624 |
| 295 | 170 | 208 | 1.3776 | 0.3546 | 1.5813 | 0.0447 | 0.0160 | 0.0714 |
| 420 | 255 | 268 | 1.7660 | 0.5952 | 1.8778 | 0.0586 | 0.0269 | 0.0848 |
| 453 | 275 | 358 | 1.8349 | 0.6209 | 1.9060 | 0.0608 | 0.0280 | 0.0861 |
| 588 | 390 | 434 | 2.1027 | 0.7712 | 2.0492 | 0.0732 | 0.0348 | 0.0925 |
| 620 | 405 | 506 | 2.1596 | 0.7876 | 2.0652 | 0.0744 | 0.0356 | 0.0933 |
| 675 | 430 | 596 | 2.2728 | 0.8304 | 2.1035 | 0.0769 | 0.0375 | 0.0950 |

$A_q$ ridger size for all the 3 models. The test F- and p- values of the ANOVA for the 2 sets of widths comparison are shown in Table 4.27. A ridger width of 0.3426 m, 0.5785 m, 1.2973 m and 1.7018 m was obtained for the $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model. These $A_q$ correspond to $A$ of 45 ha, 145 ha, 420 ha and 675 ha respectively. The selected widths contrasted distinctly with ridger widths of 0.4794 m, 0.8813 m, 1.7660 m and 2.2728 m obtained for these $A$ in the same order with the model. For the ANOVA of the 2

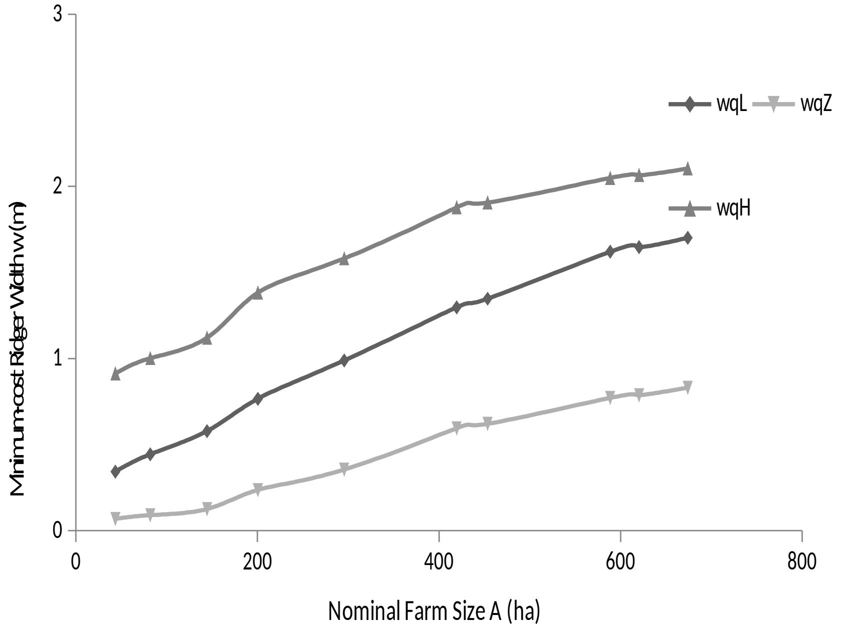



Figure 4.24A: Minimum-cost ridger width for equivalent farm size

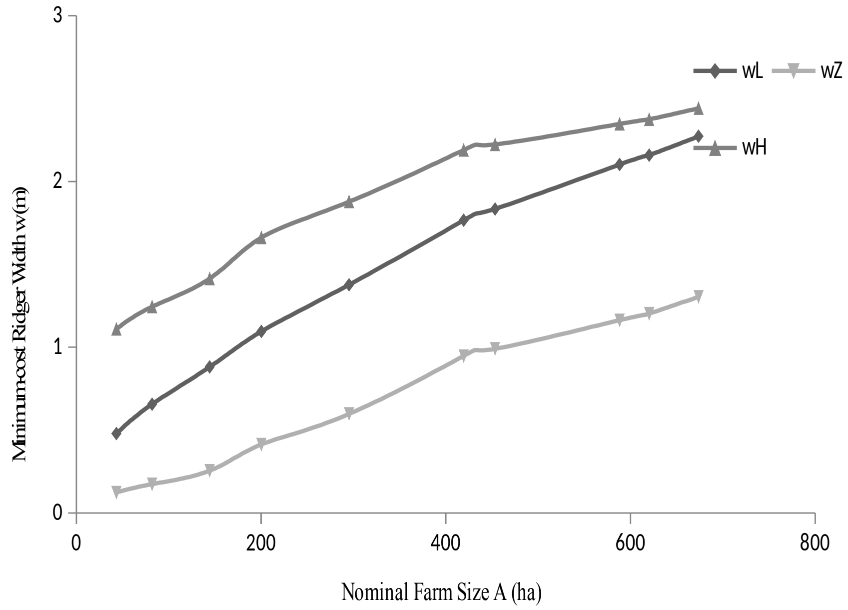



Figure 4.24B: Minimum-cost ridger widths for nominal farm sizes

sets of width predicted with the model, the test F of 2.7495 was less than the 4.4138 F-critical. Also the p-value of 0.1146 was higher than the 0.05 p-value for 95 % confidence level. This showed that there was no significant difference between the ridger widths from both farm size types.

The width obtained with the Z- model was 0.0684 m, 0.1256 m, 0.5952 m and 0.8304 m for the same $A_q$ in that order. In contrast, ridger widths of 0.1241 m, 0.2554 m, 0.9480 m and 1.3041 m were obtained for the corresponding listed $A$ in that same order with the Z- model. The ANOVA F-test value of 24.6401 was higher than the 4.4138 F-critical, and p-value of 0.0001 was less than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between the ridger widths selected for both farm size types.

The least-cost ridger width selected by the H- model for was 0.9133 m, 1.1205 m, 1.8778 m and 2.1035 m for the same $A_q$ in that same order. This contrasted with the 1.0917 m, 1.3610m, 2.1083 m and 2.3333 m ridger width obtained for the corresponding $A$ in that same order. The F-test value of 60.0511 was higher than the 4.4138 F-critical, and the p-value of 3.85E-10 was less than the 0.05 p-value for 95% confidence level. This showed that there was a significant difference between the ridger widths selected for both farm size types.

Table 4.28: ANOVA F- and p- values for comparison of equivalent and nominal farm sizes ridger widths and corresponding costs

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| F-crit = 4.4138 at p = 0.05 | Width / Cost per Hectare Groups Compared | | | | | |
| | $wR_L : wR_{qL}$ | $wR_Z : wR_{qZ}$ | $wR_H : wR_{qH}$ | $AC_L : AC_{qL}$ | $AC_Z : AC_{qZ}$ | $AC_H : AC_{qH}$ |
| F-test | 2.74959 | 24.64016 | 60.05118 | 31.79414 | 2.528709 | 32.64049 |
| p-value | 0.11460 | 0.00010 | 3.85E-7 | 2.38E-5 | 0.129201 | 2.04E-5 |

The percentage difference of the minimum-cost ridger widths for the $A_q$ type from the $A$ type for each of the 3 models is shown in Table 4.27. The difference for the L- model widths was 49.03 %, 84.67 %, 94.71 % and 96.75 % for the 45 ha, 145 ha, 420 ha and 675 ha nominal size farm ($A$), respectively. The average variation was 86.74 %. For the Z- model the difference was 48.39 %, 84.21 %, 94.80 % and 96.80 % for the same farm sizes in the same order. The average variation was 86.63 %. The H- model the difference was 49.03 %, 84.58 %, 94.69 % and 96.74 % for the same farm sizes in the same order. The average variation was 86.72 %.

The annual ridger machinery costs per hectare corresponding to these obtained minimum-cost ridger widths for the considered $A_q$ from the 3 models are shown in Table 4.29 and plotted in Figure 4.25A against varying nominal pool farm sizes. The costs incurred for the ridger widths obtained for the corresponding nominal farm sizes $A$ also are shown in Table 4.29 and plotted in Figure 4.25B for comparison. The ridger machinery cost per hectare was ₦8,339.32, ₦4,987.70, ₦4,842.60 and ₦4,522.59 for the $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model ridger width. These costs were lower than the corresponding plough machinery costs per hectare of ₦12,572.58, ₦8,705.09, ₦7,312.15 and ₦6,657.42 in the same order incurred for the ridger widths obtained on $A_q$ basis with the model.

Table 4.29: Disc ridger cost per hectare for different equivalent pool farm sizes

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Equivalent Farm Size Based Harrow Machinery Cost per Hectare (₦/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | | | | Machinery and Transport | | |
| | | | | | | Variation (%) | | | | | |
| | | | $AC_{qL}$ | $AC_{qZ}$ | $AC_{qH}$ | $AC\%_{qL}$ | $AC\%_{qZ}$ | $AC\%_{qH}$ | $AC_{TqL}$ | $AC_{TqZ}$ | $AC_{TqH}$ |
| 45 | 24 | 32 | 8339.32 | 22404.37 | 8329.84 | 33.67 | 11.02 | 32.77 | 9157.27 | 23226.04 | 9742.85 |
| 82 | 40 | 56 | 6180.79 | 15721.12 | 5956.54 | 39.44 | 17.61 | 39.30 | 6757.52 | 16302.28 | 7087.68 |
| 145 | 70 | 122 | 4987.70 | 11331.21 | 4746.91 | 42.70 | 21.70 | 43.31 | 5537.10 | 11887.58 | 5985.22 |
| 200 | 110 | 148 | 5135.79 | 8333.82 | 4968.61 | 37.98 | 25.59 | 38.42 | 5592.54 | 8797.61 | 6032.35 |
| 295 | 170 | 208 | 4846.35 | 6877.85 | 4710.09 | 36.01 | 26.20 | 36.63 | 5251.92 | 7291.34 | 5698.79 |
| 420 | 255 | 268 | 4842.60 | 5827.86 | 4762.43 | 33.77 | 28.08 | 34.27 | 5193.71 | 6186.76 | 5648.37 |
| 453 | 275 | 358 | 4754.13 | 5692.83 | 4677.19 | 33.89 | 28.30 | 34.42 | 5172.63 | 6121.26 | 5757.46 |
| 588 | 390 | 434 | 4815.77 | 5610.87 | 4754.68 | 29.32 | 24.38 | 29.88 | 5196.20 | 6001.96 | 5757.84 |
| 620 | 405 | 506 | 4696.78 | 5455.33 | 4639.67 | 30.41 | 25.54 | 30.97 | 5111.78 | 5882.26 | 5743.77 |
| 675 | 430 | 596 | 4522.59 | 5199.95 | 4472.52 | 32.07 | 27.33 | 32.64 | 4966.58 | 5656.99 | 5664.90 |
| | | | Average Variation | | | 34.93 | 23.57 | 35.26 | | | |

| Farm Area A (ha) | Equivlt Farm Area $A_q$ (ha) | Cum. Transpt Distnce D (km) | Nominal Farm Size Based Harrow Machinery Cost per Hectare (₦/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Machinery Alone | | | | Machinery and Transport | | |
| | | | $AC_L$ | $AC_Z$ | $AC_H$ | | $AC_{TL}$ | $AC_{TZ}$ | $AC_{TH}$ |
| 45 | 24 | 32 | 12572.58 | 25179.19 | 12389.83 | | 15348.65 | 27955.26 | 15760.25 |
| 82 | 40 | 56 | 10206.60 | 19082.23 | 9812.90 | | 12602.40 | 21478.03 | 12767.44 |
| 145 | 70 | 122 | 8705.09 | 14471.34 | 8373.45 | | 11506.21 | 17272.46 | 11876.48 |
| 200 | 110 | 148 | 8280.45 | 11199.44 | 8068.64 | | 10708.12 | 13627.11 | 11123.83 |
| 295 | 170 | 208 | 7573.07 | 9319.12 | 7433.26 | | 9860.66 | 11606.71 | 10330.80 |
| 420 | 255 | 268 | 7312.15 | 8102.72 | 7245.37 | | 9374.88 | 10165.45 | 9876.89 |
| 453 | 275 | 358 | 7191.51 | 7939.61 | 7131.52 | | 9725.64 | 10473.73 | 10370.50 |
| 588 | 390 | 434 | 6813.88 | 7420.16 | 6780.74 | | 9173.98 | 9780.25 | 9806.21 |
| 620 | 405 | 506 | 6749.23 | 7326.91 | 6721.66 | | 9353.63 | 9931.31 | 10063.55 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 675 | 430 | 596 | 6657.42 | 7155.16 | 6639.53 | | 9476.29 | 9974.02 | 10262.56 |

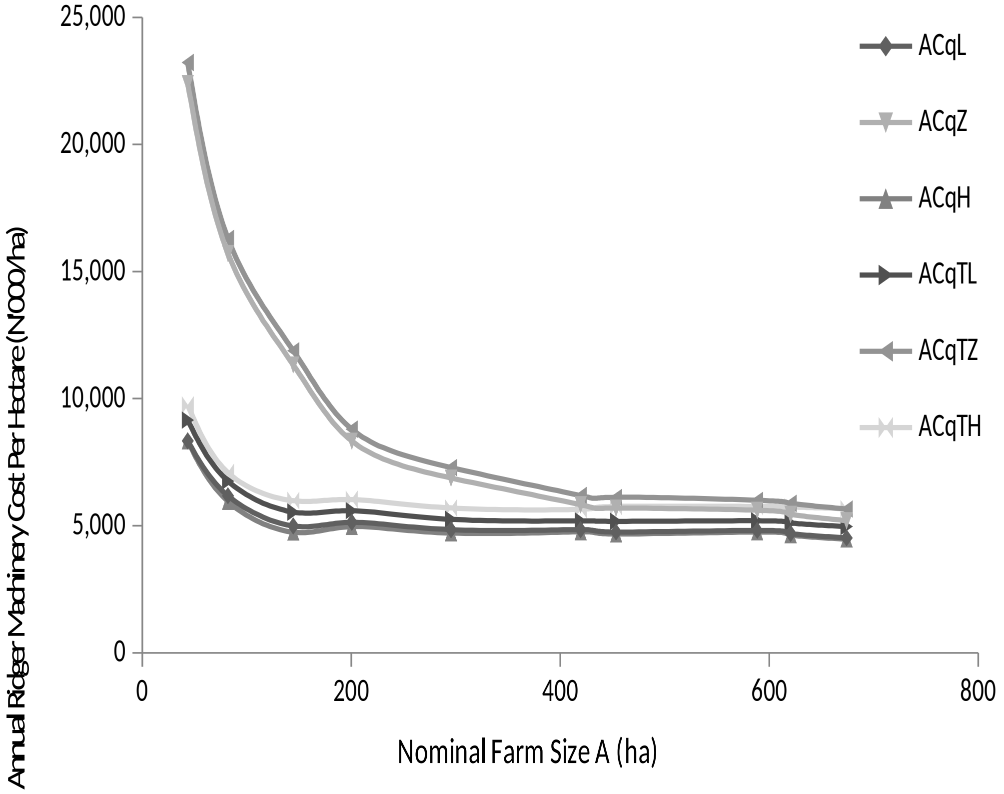



Figure 4.25A: Annual ridger machinery cost per hectare for equivalent farm size type

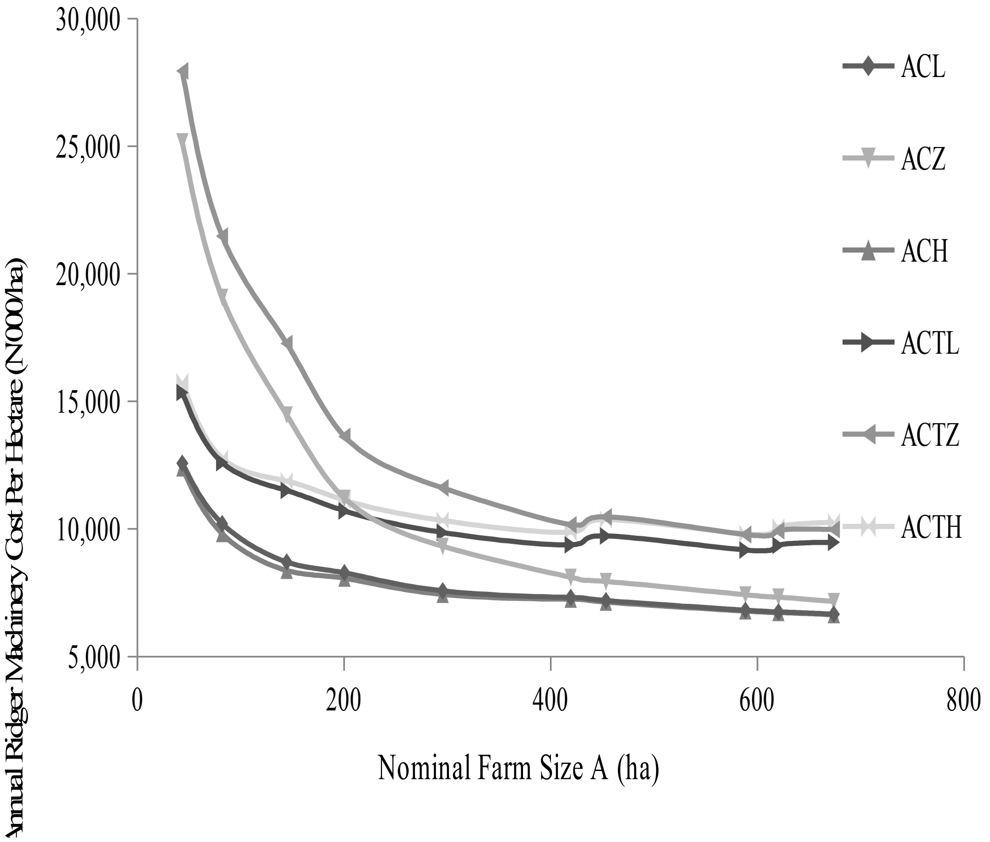



Figure 4.25B: Annual ridger machinery cost per hectare for nominal farm size type

The ANOVA for the 2 sets of costs as can be seen in Table 4.28, gave an F-test of 31.7941 which is higher than the 4.4138 F-critical. The 2.38E-5 p-value is less than the 0.05 p-value for 95% confidence level. This showed that there was a significant difference between the ridger machinery costs incurred for the widths from both farm size types selected by this model.

The annual ridger machinery cost per hectare incurred for the Z- model width was ₦22,404.37, ₦11,331.21, ₦5,827.86 and ₦5,199.95 for the same listed $A_q$ in that same order. The costs were lower than the ridger machinery costs per hectare of ₦25,179.19, ₦14,471.34, ₦8,102.72 and ₦7,155.16 obtained with the same model on the basis of the corresponding $A$ in the same order. The ANOVA result for the 2 sets of costs as can be seen in Table 4.28, gave an F-test value of 2.5287 which is less than the 4.4138 F-critical. The 0.1292 p-value is higher than the 0.05 p-value for 95 % confidence level. This showed that there was no significant difference between the ridger machinery costs incurred for the widths selected for both farm size types by this model.

The annual ridger machinery cost per hectare for the H- model width was ₦8,329.84, ₦4,746.91, ₦4,762.43 and ₦4,472.52 for the same $A_q$ in that same order. The costs were lower than those of the corresponding $A$ width; which was ₦12,389.83, ₦8,373.45,

₦7,245.37 and ₦6,639.53 in the same farm size order with the model. The test F- and p-values of the ANOVA for the 2 sets of costs is shown in Table 4.28, gave an F-test value of 32.6404 which is higher than the 4.4138 F-critical. The 2.04E-5 p-value is less than the 0.05 p-value for 95 % confidence level. This showed that there was a significant difference between the ridger machinery costs incurred for the widths from both farm size types selected by this model.

The percentage difference of the machinery costs per hectare for the $A_q$ type from the $A$ type ridger widths for each of the 3 models are shown in Table 4.29. The difference for the L- model costs was 33.67 %, 42.70 %, 33.77 % and 32.07 % for the 45 ha, 145 ha, 420 ha and 675 ha nominal size farm ($A$), respectively. The average variation was 34.93 %. For the Z- model the difference was 11.02 %, 21.70 %, 28.08 % and 27.33 % for the same farm sizes in the same order. The average variation was 23.57 %. The H- model the difference was 32.77 %, 43.31 %, 34.27 % and 32.64 % for the same farm sizes in the same order. The average variation was 35.26 %.

The annual ridger machinery and transport costs per hectare at the serviced-field distances corresponding to $A_q$ minimum-cost ridger widths from the 3 models are also shown in Table 4.29. The plots of the costs against varying $A_q$ are also shown in Figure 4.25A. The annual ridger machinery and transport cost per hectare as is expected was higher than the plain annual ridger machinery cost per hectare for any given $A_q$. It was ₦9,157.27, ₦5,537.10, ₦5,193.71 and ₦4,966.58 for $A_q$ of 25, 70, 255 and 430 hectares respectively with the L- model ridger width. The cost for the Z- model width was ₦23,226.04, ₦11,887.58, ₦6,188.76 and ₦5,656.99 for the same listed $A_q$ in that same order. For the H- model, the cost per hectare was ₦9,742.85, ₦5,985.22, ₦5,648.37 and ₦5,664.90 for the same listed pool farm sizes in that same order. The cost per hectare incurred with the 3 models tended towards close values at $A_q$ of 255 ha and above (ie 420 ha $A$ and above). The H- model and the L- model costs were close to each other and were lower than that of the Z- model. The L- model gave a higher ridger width and a lower machinery cost per hectare than the Z- model. The H- model gave highest ridger width of all the 3 models at each studied farm size. However its corresponding machinery cost per hectare was lower than the Z- model and the L- model costs.

There was a hiked annual cost per hectare for the 25 ha total $A_q$ as the machinery annual fixed cost must be recovered from only the small farm size processed. This again demonstrates the economic non-viability of mechanizing very small farms. The developed Z- model annual machinery cost per hectare was very high compared to the L- model case for all implements.

Increased field processing labour cost owing to its selection of very small tillage machinery capacity increased the cost per hectare greatly even though the initial machinery investment cost was lower. The foregoing elaborates the need for a thorough cost analysis of alternatives as afforded by relevant models like the ones developed in this study before deciding on a machinery selection option.

The tillage machinery capacities selected, and by extension the derived widths were less for $A_q$ than for the corresponding $A$. The associated annual plough machinery costs were lower for $A_q$ basis than for the $A$ basis. Differing operation timing as afforded by multiple crop farming and the studied locations' differing ecological conditions as in Anambra State Nigeria, can lead to the use of $A_q$ basis machinery selection. Enhanced machinery cost reduction in Anambra State-wide tractor hiring service for example can thus be made possible through. The gap between the tillage machinery capacities selected with the $A_q$ and the ones with the corresponding $A$ grew wider with increasing farm size. The opposite went for their associated annual costs. Again a decreasing difference was observed between the annual tillage machinery cost per hectare and the transport cost-incorporated annual tillage machinery cost per hectare with increasing equivalent farm size. This shows that the effect of machinery transportation cost gets smaller with equivalent farm size increase.

## 4.4 Tillage Machinery Selection for Small Farms

The result of the models application in machinery selection for scattered small farms' pool and independent machinery use arrangement was discussed in this section. The total machine width chosen for each of the case and the corresponding total machinery cost are discussed. The total cost considered for the independent machinery use did not include inter-farm machinery transport cost since the selected implement size was meant for only the concerned farm. However the total incurred cost considered for the plough machinery selected under machinery sharing arrangement included the cost of the inter-farm machinery transport. The minimized total distance realized from the LP routing modelling was 8.72 km.

### 4.4.1 Selected plough machinery for small farms

The sum of the plough widths selected with the 3 models and their total machinery cost per hectare for the small farms are shown in Table 4.30 and Figure 4.26. When the 6 farms were treated independently the sum of the widths selected was 1.6043 m for the L- model, 0.2062

Table 4.30: Predicted ploughs width and machinery costs per hectare under different machinery use arrangements for small farms

| Machinery Sharing | Selected Plough Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| Yes | 0.7480 | 0.2062 | 0.7935 | 8861.50 | 15023.60 | 8885.88 |
| None | 1.6043 | 0.2062 | 2.6234 | 105517.48 | 798859.45 | 102736.45 |

for the Z- model and 0.7935 m for the H- model. But when the small farms are pooled into a medium-sized farm (of 100 ha), the selected width decreased to 0.7480 m for the L- model and 0.7935 m for the Z- model. The total width predicted with the Z- model for the independent or combined machinery use for the farms was unchanged for the farm sizes considered. The incurred total cost per hectare for all the plough machinery selected was ₦105,517.48 with the L- model, ₦798,859.45 with the Z- model and ₦102,736.45 with the H- model when the farms were treated independently. The sum of the total cost per hectare was ₦8,861.50 with the L- model, ₦15,023.60 with the Z- model and ₦8,885.88 with the H- model when the farms were treated independently. The total machinery cost per hectare was very much less when the pool farms shared the plough machinery than for the independent machinery use situation. Despite the unchanged size of plough machinery predicted by the Z- model for each machinery use case, the total machinery cost per hectare was enormously increased for the independent machinery use for the farms.

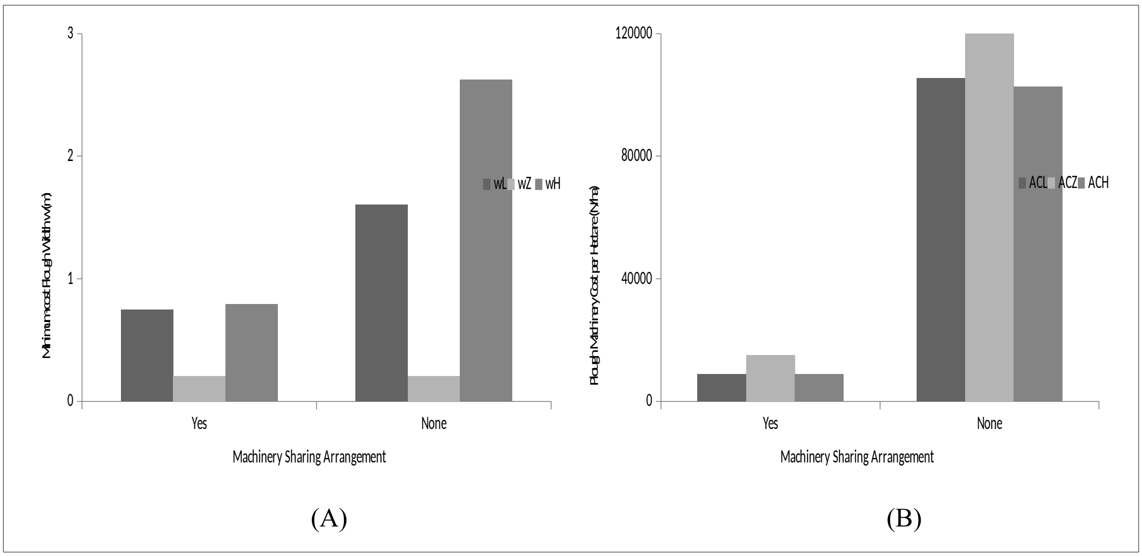



Figure 4.26: Selected minimum-cost plough width (A) and annual plough machinery cost per hectare (B) under different machinery use arrangements for small farms

### 4.4.2 Selected harrow machinery for small farms

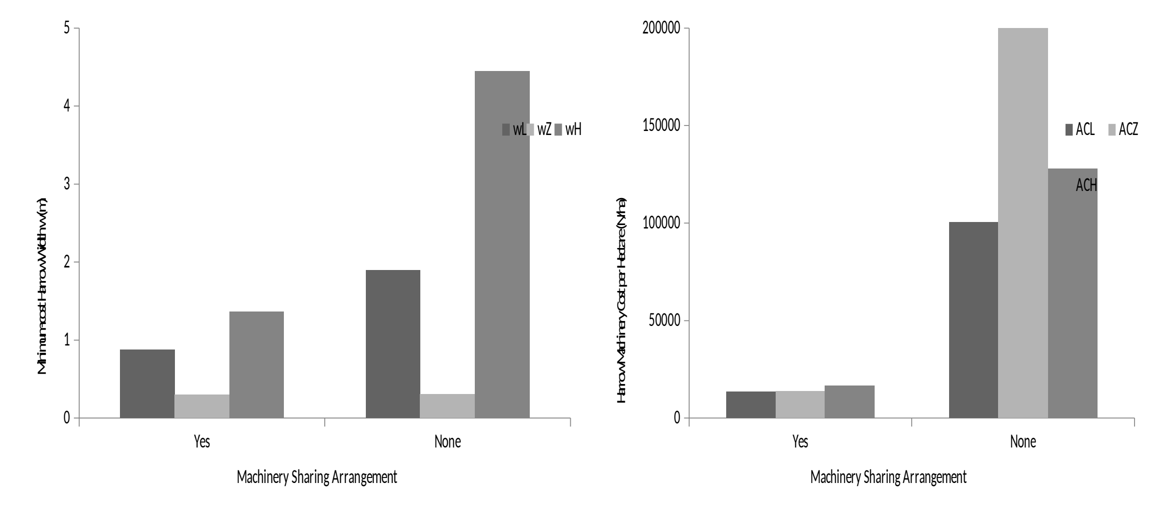
The sum of the harrow widths selected wth the 3 models and their total machinery cost per hectare for the small farms are shown in Table 4.31 and Figure 4.27. When the 6 farms were treated independently the sum of the harrow widths selected was 1.8961 m for the L- model,

Table 4.31: Predicted harrow width and machinery costs per hectare for machinery sharing arrangements

| Machinery Sharing | Selected Harrow Width *w* (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| Yes | 0.8752 | 0.3020 | 1.3610 | 13386.80 | 13666.69 | 16728.11 |
| None | 1.8961 | 0.3058 | 4.4465 | 100481.42 | 548958.32 | 127925.82 |

0.3058 for the Z- model and 4.4465 m for the H- model. But when the small farms are pooled into a medium-sized farm (of 100 ha), the selected width decreased to 0.7480 m for the L- model and 1.310 m for the H- model. The total width predicted with the Z- model for the combined machinery use for the farms changed slightly to 0.3020 m. considered.

The incurred total cost per hectare for all the plough machinery selected was ₦10,0481.42 with the L- model, ₦548,958.32 with the Z- model and ₦127,925.82 with the H- model when the farms were treated independently. The total incurred cost considered for the plough machinery selected under machinery sharing included the cost of the inter-farm machinery transport. The total cost per hectare was ₦13,386.80 with the L- model, ₦13,666.69 with the Z- model and ₦16,728.11 with the H- model when the farms were treated independently. The total machinery cost per hectare was very much less when the pool farms shared the plough machinery than for the independent machinery use situation.




(A) (B)

Figure 4.27: Selected minimum-cost harrow width (A) and annual harrow machinery cost per hectare (B) under different small farm's machinery use arrangements

Despite the very slight change in size of the harrow machinery predicted by the Z- model from that of the combined machinery use case, the total machinery cost per hectare was enormously increased for the independent machinery use for the farms.

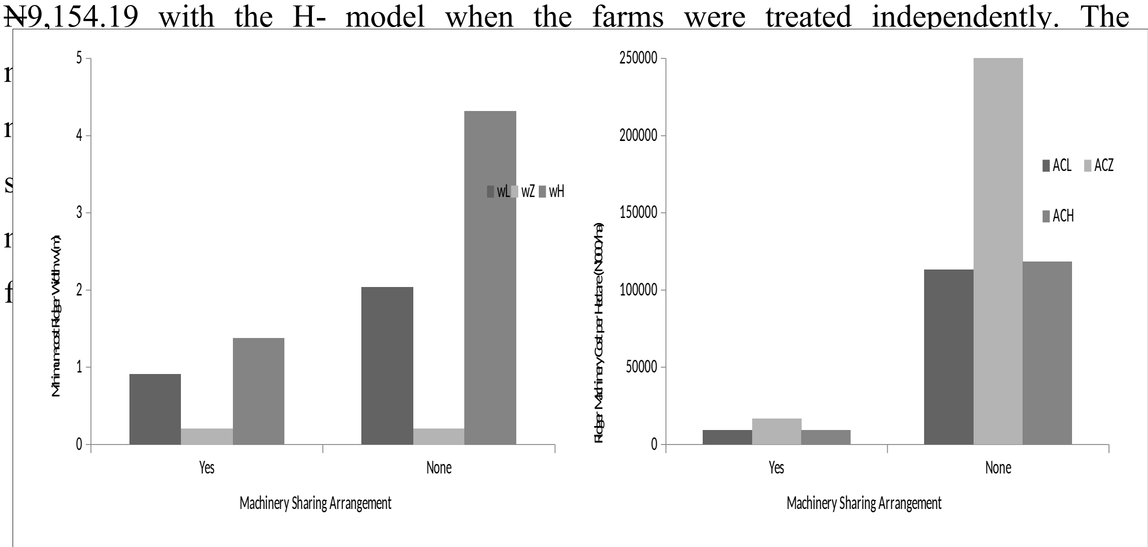
### 4.4.3 Selected ridger machinery for small farms

The sum of the ridger widths selected wth the 3 models and their total machinery cost per hectare for the small farms are shown in Table 4.32 and Figure 4.28. When the 6 farms were treated independently the sum of the widths selected was 2.0384 m for the L- model, 0.2080 for the Z- model and 4.3178 m for the H- model. But when the small farms were pooled into a medium-sized farm (of 100 ha), the selected width decreased to 0.9129 m for the L- model and 1.3754 m for the H- model. The total width predicted with the Z- model for the combined machinery use case for the farms reduced slightly to 0.2075 m. The incurred total cost per hectare for all the ridger machinery sizes selected was ₦113,112.20 with the L- model, ₦1,186,922.68 with the Z- model and ₦118,511.51 with the H- model when the farms were treated independently. The total incurred cost considered for the ridger machinery selected

Table 4.32: Predicted ridger widths and machinery costs per hectare for machinery sharing arrangements

| Machinery Sharing | Selected Ridger Width $w$ (m) | | | Annual Machinery Cost per Hectare (₦/ha) | | |
|---|---|---|---|---|---|---|
| | $w_L$ | $w_Z$ | $w_H$ | $AC_L$ | $AC_Z$ | $AC_H$ |
| Yes | 0.9129 | 0.2075 | 1.3754 | 9103.25 | 16608.42 | 9154.19 |
| None | 2.0384 | 0.2080 | 4.3178 | 113112.20 | 1186922.68 | 118511.51 |

under machinery sharing included the cost of the inter-farm machinery transport. The total cost per hectare was ₦9,103.25 with the L- model, ₦16,608.42 with the Z- model and ₦9,154.19 with the H- model when the farms were treated independently. The total




(A) (B)

Figure 4.28: Selected minimum-cost ridger width (A) and annual ridger machinery cost per hectare (B) under different small farm machinery use arrangements

The sum of the widths selected for the small farms based on independent machinery use were in comparison higher than that selected for the. annual cost per hectare for the 25 ha total $A_q$ as the machinery annual fixed cost must be recovered from only the small farm size processed. This again demonstrates the economic non-viability of mechanizing very small farms.

**4.5 Tillage Machinery Capacity Adjustment for Machinery Transport Time Loss**

To employ the machine selection models for non contiguous combined farms case, the loss of part of the time available for field processing to machinery transport needs consideration in the implement size selected. The time lost to machinery transport between the farm plots was not captured in the differentiation process of the model development. The selected tillage capacity ($C_e$) should thus be adjusted to accommodate the inter-field transport time loss based on Equation 3.119. A new adjusted capacity ($C_{eR}$) for the implement size selected with each model was, evaluated. The basal field capacity ($C_{eQ}$) was gotten from dividing the given pool farm size with the available field processing period based on Equation 3.120. The capacities selected for the 430 ha equivalent farm size *ie* 675 ha nominal farm size with the developed models and H- model are presented and compared with the adequate machinery capacity needed based on the hours within the available period of acceptable field processing.

**4.5.1 Plough machinery capacity recommended**

The predicted plough machinery capacity ($C_e$) selected for the studied total 430 ha equivalent (*ie* 675 ha nominal), pool farm with the various models are shown in Table 4.33. The adjusted plough capacities for transport time loss ($C_{eR}$) for the 3 models are also shown in

Table 4.33. The basal field capacity evaluated for the pool farm size on the basis of available hours ($C_{eQ}$) is also presented in the same Table 4.33. The corresponding annual machinery cost per hectare, and the machinery and transport cost per hectare for these implement sizes are also shown in Table 4.33.

The adjusted plough field capacity based on the L- model, Z- model, and the H- model was 0.6537 ha/hr, 0.4526 ha/hr and 0.5239 ha/hr respectively. These correspond to 1.8975 m, 1.3139 m and 1.5207 m, respectively. Based on the available field processing hours of 1060 hrs, evaluated from Figure 3.9 a plough field capacity of 0.4033 ha/hr was considered basic for processing of the 430 ha equivalent pool farm. This translates to a plough width of 1.1706 m. However, if the pool farm size to be processed were to be evaluated on the basis of the nominal 675 ha, the adequate plough capacity needed will increase to 0.6360 ha/hr; and its width to 1.8975 m.

From the foregoing, the 0.6533 ha/hr predicted plough field capacity and its adjusted 0.6537 ha/hr selected with the L- model were considered adequate, for completing the field's ploughing within the available time. The Z- model 0.4527 ha/hr adjusted capacity was seen as inadequate for processing the field timely. Similarly, the H- model 0.5239 ha/hr adjusted capacity appears adequate for the 430 ha equivalent farm size processing. It will however be more liable to failure in completing the field processing due to shocks (*ie* delays) in the system. The highest corresponding unadjusted annual plough machinery cost per hectare was recorded for the developed Z- model, and was ₦4,741.27.

Table 4.33: Recommended minimum-cost plough sizes for 430 ha equivalent farm size (ie 675 ha nominal farm size)

| Implement /Model Parameter | | Implement Size | | |
|---|---|---|---|---|
| | | L | Z | H |
| Plain Model Size Selected | Capacity $C_e$ (ha/hr) | 0.6533 | 0.4525 | 0.5238 |
| | Width $w$ (m) | 1.8964 | 1.3135 | 1.5203 |
| Adjusted Size^ | Capacity $C_{eR}$ (ha/hr) | 0.6537 | 0.4526 | 0.5239 |
| | Width $w$ (m) | 1.8975 | 1.3139 | 1.5207 |
| Corresponding Costs per Hectare (₦/ha) | | | | |
| Plain Model Machinery Cost per Hectare (₦/ha) | | 4651.20 | 4741.27 | 4718.15 |
| Plain Model Machinery and Transport Cost per Hectare (₦/ha) | | 4991.13 | 5089.39 | 5866.19 |
| Implement Size for Adequacy Comparism | | | | |
| | Capacity $C_{eQ}$ (ha/hr) | 0.6360 | | |

| | | |
|---|---|---|
| Nominal Farm Size's Basal Implement Size# | Width $w$ (m) | 1.8461 |
| Equivalent Farm Size's Basal Implement Size# | Capacity $C_{eQ}$ (ha/hr) | 0.4033 |
| | Width $w$ (m) | 1.1707 |
| Selected Implement — Implement Size | Capacity (ha/hr) | 0.6550 |
| | Width $w$ (m) | 1.8975 |
| Selected Implement — Corresponding Cost per Hectare (₦/ha) | Machinery | 4488.73 |
| | Machinery & Transport | 4828.68 |

^With Machinery Transport Hours Loss Considered
#for Available Working Hours

On the other the H- model had the highest machinery and transport cost per hectare:- ₦5,866.19. The developed $A_q$ model corresponding annual plough machinery cost per hectare and its machinery and transport cost per hectare were the lowest; with values as ₦4,651.20 and ₦4,991.13 respectively. The adjusted L- model plough field capacity of 0.6537 ha/hr (ie 1.8974 m width), was thus chosen as the plough field capacity needed. This corresponded to a plough annual machinery cost per hectare of ₦4,651.20 and machinery and transport cost per hectare of ₦4,828.68.

### 4.5.2 Harrow machinery capacity recommended

The unadjusted harrow machinery capacities ($C_e$) recommended for the studied total 430 ha equivalent (*ie* 675 ha nominal), pool farm with the studied models are shown in Table 4.34.

Table 4.34: Recommended minimum-cost harrow sizes for 430 ha equivalent farm size (675 ha nominal farm size)

| Implement /Model Parameter | | Implement Size | | |
|---|---|---|---|---|
| | | L | Z | H |
| Model Size Selected | Capacity $C_e$ (ha/hr) | 0.7518 | 0.4955 | 0.8953 |
| | Width $w$ (m) | 1.7025 | 1.1220 | 2.0275 |
| Adjusted Size^ | Capacity $C_{eR}$ (ha/hr) | 0.7523 | 0.4957 | 0.8960 |
| | Width $w$ (m) | 1.7036 | 1.1225 | 2.0290 |
| Corresponding Costs per Hectare (₦/ha) | | | | |
| Model Machinery Cost per Hectare (₦/ha) | | 3234.82 | 3308.21 | 3292.72 |
| Model Machinery and Transport Cost per Hectare (₦/ha) | | 3680.81 | 3759.52 | 4483.69 |
| Implement Size for Adequacy Comparison | | | | |
| | Capacity $C_{eQ}$ (ha/hr) | 0.6360 | | |

| | | | |
|---|---|---|---|
| Nominal Farm Size's Basal Implement Size[#] | | Width $w$ (m) | 1.4402 |
| Equivalent Farm Size's Basal Implement Size[#] | | Capacity $C_{eQ}$ (ha/hr) | 0.4033 |
| | | Width $w$ (m) | 0.9132 |
| ImplementSelected | Implement Size | Capacity (ha/hr) | 0.7523 |
| | | Width $w$ (m) | 1.7036 |
| | Corresponding Cost per Hectare (₦/ha) | Machinery | 3129.23 |
| | | Machinery and Transport | 3596.52 |

^With Machinery Transport Hours Loss Considered
[#]for Available Working Hours

The adjusted harrow capacities for transport hours loss ($C_{eR}$) for the various models are also shown in Table 4.34. The basal harrow field capacity that processes the pool farm size based on the available hours ($C_{eQ}$) is also presented in the same Table 4.34. The corresponding annual machinery cost per hectare, and the machinery and transport cost per hectare for these implement sizes are also shown in Table 4.34. The selected plain harrow field capacity based on the L- model, Z- model, and the H- model was 0.7518 ha/hr, 0.4955 ha/hr and 0.8953 ha/hr respectively. These correspond to 1.7025 m, 1.122 m and 2.0275 m harrow widths respectively. Based on the available field processing hours of 1060 hrs a basal harrow capacity of 0.6835 ha/hr was considered adequate for timely processing of the 430 ha equivalent pool farm. This translates to a harrow width of 1.5478 m.

However, if the pool farm size to be processed were evaluated as the nominal 675 ha-pool farm size, the adequate harrow capacity needed will increase to 0.6360 ha/hr; and its width to 1.4402 ha/hr. The highest corresponding annual harrow machinery cost per hectare was recorded for the developed Z- model, and was ₦3,308.21. On the other the H- model had the highest harrow machinery and transport cost per hectare, with a value of ₦4,483.69. The developed L- model corresponding annual plough machinery cost per hectare and its machinery and transport cost per hectare were the lowest; with values as ₦3,234.82 and ₦3,680.81 respectively.

From the foregoing, the 0.7518 ha/hr basic harrow field capacity and its adjusted 0.7523 ha/hr selected with the L- model were both considered adequate, for completing the harrowing operation within the available time. The 0.4955 ha/hr plain harrow capacity selected by the Z- model and its adjusted capacity of 0.4957 ha/hr appear inadequate for processing the field timely but very susceptible to failure from shocks in the system. On the other hand, the H- model 0.8953 ha/hr plain harrow capacity and its, 0.8960 ha/hr- adjusted capacity appear oversized for the 430 ha equivalent pool farm size. If the pool farm size was based on nominal size, all the 3 models selected basic harrow capacity and their adjusted version appear adequate to meet the 1.0779 ha/hr field capacity considered big enough.

The corresponding plain annual harrow machinery cost per hectare was highest for the Z- model with ₦3,308.21 as the value. The machinery and transport cost per hectare were highest for the H- model, with value as ₦4,483.69. The annual harrow machinery cost per hectare and the machinery and transport cost per hectare corresponding to the L- model capacity; with values ₦3,234.82 and ₦3,680.81, respectively were the lowest. The adjusted 0.7523 ha/hr harrow field capacity selected with the L- model was finally chosen as the harrow field capacity needed. This corresponded to a harrow width of 1.7687 m, and an annual machinery cost per hectare of ₦3,234.82 and a harrow machinery and transport cost of ₦3,680.81.

### 4.5.3 Ridger machinery capacity recommended

The plain ridger machinery capacities ($C_e$) recommended for the studied total 430 ha equivalent (ie 675 ha nominal), pool farm with the studied models are shown in Table 4.35. The adjusted ridger capacities for transport hours loss ($C_{eR}$) for the various models are also shown in Table 4.35. The basal ridger field capacity based on the available hours ($C_{eQ}$) is also shown in Table 4.35. The corresponding annual ridger machinery cost per hectare, and the

Table 4.35: Recommended minimum-cost ridger sizes for 430 ha equivalent farm size (*ie* 675 ha nominal farm size)

<table>
<tr><td colspan="2" rowspan="2">Implement /Model Parameter</td><td colspan="3">Implement Size</td></tr>
<tr><td>L</td><td>Z</td><td>H</td></tr>
<tr><td rowspan="2">Model Size Selected</td><td>Capacity $C_e$ (ha/hr)</td><td>0.5054</td><td>0.2466</td><td>0.6247</td></tr>
<tr><td>Width $w$ (m)</td><td>1.7018</td><td>0.8304</td><td>2.1035</td></tr>
<tr><td rowspan="2">Adjusted Size^</td><td>Capacity $C_{eR}$ (ha/hr)</td><td>0.5056</td><td>0.2467</td><td>0.6247</td></tr>
<tr><td>Width $w$ (m)</td><td>1.7025</td><td>0.8306</td><td>2.1046</td></tr>
<tr><td colspan="5">Corresponding Costs per Hectare (₦/ha)</td></tr>
<tr><td colspan="2">Model Machinery Cost per Hectare (₦/ha)</td><td>4522.59</td><td>5199.95</td><td>4472.52</td></tr>
<tr><td colspan="2">Model Machinery and Transport Cost per Hectare (₦/ha)</td><td>4966.58</td><td>5656.99</td><td>5664.90</td></tr>
<tr><td colspan="5">Implement Size for Adequacy Comparism</td></tr>
<tr><td rowspan="2">Nominal Farm Size's Basal Implement Size#</td><td>Capacity $C_{eQ}$ (ha/hr)</td><td colspan="3">0.6560</td></tr>
<tr><td>Width $w$ (m)</td><td colspan="3">2.1413</td></tr>
</table>

| | | | |
|---|---|---|---|
| Equivalent Farm Size's Basal Implement Size# | | Capacity $C_{eQ}$ (ha/hr) | 0.4033 |
| | | Width $w$ (m) | 1.3579 |
| Selected Implement | Implement Size | Capacity (ha/hr) | 0.5056 |
| | | Width $w$ (m) | 1.7025 |
| | Corresponding Cost per Hectare (₦/ha) | Machinery | 4499.53 |
| | | Machinery & Transport | 4965.97 |

^With Machinery Transport Hours Loss Considered
#for Available Working Hours

machinery and transport cost per hectare for these ridger sizes are also shown in the table. The selected plain ridger field capacity based on the L- model, operation labor cost-excluded model, and the H- model was 0.5054 ha/hr, 0.2466 ha/hr and 0.6247 ha/hr respectively. These corresponded to 1.7018 m, 0.8304 m and 2.1035 m ridger widths, respectively.

Based on the available field processing hours of 1060 hrs a basal ridger capacity of 0.6835 ha/hr was considered adequate for timely processing of the 430 ha equivalent pool farm. This translates to a ridger width of 1.3579 m. However, if the pool farm size to be processed were evaluated on the nominal 675 ha-pool farm size basis, the adequate ridger capacity needed will be 0.6560 ha/hr; and its width 2.1413 ha/hr. From the foregoing, the L- model and the Hunt-Wilson model selected capacities and their adjusted capacities versions appear capable of completing the ridging of the equivalent pool farms within the available time. The Hunt-Wilson model capacities appear less susceptible to failure from shocks in the system. On the other hand, the operation labour cost-excluded model plain harrow capacity and its adjusted capacity appear inadequate for the 430 ha equivalent pool farm size processing.

The highest corresponding plain annual ridger machinery cost per hectare was recorded for the developed operation labour cost-excluded model, and was ₦5,199.95. On the other the Hunt-Wilson model had the highest machinery and transport cost per hectare:- ₦5,664.90. The developed L- model corresponding annual harrow machinery cost per hectare and its machinery and transport cost per hectare were the lowest; with values as ₦4,522.59 and ₦4,966.58 respectively. The L- model adjusted capacity of 0.5056 ha/hr was chosen for processing the equivalent pool farm ridging. This corresponded to a ridger width of 1.7025 m and an annual ridger machinery cost of ₦4,499.53 and a ridger machinery and transport cost of ₦4,965.95. 0.6835 ha/hr was chosen as the ridger field capacity. This corresponds to a ridger machinery width of 2.1577 m and a ridger machinery cost per hectare and machinery and transport costs per hectare of ₦4886.39 and ₦4911.85, respectively. This shows the machinery size savings that equivalent farm size basis affords the in machine selection, when compared to nominal farm size basis.

**4.6 Choosing From the Tillage Machinery Sizes Available In the Market**

The recommended tillage machinery sizes were compared with the machine sizes available in the market, such that number of pieces of the machinery or combinations of them will add up to the required capacities. The plough capacity chosen was 0.6550 ha/hr. The smallest capacity tractor-powered disc plough available in the local market (a 0.3100 ha/hr plough) was considered for use in combination that will make up an adequate field capacity. The chosen small-sized plough will suit the small, irregular-shaped and scattered pool farms better than larger ones. Machine maneuverability problems and inter-farm transport costs will be reduced with smaller-sized machinery use. Ademiluyi and Oladele (2008) reported that smaller machinery suit the vast majority of paddy farms in the country. Accessing geographically spread out fields, and flexibility and maneuverability will be easier with the smaller machinery.

2 pieces of a 3-disc (of 70cm diameter) 0.3100 ha/hr-plough of 0.9 m working width, was chosen. With this 2 ploughs totaling 0.6201 ha/hr (ie 1.8 m) the equivalent farm size of 430 ha will be adequately processed. For the nominal farm size basis, it will need overtime work, contract work or any other suitable arrangement deemed fit by the management to cover extra 0.0350 ha/hr plough. This selected size will incur an annual plough machinery cost per hectare of ₦4,654.91 and a machinery and transport cost of ₦4,996.16. Similarly combinations of 0.7507 ha/hr- the smallest tractor-powered disc harrow size available readily in the local market will be employed to achieve the chosen harrow capacity of 0.7527 ha/hr. The chosen implement is a 20-disc off-set harrow (of 50 cm diameter discs), with 1.7 m working width. One piece of this harrow machinery will be employed. This choice will adequately process the total nominal and equivalent pool farms within the available time. This will incur an annual harrow machinery cost per hectare of ₦3,234.73 and a machinery and transport cost of ₦3,680.74.

The ridger capacity chosen was 0.5056 ha/hr. The smallest capacity tractor-powered disc plough available in the local market (a 0.5346 ha/hr ridger- with 1.8 m working width) was considered for use in a combination that will make up an adequate field capacity. 1 piece of the 0.5346 ha/hr ridger; a 4-disc ridger (of 70cm diameter discs) was recommended to cover the ridger capacity of 0.5056 ha/hr chosen. This choice will adequately process the 430 ha equivalent pool farm within the available time. If the choice is for the nominal farm size basis, a shortfall of 0.1214 ha/hr ridger capacity will result and can be taken care of through overtime work, contract work or any other suitable arrangement the management deems fit. This choice will incur an annual harrow machinery cost per hectare of ₦4,502.01 and a machinery and transport cost of ₦4,944.58.

### 4.7 Size of Tractor Recommended

Table 4.36 shows the summary of the selected tillage machinery for the total 430 ha equivalent farm (ie 675 ha nominal farm) size. The ploughing operation put a maximum of 58.8 % PTO power load on the 48.5 kW tractor. For some of the studied locations the ploughing power load was not more than 28.2 %. Two 48.5 kW tractors were chosen for powering the two 0.3100 ha/hr ploughs. For harrowing operations, a 61.1 kW tractor was chosen as the tractor power for the 1 piece of 0.7507 ha/hr harrow selected, see Table 4.36.

Table 4.36: Summary of the selected tillage machinery for 430 ha equivalent (*ie* 675 nominal) pool farm studied

| Parameter | | Plough Machinery | Harrow Machinery | Ridger Machinery |
|---|---|---|---|---|
| Implement | Size (ha/hr) [width (m)] | 0.3105 [0.9000] | 0.7507 [1.7000] | 0.5346 [1.8000] |
| | Quantity | 2 | 1 | 1 |
| Tractor | Size (kW) | 48.5 | 61.1 | 61.1 |
| | Quantity | 2 | 1 | 1 |

ploughing power load was not more than 28.2 %. Two 48.5 kW tractors were chosen for powering the two 0.3100 ha/hr ploughs. For harrowing operations, a 61.1 kW tractor was chosen as the tractor power for the 1 piece of 0.7507 ha/hr harrow selected, see Table 4.36.
For the high soil-draught locations the percentage power loading on the lower power size tractors will exceed the maximum 80 % of the tractor PTO power prescribed by Roberson (2012). The 61.1 kW tractor will have a percentage power loading of 78.54 % PTO power for these highest draft locations. The piece of chosen 0.5702 ha/hr disc ridger will be powered by a 61.1 kW tractor. This resulted in 80.18 % percentage PTO power loading on the tractor.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Study Conclusion

This study proffered a possible solution to 2 key hindrances to engine-powered agricultural mechanization, namely small capital and fragmented scattered holdings. Machinery transport cost was incorporated into the Hunt-Wilson (2015) annual tillage machinery cost and its least-cost size selection model. The resulting models were adopted for tillage machinery size selection for fragmented scattered farms. The developed models circumvented the need of a prior width-dependent capacity input for machinery width selection. It selected the minimum-cost machinery size in the terms of machinery capacity, rather than width. Validation of the model was done with parameters from the tractor and machinery hiring services operations of the Anambra State Ministry of Agriculture, Awka Nigeria.

The following conclusions were made on application of the models in farm mechanization in Anambra State Nigeria.

1. The models need fuel, tractor and implement costs, and farm size as input, and are sensitive to farm size and labour rate.

2. The tillage machinery size seleted is affected by the percentage of the tractor power required by the machinery. The soil tillage draught influenced this required tillage power and was affected by the soil type. For a 420 ha farm for example, plough widths of 0.9988 m, 0.7837 m, and 0.8534 m was selected for clay loam soil with the L-, Z- and H- models respectively. Sandy loam soil farm of the same size required plough widths of 0.5588 m, 0.2235 m and 0.3386 m based on those models in the same order. For loam soils farm of such size it was 1.7275 m, 1.2738 m and 1.4627 m with the 3 models in the same order.

3. Increasing labour rate led to increase in minimum-cost tillage implement size selected and in the corresponding annual machinery cost per hectare incurred. For the stated farm size, the minimum-cost plough width selected by the L- model was 1.6663 m, 1.8059 m to 1.9327 m and 2.0495 m for labour rates varying from ₦550.00, ₦700.00, ₦850.00 and ₦1000.00 labour rate respectively. The incurred cost per hectare increased from ₦6,165.13 to ₦6,392.60, ₦6,598.44 and ₦6,788.20 for the same labour rates in the same order.

4. Increasing farm size led to increase in minimum-cost tillage implement size selected. The minimum-cost plough width selected by the L- model was 0.5481 m, 0.9740 m to 2.1009 and 2.5995 m for pool farm sizes varying from 45 ha to 145 ha, 420 ha and 675 ha respectively.

The corresponding annual machinery cost per hectare decreased with the increase in farm size. The incurred cost per hectare decreased from ₦12,485.44 to ₦8,480.44, ₦7,611.25 and ₦6,892.56 for the same farm sizes in the same order.

5. The values of the tillage machinery capacity selected with the L- model developed in the study and their corresponding annual machinery costs were most times lower than the ones from the H- model. The Z- model plough width selected was 0.2251 m, 0.4242 m, 1.5880 and 2.0579 m and the H- model width 0.8186 m, 1.0201 m, 1.5880 m and 1.7587 m, in comparison with the L- model's values. The ANOVA of the widths from the 3 models showed no significant difference at a 0.05 level of significance. The tillage implement widths predicted by the models from the farm size followed a 2nd order polynomial trend. The $R^2$ values varied from 0.987 to 0.998 for the plough.

6. The values of the corresponding annual machinery costs incurred per hectare for the capacity selected was lower with the L- model than the H- model as from farm sizes higher than 145 ha. The cost was ₦16,470.60, ₦10,452.75, ₦7,650.97 and ₦6,891.91 for the Z- model,while for the H- model it and was ₦12,378.38, ₦8,471.28, ₦7,708.13 and ₦7,010.44 for the listed farm sizes in that order. The ANOVA of the cost per hectare from the 3 models showed no significant difference at a 0.05 level of significance. The corresponding machinery cost per hectare predicted by the models from the farm size followed a power trendline. The $R^2$ values varied from 0.938 to 0.979 for the plough.

7. The annual depreciation per tractor power was shown to influence implement capacity selected and the corresponding annual cost of tillage machinery rather than the mere tractor purchase price.

8. The annual tillage machinery cost per hectare and the machinery transport cost-incorporated machinery cost per hectare generally decreased sharply with farm size increase at smaller farm sizes of up to 145 ha, and thereafter, more gradually. This agrees with the well known fact that the mechanization of larger farms is more economical than that of the smaller ones. The annual tillage machinery cost per hectare from the 3 hectares tended towards close values beyond 420 ha farm size. It could be inferred on per hectare cost basis that multi-farm deployment of engine-powered mechanization on above 400 ha pool farm will yield a better cost-effectiveness than trying it on less than 100 ha pool farm.

9. Based on differing time frame for any given operation for the different farms and / or crops, the model reduces to an equivalent farm size, any given nominal farm size. An

otherwise smaller implement capacity will be selected based on this equivalent farm size, and can adequately process the nominal farm size within the available period. The 675 ha total nominal pool farm size was resolved to 430 ha. Based on the model, the Anambra State-wide tractor and machinery hiring services (in Nigeria) can take advantage of the differing operation time occasioned by serviced farms' ecological and crop differences to evaluate a smaller equivalent total farm size. This requires a smaller implement capacity, resulting in reduced annual machinery cost per hectare.

10. The capacity selected for any equivalent farm size when adjusted for implement transport time ($h_t$) loss ($C_{eR}$) was higher than the needed basic capacity ($C_{eQ}$) obtained by merely considering the available tillage period and equivalent farm size to be processed. The $C_{eR}$ was 0.6537 ha, 0.7523 ha and 0.5056 ha for the plough, harrow and ridger respectively, while the $C_{eQ}$ was 0.4033 ha.

11. The deployment of the findings of this research in the studied location and other places, it is hoped will enhance appropriate machinery selection and cost-effective mechanization of agriculture with engine-powered technology for scattered big and small farms.

## 5.2 Recommendations for Further Studies

The following recommendations are made for further studies:

1. Determination of actual machinery transport distances and further studies of the effect of the operations scheduling is suggested, to properly take care of the real world conditions.

2. In-depth study of soil types for the key agrarian areas of Anambra State Nigeria so as to afford a more reliable application of the model and machinery allocation.

3. Determining the suitable field work days of any farm location which the models will be applied to their mechanization, so as to afford a good estimation of suitable work days for tractorized operations, for enhancing their agricultural mechanization.

4. Determining the probability distribution of hired tractorized farming operation requests from clients is suggested for further studies, so as to evaluate a more precise farm size values for selecting the required implement capacity.

5. Finding off-season uses for tractors eg haulage, powering irrigation water pumping, minor excavations, etc will increase tractors annual use and consequently reduce the farm operation share of tractors fixed cost.

6. Approaches like making rural farm lands more accessible, developing more farmlands through appropriate land clearing and development, doing more farmer enlightenment and intensive extension services will enhance increased annual farm machinery use. This will make their deployment in farming operations more cost effective.

7. Appropriate and relevant farm record keeping will help in mechanization studies and tractor and equipment management in the country.

### 5.3 Contribution to Knowledge

The contributions to knowledge made by the study are as follows:

1. Developing models that incorporate field operation labour cost and machinery transport cost into the Hunt-Wilson annual tillage machinery cost and consider same in the minimum-cost tillage machinery selection models determination. Employing the developed models in machinery selection for multi-crop fragmented scattered pool farms, thereby attempting a solution to capital poverty and small size bottlenecks of mechanizing small farms.

2. Developing models that circumvented the need of a prior arbitrary width dependent machine capacity function, for tillage machine width selection prevalent in Hunt-Wilson model. This will make tillage machinery selection less dependent on the user's experience and thus less subjective than with the Hunt-Wilson's model.

3. Developing models that reduces any given total nominal pool farm size to an equivalent arm size, based on non-coinciding timing of any given operation for the different farms plots. An otherwise smaller implement capacity selection will ensue that can process the farms within the more spread out available period. The model applied this to the Anambra State government-run tractor and machinery hiring services. The differing operations time window occasioned by the pedoclimate and crops requirement differences of serviced farms' can be advantageously employed to reduce the 675 ha nominal pool farm to 430 ha. This increases the machinery annual use and reduces the required farm machinery size, making the mechanization enterprise more cost-effective.

4. Amaefule, D. O.; Oluka, S. I. and Nwuba, E. I. U. (2018). Tillage machinery selection model for combined non-contiguous farms. (JEAS) Vol. X pp 0-0

5. Amaefule, D. O.; Oluka, S. I. and Nwuba, E. I. U. (2018). A field machinery capacity selection model for tillage operations in Nigeria. Journal of Engineering and Applied Science (JEAS) Vol. X pp 0-0

6. Amaefule, D. O., Matthias B. A. and Umeghalu, I. C. E. (2012). Promoting rural development through mechanized farming ventures; a Nigerian case study. Proceedings of National Conference on Infrastructural Development and Maintenance in the Nigerian Environment, Nnamdi Azikiwe University Awka, Nigeria. August 27-28, 2012: 221 - 233

## REFERENCES

Abubakar, M. S., Zakari M. D., Shittu S. K. and Attanda M. L. (2013). Determination of repair and maintenance cost for MF375 tractor: a case study in Kano Metropolis, Nigeria. Arid Zone Journal of Engineering, Technology and Environment (AZOJETE), 9: 27-35.

Adama, J. C., Onwualu, A. P. and Akubuo, C. O. (2009). A proposed community-based participatory technology development programme (COPATED) for mechanization of small farms in Nigeria. Journal of Agricultural Engineering and Technology (JAET), 17(2): 19-32.

Ademiluyi, S. Y. and Oladele, O. I. (2008). Field performance of VST SHAKTI power tiller on sawah rice plots in Nigeria and Ghana. Bulgarian Journal of Agricultural Science,14: 517-522.

Adewoyin, A. O. and Ajav. E. A. (2013). Fuel consumption of some tractor models for ploughing operations in the sandy-loam soil of Nigeria at various speeds and ploughing depth. Agricultural Engineering International (Agric Eng Int): CIGR Journal, 15(3): 67—74.

Ahaneku, I. E. and Onwualu, A. P. (2007). Predicting suitable field workdays for soil tillage in northcentral Nigeria. Nigerian Journal of Technology, (NIJOTECH) 26(1): 81-88.

Ajah, J. (2014). Factors limiting small-scale farmers' access and use of tractors for agricultural mechanization in Abuja, north central zone, Nigeria. European Journal of Sustainable Development, 3(1): 115-124

Akinnuli, B. O., Akerele, F. O. and Nathaniel, A. B. C. (2014). Model developed for farm tractors and implements selection for optimum utilization. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 5(4): 248-255

Ali Osman, N. O. (2011). A Model for Farm Machinery Selection. Unpublished Master of Science Thesis Submitted to the Agricultural Engineering Department, University of Khartoum, Sudan.

Amaefule, D. O., Matthias B. A. and Umeghalu, I. C. E. (2012). Promoting rural development through mechanized farming ventures; a Nigerian case study. Proceedings of National Conference on Infrastructural Development and Maintenance in the Nigerian Environment, Nnamdi Azikiwe University Awka, Nigeria. August 27-28, 2012: 221 - 233

Anazodo, U. G. N. (1976). A field study and analysis of problems of and prospects for mechanization of family farms in Anambra and Imo States of Nigeria: A Research Report. Department of Agricultural Engineering, University of Nigeria, Nsukka.

ASABE (2006). Agricultural Machinery Management Data. ASAE EP496.3 American Society of Agricultural and Biological Engineers. St Josef, Michigan, USA.

ASABE (American Society of Agricultural and Biological Engineers) (2011). Agricultural Machinery Management Data - Standards, D497.7. ASABE Standards.

ASADAP (Anambra State Agriclltural Development Programme) Anambra State Nigeria (2016). Tractor and machinery Hiring Records for 2016 Planting Season (obtained by permission of the Commisioner for Agriculture Mechanization Processing and Export)

Asoegwu, S., and Asoegwu, A. (2007). An Overview of Agricultural Mechanization and its Environmental Management in Nigeria. Agricultural Engineering International: the CIGR Ejournal, 9: 13-18.

Awulu, J. O., Enokela, J. A. and Arubi, A. (2016). Efficient matching of tillage implements with tractors using a computer program. International Journal of Agriculture Innovations and Research, 4(6): 2319-1473

Babeir, A.S.; Colvin, T.S. and Marley, S.J. (1986). Predicting field tractability with a simulation model. Transactions of the ASAE, 29(6): 1520-1525.

Bagheri, N., and Moazzen, S. A. A. (2004). Optimal strategies for the development of agricultural mechanization in Iran. Articles Collections of the Fifth National Congress of Agricultural Machinery and Mechanization Engineering. Ferdowsi University of Mashhad.

Bakhtiari, A. A.; Navid, H.; Mehri, J. and Bochti, D. D. (2011). Optimal route planning of agricultural field operations using ant colony optimization. Manuscript No. 1939, Agric Eng Int: CIGR Journal, 13(4).

Bluman, A. G. (2004) Elementary Statistics: A Step By Step Approach. (5th Edition), McGraw-Hill Company New York. p527

Bol, M. B. and Mohammed, H. I. (2005). A mathematical algorithm for farm machinery selection. Journal of Science and Technology, 6(2).

Calcante, A., L. Fontanini, and F. Mazzetto. 2013. Coefficients of repair and maintenance costs of self-propelled combine harvesters in Italy. Agric Eng Int: CIGR Journal, 15(3): 41－147.

Çanakci, M.; Unal, İ. and Topakci, (2011). Development of computer software for determination of optimum tractor power and machinery sizes. Journal of Agricultural Machinery Science, 7(4): 415-420

Chapman, D. F., Kenny, S. N., Beca, D. and Johnston, I. R. 2008. Pasture and forage crop systems for non-irrigated dairy farms in southern australia. Agricultural Systems, 97: 108-125.

Charles-Owaba, O. E. (1997). Lecture Notes on Advanced Work System Design. Industrial and Production Engineering Department, University of Ibadan, Ibadan.

Chigbo, A. C. (2016) Operation Record Excerpt. Engineering Division, Ministry of Agriculture Mechanization Processing and Export, Anambra State Nigeria.

Chukwu, G. O., Chude, L. A. and Ekpo, I. E. (2009). Wetland of southeastern Nigeria: extent and characteristics. Nigerian Journal Agriculture, Food and Environment, 5(2-4):42-46

Darling, T. and Green, M. (1999). Cost component and the calculation of the cost of agricultural machinery activities. Agekon Internet Seminar. An Economical Approach to Agricultural Machinery Management.

Dash, R. C. and Sirohi, N. P. S. (2008). A computer model to select optimum size of farm power and machinery for paddy-wheat crop rotation in northern India”. Agricultural Engineering International: The CIGR Ejournal. Manuscript PM 08 012.Vol. X.

Davies, L. and Patton, D. (2000). Calculating machinery costs and contract rates. Farm Business and Trade. Agtact, M2.6, First Edition.

Dawelbeit, M. I. (1997). Effect of tillage and method of sowing on wheat yield in irrigated sector, Rahad, Sudan. Soil and Tillage Research, 42: 127-123.

De Toro, A. (2005). Influences on timeliness costs and their variability on arable farms. Biosystems Engineering, 92: 1-13.

Doll, J. D., Piedrahita, C. W. and Leihner, D. E. (1982). Methodos de control de malezas en yuca (*Manihot esculenta* Cratz) Yuca Investiga, Production y Utilization. Referenciade los cursos de capacitacion sobre yuca dictados por el. Centro Internationa de Agricultura Tropical, CIAT and Programa de las Naciones Unidas para el Desarrollo (PNUD), Cali, Colombia, pp 241-249

Edwards, W. (2009). Farm Machinery Selection. Ag Decision Maker Iowa State University Extension Service, USA

Ekman, S. (2000). Tillage system selection: a mathematical programming model incorporating weather variability. J. Agric. Eng. Res., **77**:267-276.

Eurostat (eurostat) (2017). Small and Large Farms in the EU - Statistics from the Farm Structure Survey. Statistics Explained.
http://ec.europa.eu/eurostat/statistics-explained/index.php/
Small_and_large_farms_in_the_EU_-_statistics_from_the_farm_structure_survey
#Size_classes

Field, H. L. and Solie, J. B. (2007). Introduction to Agricultural Engineering Technology A Problem Solving Approach 3rd Edition. Springer Science+Business Media, NY.

Fonteh, M. (2013). Agricultural mechanization in west and central Africa. Mechanization for Rural Development: A Review of Patterns and Progress From Around the World, FAO Rome, 20: 47-66

Gbadamosi, A. (2018). Understanding the Developed/Developing Countriies Taxanomy. Advocates for International Development A41D
http://www.a4id.org/policy/understanding-the-developeddeveloping-country-taxonomy/

Gbadamosi, I. and Magaji, A. S. (2004). Field study on animal draught power for farming in Zuguma village of Niger State. Proceedings of the 5th International Conference of the Nigerian Institution of Agricultural Engineers, 26: 84-86.

Gifford, R. C. (1992). Agricultural Engineering in Development Mechanization Strategy Formulation: Vol 1 -Concepts and Principles FAO Agricultural Services Bulletin 99/1 FOA Rome

Graham, R. L., Nelson, R., Sheehan, J., Perlack, R. D. and Wright, L. L. (2007). Current and potential U.S. corn stover supplies. Journal of Agronomy, 99: 1–11

Grisso, R., Helsel, R. N. and Grubinger, V. (2012). Match Implement Size to Tractor to Save Fuel.

Gunnarsson C. (2008). Timeliness Costs in Grain and Forage Production Systems Doctoral Thesis Department of Energy and Technology, Swedish University of Agricultural Sciences Uppsala, Sweden. SLU Service/Repro, Uppsala

Gupta, J. P. and Kumar**,** S. (2001). Status of power tiller use in Binar; a case study Nalanda district. Agricultural Mechanization in Asia, Africa and Latin America 32(1): 19-22.

Harrigan, T.M. and Roosenberg R. J. (2002). Estimating Tillage Draft Tillers International Techguide 2G-210 Tillers International, Scotts MI Michigan. www.tillersinternational.org

Hunt, D. (1999a). Field machinery management. CIGR Handbook of Agricultural Engineering Volume III Plant Production Engineering American Society of Agricultural Engineers: 565-573.

Hunt, D. (1999b). Cost analysis. CIGR Handbook of Agricultural Engineering Volume III Plant Production Engineering. American Society of Agricultural Engineers: 574-584.

Hunt, D. R. (2001). Farm Power and Machinery Management (12thEdition).Iowa State University Press. Ames.

Hunt, D. R. and Wilson, E. (2015). Farm Power and Machinery Management (15thEdition).Iowa State University Press. Ames.

ICS/USAID (Information and Communication Support for Agricultural Growth in Nigeria/United States Agency for International Development) (undated). Growing Cassava In Nigeria. Commercial Crop Production Guide Series. The ICS. www.ics-nigeria.org

Igbeka, J.C. (1986). Evaluation of tillage operation in some mechanized farm in Nigeria – Agricultural mechanization in Asia, Africa and Latin America (AMA), 17(2): 17-22.

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. S. C. (1995). The use of some soil aggregate indices to assess potential soil loss in soils of south-eastern Nigeria. International Journal of Agrophysics 9:95-100.

ISU (Iowa State University) Extension Outreach (2015). Estimating Farm machinery Costs. Ag decision Maker File A3-29 (PM 710)

Ismail, Z.E. and Abdel-Mageed, A.E. (2010). Workability and machinery performance for wheat harvesting Misr Journal of Agricultural Engineering, 27 (1): 90-103.

Jekayinfa, S. O.. Adebiyi, K., Waheed, M. A. and owolabi, O. O. (2005). Appraisal of Farm tractor maintenance practices. Journal of Quality in Maintenance Engineering 11(2): 152-168.

Karin Larsén (2008). Economic Consequences of Collaborative Arrangements in the Agricultural Firm. A Doctoral Thesis Submitted to the Department of Economics, Swedish University of Agricultural Sciences Uppsala.

Kastens, T. (1997). Farm Machinery Operation Cost Calculations. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.www.oznet.ksu.edu

Kazami, R. H. and Ahmed, T. (1996). Mathematical models for diesel consumption of farm tractors in Allahabad district, India. AMA, 27(3): 73-75.

Kepner, R. A; Bainer, R. and Berger, E. L. (2003). Principles of Farm Machinery (9th Edition). CBS Publishers and Distributors New Delhi

Khani, M., Keyhani, A., Parsinejad, M. and Alimardani, R., (2011). Verification and sensitivity analysis of a model for determination of probability of a working day for tillage. International Agrophysics, 25: 27-35.

Lai, W., Roe, B. and Liu, Y. (2015). Estimating the Effect of Land Fragmentation on Machinery Use and Crop Production. Paper presented at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28

Lamidi, W. A. and Akande, l. O. (2013). A study of status, challenges and prospects of agricultural mechanization in Osun State, Nigeria Journal of Education, Arts and Humanities 1(1): 001-008.

Leihner, D. (2002). Agronomy and cropping systems. Cassava: Biology, Production and Utilization (Hillocks, J. M., Thresh, J. M. and Bellotti, A. C. eds) CAB International.

Leihner, D. E. and Castro, M. A. (1979). Prácticas sencillas para aumenter el rendimiento del cultivo de la yuca (*Manihot esculenta* Cratz). Proceedings of the 20th Annual Assembly of

*'Programma Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA)'* Tegucigalpa, DC, Honduras 19-23 March

Liljedahl, J. B. Carlton, W.M. Tumquist, P. K. and Smith, D. W. (1979). Tractors and Their Power Units. 3rd edition, John Wiley and Sons. INC. N.Y. Chichester, Brisbane, Torando, Singapore.

Maruthi Sankar, G. R. and Vanaja, M. (2003). Crop growth prediction in sunflower using weather variables in a rainfed alfisol. HELIA, 26(39): 125-140.

Mas'oud, F. H. (2005). A Computer Model for Farm Machinery Selection. PhD Thesis University of Khartoum, Sudan.

Midwest Plan Service (MWPS) (1992). Conservation Tillage Systems and Management. MWPS 45. Iowa State University.

Mohammed, M. A., Ibrahim Mohammed, H., Mohamed, O. E. and Abbas, O. M. (2011). Effect of changing crop rotations on machinery management using a decision-aid model. Agriculture and Biology Journal of North America, 2 (3): 440-447.

Nairaland Nigeria Forum (2016). Anambra State Inaugurates Tractor Service For Farmers. Nairaland Nigeria Forum. http://www.enzyhub.com/anambra-state-inaugurates-tractor-service-for-farmers/

Najafi, B. and Torabi Dastgerduei, S. (2015). Optimization of machinery use on farms with emphasis on timeliness costs. Journal of Agricultural Science and Technology, 17: 533-541

National Daily A News (2016). Agric interest rate still an outcry National Daily A News Feb. 1 2016. https://nationaldailyng.com/2015/author/graphics

NBS/FMARD (National Bureau of Statistics/ Federal Ministry of Agriculture and Rural Development) (2012). National Bureau of Statistics/ Federal Ministry of Agriculture and Rural Development Collaborative Survey on National Agriculture Sample Survey (NASS), 2010/2011 Draft Report.

NRCRI (National Root Crop Research Institute) Igbariam Outstation (2016). Personal Communication with Head of Station.

Nwabuike, I. (2017). E-force - ASADAP Public Private Partnership Tractor and Equipment Hiring Outfit Awkuzu Anambra State Nigeria. Tractor and machinery Hiring Records for 2016 Planting Season.

Nwuba, U. (2009). Agricultural Mechanization in Nigeria Using Cowpea as A Case Study. 12th Inaugural Lecture Nnamdi Azikiwe Univerity Awka, Nigeria April 2, 2009.

Oasis Insurance, 2016 Oasis House P.M.B. 21170 Ikeja Lagos Nigeria. Operatoins Records.

Odigboh, E. U. (1985). Mechanization of Cassava Production and Processing: A Decade of Design and Development. An Inaugural Lecture. University of Nigeria, Nsukka (UNN).

Odigboh, E. U. (1999). Machines for Crop Production. CIGR Handbook of Agricultural Engineering Volume III Plant Production Engineering. American Society of Agricultural Engineers:1-22

Odigboh E. U. (2000). Mechanization of the Nigeria agricultural industry, pertinent notes, pressing issues, pragmatic options. A public lecture delivered at the Nigeria Academy of Science, International Conference Centre, Abuja. April 15, 2000.

Oduma, O., Igwe, J. E. and Ntunde, D. I. (2015). Performance evaluation of field efficiencies of some tractor drawn implements in Ebonyi State. International Journal of Engineering and Technology (IJET) 5 (4): 199- 204

Ofori, G. and Toor, S. (2008). Leading the development of sustainable organizations, in Proc. of the CIB Joint W065/W055 International Symposium: Transformation through construction. 17-19 November, 2008, Dubai, UAE: 1-11.

Olarinmoye, S. (2017). How to get car Insurance in Nigeria. nairametrics.com/get-car-insurance-nigeria/

Oluka, S. I. (2000). Costs of tractor ownership under different management systems in Nigeria. Nigerian Journal of Technology, 19 (1): 15-28.

Oluka S.I. and Nwani S. I. (2013). Models for repair and maintenance costs of rice mills in southeastern states of Nigeria. Journal of Experimental Research. 1 (1): 10-15 www.er-journal.com

Oluka, S. I. (2014). Engineering Nigerian Agriculture for Sustainable Economic Transformation.19th Inaugural Lecture of Enugu State University of Science and Technology. March 27, 2014.

Onuachu, A. C. (1983). Evaluation of Farm Power and Machinery Use in Kwarra State of Nigeria. Unpublished B. Engr. Project Report Submitted To the Agricultural Engineering Department UNN

Onwualu, A. P.; Akubuo, C. O. and Ahaneku, I. E. (2006). Fundamentals of Engineering for Agriculture. Immaculate Publications Limited, Enugu, Nigeria.

Onwualu, A. P. and Pawa, N. P. (2004). Engineering infrastructure for the manufacture of agricultural machines in Nigeria: the role of NASENI. Proceedings of the 2nd West African Society for Agricultural Engineering (WASAE), International Conference on Agricultural Engineering held at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 20th to 24th September, 2004: 27-35.

Onyeokoro, C. A. (2016). Operation Record Excerpts, Lower Anambra Irrigation Project Omor Ayamelum Local Government area Anambra State.

Opara, L. U. (1987). Development of A Nomograph-based Model for Farm Power and Machinery Selection in Nigeria. Unpublished B. Engr. Project Report Submitted To the Agricultural Engineering Department UNN.

Phil-Eze, P. O. (2010). Variability of soil properties related to vegetation cover in a tropical rainforest landscape. Journal of Geography and Regional Planning 3(7): 177-184

Rasouli, F., Sadighi, H. and Minaei, S. (2009). Factors affecting Agricultural Mechanization; a case study on sunflower seed farms in Iran. Journal of Agricultural Science Technology 11: 39-48.

Rijk, A. G. (1999). Agricultural mechanization strategy. CIGR Handbook of Agricultural Engineering Volume III Plant Production Engineering American Society of Agricultural Engineers: 536-553.

Roberson, G. (2012). Machinery Management. Professional Engineering Exam Review. North Carolina State University, USA. ASABE machinery_management_pe_review-2012

Rotz, C. A.and Harrigan T. M. (2005). Predicting suitable days for field machinery operations in a whole farm simulation Applied Engineering in Agriculture 21(4): 563−571

Saglam, C. and Ibrahim, T. (2011). Distribution of tractor available workdays over the southeastern Anatolia project (GAP) area. African Journal of Agricultural Research. 6, 30: 6416-6424 www.academicjournals.org/ajar/PDF/.../Saglam %20and%20Tobi.pdf.

Scheffer, F. and Schachtschabel, P. (1992). Lehrbuch der Bodenkunde. Stuttgart: Ferdinand EnkeVerlag.

Shuttle Radar Topographic Mission Maps (SRTM 30.) http://dds.cr.usgs.gov/srtm/version2_1/SRTM30/

Simalenga, and Have (1994). Predicting soil moisture status and suitable field workdays under tropical conditions AMA 25(3): 9-12.

Sims, B. G. and Kienzle J. (2006). Farm power and mechanization for small farms in sub-Saharan Africa. Agricultural and Food Engineering Technical Report, FAO Rome.

Sims, B. and Kienzle J. (2017). Sustainable agricultural mechanization for smallholders: What is it and how can we implement it? Agriculture 7(50): 1-21. doi:10.3390/agriculture7060050 www.mdpi.com/journal/agriculture

Søgaard, H. T. and Sørensen, C. G. (2004). A model for optimal selection of machinery sizes within the farm machinery system. Biosystems Engineering 89(1), 13–28 doi:10.1016/j.biosystemseng.2004.05.004 www.sciencedirect.com

Soni, P. and Ou, Y. (2010). Agricultural Mechanization at a Glance in Selected Country Studies in Asia on Agricultural Machinery Development http://www.fao.org/docrep/004/y3557e/y3557e04.htm

Srivastava, A. K., Goering, C. E., Rohrbach, R. P. and Buckmaster, D. R. (2006). Engineering Principles ofAgricultural Machines. 2nd Edition American Society of Agricultural and Biological Engineers (ASABE) 2950 Niles Road, St. Josef, Michigan

Starkey, P. (ed), 1998. Integrating mechanization into strategies for sustainable agriculture. Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.

Taha, H. A. (2007). Operations Research: An Introduction. ($8^{th}$ edition) Pearson Prentice Hall New Jersy: 209, 248, 258

Takeshima, H., Pratt, A. N. and Diao, X. (2013). Agricultural mechanization parterns in Nigeria; insights from farm household typology and agricultural household model simulation. Nigeria Strategy Support Program Policy Note No. 22 International food policy Research Institute (IFPRI), Discussion Paper 01291

Takeshima, H and Salau, S (2010). Agricultural mechanization and the small holder farmer in Nigeria. Nigeria Strategy Support Program Policy Note No. 22 International Food Policy Research Institute (IFPRI), Abuja

Van den Berg, M. M., Hengsdijk, H., Wolf, J., Van Ittersum, M. K., Guanghuo, W. and Roetter, R. P. (2007). The impact of increasing farm size and mechanization on rural income and rice production in Zhejiang province, China Agriicultural Systems doi:10.1016/j.agsy.2006.11.010

Weise, G. and Bourarach, E. H. (1999). Tillage machinery. The International Commission of Agricultural Engineering (CIGR) Handbook of Agricultural Engineering Volume III (Plant Production Engineering) Stout, B. A. and Cheze, B. (Eds).

Witney, B. D. and Saadoum, T. (1989). Annual Cost of Farm Machinery Ownership. Scotland Centre of Agricultural Engineering (ACAE). East Scotland College of Agriculture, Edinburgh.

Yassin (2001). Comparison between machinery ownership costs and contract charge using computer model. University of Khartoum.

Yiljep, Y. D. and Gwarzo, M. A. (undated). Estimating Farm Machinery Cost. Extension Bulletin No. 82 Agricultural Engineering Series No. 3. National Agricultural Extension and Research Liaison Services Ahmadu Bello University Zaria.

Yohanna, J.Y. (2004). A survey of tractor and implements Utilization for Crop production in Nasarawa State of Nigeria. Proceedings of the Nigeria institution of Agricultural Engineers 26: 53-58.

Yohanna, J. K. and Ifem, J. L. C. (2004). Performance evaluation of field efficiencies of farm machinery in Nassarawa and Plateau States. Proceedings of the 5th International Conference of the Nigerian Institution of Agricultural Engineers, 26: 88-92.

Yulan, L., Youpan, S., Shihao, L. Danping, C. and Gaoping, W. (2012). Development and prototype trial of digging-pulling style cassava harvester. Transactions of the Chinese Society of Agricultural Engineering (CSAE), 28(2): 29-35.

Zaied, M. B., Naim, A. M. E. and Mahmoud, T. E. (2014). Computer modeling for prediction of implement field performance variables. World Journal of Agricultural Research, 2(2): 37-41.

Zoz, F. M. and Grisso, R. D. (2003). Traction and Tractor Performance. ASAE Distinguished Lecture Series; Tractor Design No. 27

http://www.latlong.net/

http://www.nationsencyclopedia.com/Africa/Nigeria-AGRICULTURE.htmlAgriculture-Nigeria-export, growth FILE

www.bankofagricultureng.com/…uments/AB83MN65EF77 EarthTrendAgr and Food- -Nigeria

http://www.nhc.noaa.gov/gccalc.shtml

# APPENDICES

## APPENDIX A-1: Field Operations Speed, Repair and Maintenance Factors

| Machinery | Field Efficiency | | Field Speed | | EUL | | Repair Factors | |
|---|---|---|---|---|---|---|---|---|
| | Range % | Typical % | Range km/hr | Typical km/hr | Est. Life (hrs) | Tot. Life Cost %[a] | RF1 | RF2 |
| **TRACTORS** | | | | | | | | |
| 2WD & stationary | | | | | 12,000 | 100 | 0.007 | 2.0 |
| 4WD & crawler | | | | | 16,000 | 80 | 0.003 | 2.0 |
| **TILLAGE & PLANTING** | | | | | | | | |
| Mouldboard plow | 70-90 | 85 | 4.83-9.66 | 7.24 | 2,000 | 100 | 0.29 | 1.8 |
| Heavy-duty disk | 70-90 | 85 | 4.83-9.66 | 7.24 | 2,000 | 60 | 0.18 | 1.7 |
| Tadem disk harrow | 70-90 | 80 | 6.44-11.27 | 9.66 | 2,000 | 60 | 0.18 | 1.7 |
| (Coulter) chisel plow | 70-90 | 85 | 6.44-10.46 | 8.05 | 2,000 | 75 | 0.28 | 1.4 |
| Field cultivator | 70-90 | 85 | 8.05-12.87 | 11.27 | 2,000 | 70 | 0.27 | 1.4 |
| Spring tooth harrow | 70-90 | 85 | 8.05-12.87 | 11.27 | 2,000 | 70 | 0.27 | 1.4 |
| Roller-packer | 70-90 | 85 | 7.24-12.07 | 9.66 | 2,000 | 40 | 0.16 | 1.3 |
| Mulch-packer | 70-90 | 80 | 6.44-11.27 | 8.05 | 2,000 | 40 | 0.16 | 1.3 |
| Rotary hoe | 70-85 | 80 | 12.87-22.53 | 19.31 | 2,000 | 60 | 0.23 | 1.4 |
| Row crop cultivator | 70-90 | 80 | 4.83-11.27 | 8.05 | 2,000 | 80 | 0.17 | 2.2 |
| Rotary tiller | 70-90 | 85 | 1.61-7.24 | 4.83 | 1,500 | 80 | 0.36 | 2.0 |
| Row crop planter | 50-75 | 65 | 6.44-11.27 | 8.85 | 1,500 | 75 | 0.32 | 2.1 |
| Grain drill | 55-80 | 70 | 6.44-11.27 | 8.05 | 1,500 | 75 | 0.32 | 2.1 |
| **HARVESTING** | | | | | | | | |
| Corn picker sheller | 60-75 | 65 | 3.22-6.44 | 4.02 | 2,000 | 70 | 0.14 | 2.3 |
| PT Combine | 60-75 | 65 | 3.22-8.05 | 4.83 | 2,000 | 60 | 0.12 | 2.3 |
| SP Combine | 65-80 | 70 | 3.22-8.05 | 4.83 | 3,000 | 40 | 0.04 | 2.1 |
| Mower | 75-85 | 80 | 4.83-9.66 | 8.05 | 2,000 | 150 | 0.46 | 1.7 |
| Mower (rotary) | 75-90 | 80 | 8.05-19.31 | 11.27 | 2,000 | 175 | 0.44 | 2.0 |
| Mower-conditioner | 75-85 | 80 | 4.83-9.66 | 8.05 | 2,500 | 80 | 0.18 | 1.6 |
| Mower-cond (rotary) | 75-90 | 80 | 8.05-19.31 | 11.27 | 2,500 | 100 | 0.16 | 2.0 |
| SP Windrower | 70-85 | 80 | 4.83-12.87 | 8.05 | 3,000 | 55 | 0.06 | 2.0 |
| Side delivery rake | 70-90 | 80 | 6.44-12.87 | 9.66 | 2,500 | 60 | 0.17 | 1.4 |
| Square baler | 60-85 | 75 | 4.02-9.66 | 6.44 | 2,000 | 80 | 0.23 | 1.8 |
| Large square baler | 70-90 | 80 | 6.44-12.87 | 8.05 | 3,000 | 75 | 0.10 | 1.8 |
| Large round baler | 55-75 | 65 | 4.83-12.87 | 8.05 | 1,500 | 90 | 0.43 | 1.8 |
| Forage harvester | 60-85 | 70 | 2.41-8.05 | 4.83 | 2,500 | 65 | 0.15 | 1.6 |
| SP Forage harvester | 60-85 | 70 | 2.41-9.66 | 5.63 | 4,000 | 50 | 0.03 | 2.0 |
| Sugar beet harvester | 50-70 | 60 | 6.44-9.66 | 8.05 | 1,500 | 100 | 0.59 | 1.3 |
| Potato harvester | 55-70 | 60 | 2.41-6.44 | 4.02 | 2,500 | 70 | 0.19 | 1.4 |
| SP Cotton picker | 60-75 | 70 | 3.22-6.44 | 4.83 | 3,000 | 80 | 0.11 | 1.8 |
| **MISCELLANEOUS** | | | | | | | | |
| Fertilizer spreader | 60-80 | 70 | 8.05-16.09 | 11.27 | 1,200 | 80 | 0.63 | 1.3 |
| Boom-type sprayer | 50-80 | 65 | 4.83-11.27 | 10.46 | 1,500 | 70 | 0.41 | 1.3 |
| Bean puller/windrower | 70-90 | 80 | 6.44-11.27 | 8.05 | 2,000 | 60 | 0.20 | 1.6 |
| Beet topper/chopper | 70-90 | 80 | 6.44-11.27 | 8.05 | 1,200 | 35 | 0.28 | 1.4 |

(Source: ASAE Standard 1993, as quoted in Srivastava et al, 2006). [a]Percent of current list price

APPENDIXA-2: Wear-out lives and field capacities of some agro-machinery

| Machine | Wear-out Live** (hr) | Annual Use (hr) | | Field Capacity (ha/hr) | | Average Fuel Consumption | |
|---|---|---|---|---|---|---|---|
| | | Standard* (Std) | Nigeria** | Std* | Nigeria[##] | (l/hr)* | (l/ha)[##] |
| Tractors | 12,000 | 1000 | 300 | | | 4.16 | |
| Tillage Machines (General) | 2,500 | | | | 0.30[#] | | |
| Plough | | 180 | 175 | 0.250 | 0.630 | 4.25 | 22.87 |
| Harrow | | 200 | 180 | 0.270 | 1.423 | 4.20 | 21.81 |
| Ridging | | 200 | 200 | 0.310 | 0.799 | 4.30 | 18.41 |
| Seeders | 1,200 | | | na | 1.897 | na | 17.42 |
| Harvesters | 2,000 | | | | | | |
| Slasher | | 170 | 150 | 0.290 | | 5.0 | |

[#]Average for operations studied by Onuachu, 1983 on 44-80 hp Tractors
(Sources: *Hunt, 2001, **Onuachu, 1983and [##]Oduma *et al*, 2015)

**APPENDIXB-1: Derivation of the minimum-cost field machine width (for operation labour cost-included annual machinery cost**

Fitting Equations 3.27 and 3.31 into Equation 3.36 and differentiating with respect to machine width in order to solve for the minimum-cost width proceeded as below. Machinery capacity ($C_e$) in the labour cost part and and the soil texture factor ($C_1$) component of the tractor cost part were transformed into their machine width-containing forms. The draught function variable ($\Theta$) was also transformed into its machine width-containing form and differentiation carried out. $C_e$ and its equivalent $\frac{Swe}{10}$ for any of the variables expression were substituted to effect easier mathematical manipulations wherever the need arose.

$$\frac{d}{dw}\left(AC_g\right)=\frac{d}{dw}\left(\mu w\right)+\frac{d}{dw}\left(\frac{10A}{Swe}L\right)+\frac{d}{dw}\left(\frac{Ad\eta}{2.66e}\left(C_1+C_2\frac{100{C_e}^2}{w^2e^2}\right)\right)+\frac{d}{dw}\left(\frac{\pi d}{2.66\delta}\left(C_1\frac{Sw}{10}+C_2\frac{100{C_e}^2}{w^2e^2}\right)\right)$$

(B.1)

¿ $\mu+\frac{\pi d}{2.66\delta}C_1S-\frac{10A}{Sw^2e}L-\frac{2\pi d}{2.66\delta}C_2\frac{100{C_e}^3}{w^3e^3}-\frac{2Ad\eta}{2.66}C_2\frac{100{C_e}^2}{w^3e^3}$

(B.2)

Equating the derivative to zero and solving progressed as follows:

¿ $\mu+\frac{\pi d}{2.66\delta}C_1S=\frac{10A}{Sw^2e}L+\frac{2\pi d}{2.66\delta}C_2\frac{100{C_e}^3}{w^3e^3}+\frac{2Ad\eta}{2.66}C_2\frac{100{C_e}^2}{w^3e^3}$ (B.3)

¿ $\mu+\frac{\pi d}{2.66\delta}C_1S=\left[\frac{Awe^2}{10C_2Sd}L+\frac{2A\eta}{2.66}{C_e}^2+\frac{2\pi}{2.66\delta}{C_e}^3\right]\frac{100C_2d}{w^3e^3}$ (B.4)

Changing the width variable $w$ in the labour containing term to its field capacity ($C_e$) equivalent, we get the further solution;

$$\left[\mu+\frac{\pi d}{2.66\delta}C_1S\right]w^3=\left[\frac{AC_ee}{C_2S^2d}L+\frac{2A\eta}{2.66}{C_e}^2+\frac{2\pi}{2.66\delta}{C_e}^3\right]\frac{100C_2d}{e^3} \quad \text{(B.5)}$$

Setting $\varphi=C_2S^2d$ (B.6)

$\rho=C_1Sd$ (B.7)

$$w^3=\frac{C_2d}{\left[\mu+\frac{0.0375\pi\rho}{\delta}\right]e^3}\left[\frac{100AC_ee}{\varphi}L+75A\eta{C_e}^2+\frac{75\pi}{\delta}{C_e}^3\right] \quad \text{(B.8)}$$

The minimum-cost width thus becomes:

$$w=\sqrt[3]{\frac{C_2 d}{\left[\mu+\frac{0.0375\pi\rho}{\delta}\right]e^3}\left[\frac{100\,A\,C_e\,e}{\varphi}L+75\,A\eta\,C_e^{\,2}+\frac{75\pi}{\delta}C_e^{\,3}\right]} \quad \text{(B.9)}$$

The capacity variable ($C_e$) in the labour containing term can also be replaced with its area and available hours function-equivalent;

$$C_e=\frac{A}{h_{AV}} \quad \text{(B.10).}$$

Where the annual available hours for processing the field is evaluated as:

$$h_{AV}=AD\times G \quad \text{(B.11).}$$

The minimum-cost width can now be solved for from equation B.6 as follows:

This gives the minimum-cost width as:

$$w=\sqrt[3]{\frac{C_2 d}{\left[\mu+\frac{0.0375\pi\rho}{\delta}\right]e^3}\left[\frac{100\,A^2 e}{\varphi\,h_{AV}}L+75\,A\eta\,C_e^{\,2}+\frac{75\pi}{\delta}C_e^{\,3}\right]} \quad \text{(B.12).}$$

Test of minimization condition on model: To test for the sufficient condition for a minimized annual cost equation B.2 was differentiated with respect to implement width as follows:

$$\frac{d^2}{dw^2}(AC_g)=\frac{d\mu}{dw}+\frac{d}{dw}\left[\frac{\pi\rho}{26.6\,\delta}\right]-\frac{d}{dw}\left[\frac{10\,A}{S\,w^2 e}L\right]-\frac{d}{dw}\left[\frac{\pi d}{2.66\,\delta}C_2\frac{200\,C_e^{\,3}}{w^3e^3}\right]+\frac{d}{dw}\left[\frac{Ad\eta}{2.66}C_2\frac{200C_e^{\,2}}{w^3e^3}\right]$$

(B.13)

$$=\frac{20A}{Sw^3e}L+\frac{\pi d}{2.66\delta}C_2\frac{600C_e^{\,3}}{w^4\,e^3}+\frac{Ad\eta}{2.66}C_2\frac{600C_e^{\,2}}{w^4\,e^3}$$

$$=\frac{20A}{Sw^3e}L+\frac{\pi d}{2.66\delta}C_2\frac{600C_e^{\,3}}{w^4\,e^3}+\frac{Ad\eta}{2.66}C_2\frac{600C_e^{\,2}}{w^4\,e^3} \quad \text{(B.14)}$$

$$=\frac{20A}{Sw^3e}L+\frac{600C_2dC_e^{\,2}}{w^4\,e^3}\left(\frac{\pi}{2.66\delta}C_e+\frac{A\eta}{2.66}\right)$$

$$=\frac{20A}{Sw^3e}L+\frac{600C_2dC_e^{\,2}}{w^4\,e^3}\left(\frac{\pi}{2.66\delta}C_e+\frac{A\eta}{2.66}\right) \quad \text{(B.15)}$$

The expression in equation B.15 will yield a positive value with positive-valued factors, showing that the annual cost will be a minimum at the turning point in question.

**APPENDIX B-2: Derivation of the minimum-cost field machine capacity (for operation labour cost-included annual machinery cost)**

Multiplying both sides of equation B.5 with $\left(\frac{Se}{10}\right)^3$ to convert the $w^3 w^3$ to $C_e{}^3 C_e{}^3$ and gave:

$$\left[\mu_c + \frac{\pi\rho}{26.6\delta}\right] C_e{}^3 = \left[\frac{AC_e e}{2\varphi} L + \frac{\pi}{2.66\delta} C_e{}^3 + \frac{A\eta}{2.66} C_e{}^2\right] \frac{200 C_2 d S^3}{1000}$$


$$\left[\mu_c + \frac{\pi\rho}{26.6\delta}\right] C_e{}^3 = \left[\frac{AC_e e}{2\varphi} L + \frac{\pi}{2.66\delta} C_e{}^3 + \frac{A\eta}{2.66} C_e{}^2\right] \frac{200 C_2 d S^3}{1000}$$


(B.16)

Dividing (B.16) through by $C_e$ and collecting like terms gave equations B.17 and B.20.

$$\left(\mu_c + \frac{\pi\rho}{26.6\delta} - \frac{0.2\pi\tau}{2.66\delta}\right) C_e{}^2 - \frac{0.2A\eta\tau}{2.66} C_e - 0.1SAeL = 0$$


$$\left(\mu_c + \frac{\pi\rho}{26.6\delta} - \frac{0.2\pi\tau}{2.66\delta}\right) C_e{}^2 - \frac{0.2A\eta\tau}{2.66} C_e - 0.1SAeL = 0$$


(B.17)

where: $\mu_c = \frac{\gamma}{100} p_c$ (B.18)

$\tau = C_2 S^3 d$ (B.19)

$$\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) C_e{}^2 - 0.075A\eta\tau C_e - 0.1SAeL = 0$$


$$\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) C_e{}^2 - 0.075A\eta\tau C_e - 0.1SAeL = 0$$


(B.20)

Equation B.17 was of the quadratic format:

$$a'C_e{}^2 - b'C_e - 0.1c' = 0 a'C_e{}^2 - b'C_e - 0.1c' = 0$$

(B.21)

where:

$$a' = \mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right) a' = \mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)$$

(B.22)

$$b' = -0.075A\eta\tau b' = -0.075A\eta\tau$$

(B.23)

$$c' = -0.1SAeLc' = -0.1SAeL$$

(B.24)

The above quadratic function of machinery capacity $C_e$ was solved using the formula method as follows:

$$C_e = \frac{-b' \pm \sqrt{b'^2 - 4a'c'}}{2a'} C_e = \frac{-b' \pm \sqrt{b'^2 - 4a'c'}}{2a'}$$

(B.25)

By inspection, evaluating $C_e C_e$ (equation B.21) as

$$C_e = \frac{0.075A\eta\tau - \sqrt{(-0.075A\eta\tau)^2 + 0.4\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) SAeL}}{2\left(\mu_c + \left(\frac{\rho - 2\tau}{\delta}\right) 0.0375\pi\right)}$$

$$C_e = \frac{0.075A\eta\tau - \sqrt{(-0.075A\eta\tau)^2 + 0.4\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) SAeL}}{2\left(\mu_c + \left(\frac{\rho - 2\tau}{\delta}\right) 0.0375\pi\right)}$$

(B.26)

will yield a negative unacceptable solution. Thus $C_e$ was solved as:

$$C_e = \frac{0.075A\eta\tau + \sqrt{(-0.075A\eta\tau)^2 + 0.4\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) SAeL}}{2\mu_c + 0.075\pi\left(\frac{\rho - 2\tau}{\delta}\right)}$$

$$C_e = \frac{0.075A\eta\tau + \sqrt{(-0.075A\eta\tau)^2 + 0.4\left(\mu_c + 0.0375\pi\left(\frac{\rho - 2\tau}{\delta}\right)\right) SAeL}}{2\mu_c + 0.075\pi\left(\frac{\rho - 2\tau}{\delta}\right)}$$

(B.27)

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

(B.28)

## APPENDIX B-3: derivation of the minimum-cost field machine width (for operation labour cost-excluded annual machinery cost)

Differentiating equation 3.42 with respect to machine width in order to solve for the minimum-cost width proceeded as below. Some variables were transformed into their width-containing forms and differentiation carried out.

$$\frac{d}{dw}(AC_g) = \frac{d\mu w}{dw} + \frac{d}{dw}\left(\frac{Ad\eta}{2.66e}\left(C_1 + C_2\frac{100C_e{}^2}{w^2 e^2}\right)\right) + \frac{d}{dw}\left(\frac{\pi d}{26.6e\delta}\left(C_1\frac{Sw}{10} + C_2\frac{100C_e{}^3}{w^2 e^3}\right)\right)$$

$$\frac{d}{dw}(AC_g) = \frac{d\mu w}{dw} + \frac{d}{dw}\left(\frac{Ad\eta}{2.66e}\left(C_1 + C_2\frac{100C_e{}^2}{w^2 e^2}\right)\right) + \frac{d}{dw}\left(\frac{\pi d}{26.6e\delta}\left(C_1\frac{Sw}{10} + C_2\frac{100C_e{}^3}{w^2 e^3}\right)\right)$$

(B.29)

$$= \mu + \frac{\pi\rho}{26.6\delta} - \frac{\pi d}{2.66\delta}C_2\frac{200C_e{}^3}{w^3\ e^3} - \frac{2Ad\eta}{2.66}C_2\frac{100C_e{}^2}{w^3\ e^3}$$

$$= \mu + \frac{\pi\rho}{26.6\delta} - \frac{\pi d}{2.66\delta}C_2\frac{200C_e{}^3}{w^3\ e^3} - \frac{2Ad\eta}{2.66}C_2\frac{100C_e{}^2}{w^3\ e^3}$$

(B.30)

Equating the derivative to zero and solving for minimum-cost width gives:

$$\mu + \frac{\pi\rho}{26.6\delta} = \left[\frac{\pi}{2.66\delta}C_e{}^3 + \frac{A\eta}{2.66}C_e{}^2\right]\frac{200C_2 d}{w^3\ e^3}$$

$$\mu + \frac{\pi\rho}{26.6\delta} = \left[\frac{\pi}{2.66\delta}C_e{}^3 + \frac{A\eta}{2.66}C_e{}^2\right]\frac{200C_2 d}{w^3\ e^3}$$

(B.31)

$$\left(\mu + \frac{\pi\rho}{26.6\delta}\right)w^3 = \left[\frac{\pi}{2.66\delta}C_e{}^3 + \frac{A\eta}{2.66}C_e{}^2\right]\frac{200C_2 d}{e^3}$$

$$\left(\mu + \frac{\pi\rho}{26.6\delta}\right)w^3 = \left[\frac{\pi}{2.66\delta}C_e{}^3 + \frac{A\eta}{2.66}C_e{}^2\right]\frac{200C_2 d}{e^3}$$

(B.32)

$$w^3 = \frac{C_2 d}{(\mu + 0.0375\pi\rho/\delta)e^3}\left[\frac{75\pi}{\delta} {C_e}^3 + 75A\eta {C_e}^2\right]$$

$$w^3 = \frac{C_2 d}{(\mu + 0.0375\pi\rho/\delta)e^3}\left[\frac{75\pi}{\delta} {C_e}^3 + 75A\eta {C_e}^2\right]$$

(B.33)

This gives the optimum width as:

$$w = \sqrt[3]{\frac{C_2 d}{(\mu + 0.0375\pi\rho/\delta)e^3}\left[\frac{75\pi}{\delta} {C_e}^3 + 75A\eta {C_e}^2\right]}$$

$$w = \sqrt[3]{\frac{C_2 d}{(\mu + 0.0375\pi\rho/\delta)e^3}\left[\frac{75\pi}{\delta} {C_e}^3 + 75A\eta {C_e}^2\right]}$$

(B.34)

Test of minimization condition on model: To test for the sufficient condition for a minimized annual cost equation B.29 was differentiated with respect to implement width as follows:

$$\frac{d^2}{dw^2} AC_g = \frac{d\mu}{dw} + \frac{d}{dw}\left[\frac{\pi\rho}{26.6\delta}\right] - \frac{d}{dw}\left[\frac{\pi d}{2.66\delta} C_2 \frac{200{C_e}^3}{w^3\ e^3}\right] - \frac{d}{dw}\left[\frac{Ad\eta}{2.66} C_2 \frac{200{C_e}^2}{w^3\ e^3}\right]$$

$$\frac{d^2}{dw^2} AC_g = \frac{d\mu}{dw} + \frac{d}{dw}\left[\frac{\pi\rho}{26.6\delta}\right] - \frac{d}{dw}\left[\frac{\pi d}{2.66\delta} C_2 \frac{200{C_e}^3}{w^3\ e^3}\right] - \frac{d}{dw}\left[\frac{Ad\eta}{2.66} C_2 \frac{200{C_e}^2}{w^3\ e^3}\right]$$

(B.35)

$$= \frac{\pi d}{2.66\delta} C_2 \frac{600{C_e}^3}{w^4\ e^3} + \frac{Ad\eta}{2.66} C_2 \frac{600{C_e}^2}{w^4\ e^3} = \frac{\pi d}{2.66\delta} C_2 \frac{600{C_e}^3}{w^4\ e^3} + \frac{Ad\eta}{2.66} C_2 \frac{600{C_e}^2}{w^4\ e^3}$$

(B.36)

$$= \frac{600 C_2 d {C_e}^2}{w^4\ e^3}\left(\frac{\pi}{2.66\delta} C_e + \frac{A\eta}{2.66}\right) = \frac{600 C_2 d {C_e}^2}{w^4\ e^3}\left(\frac{\pi}{2.66\delta} C_e + \frac{A\eta}{2.66}\right)$$

(B.37)

By inspection, Equation B.36 will yield a positive value with positive-valued factors, showing that the annual cost will be a minimum at the turning point in question.

**APPENDIX B-4: Derivation of the minimum-cost field machine capacity (for operation labour cost-excluded annual machinery cost)**

The implement price per width ($pp$) in equation B.32 was replaced with price per capacity ( $p_c p_c$). Multiplying both sides of equation B.32 with $\left(\frac{Se}{10}\right)^3 \left(\frac{Se}{10}\right)^3$ to convert the $w^3 w^3$ to $C_e{}^3 C_e{}^3$ gives:

$$C_e{}^3 = \frac{C_2 S^3 d}{1000(\mu_c + 0.0375\pi\rho/\delta)}\left[\frac{75\pi}{\delta}C_e{}^3 + 75A\eta C_e{}^2\right]$$


$$C_e{}^3 = \frac{C_2 S^3 d}{1000(\mu_c + 0.0375\pi\rho/\delta)}\left[\frac{75\pi}{\delta}C_e{}^3 + 75A\eta C_e{}^2\right]$$


(B.38)

Dividing through by $C_e^2$ and collecting like terms:

$$C_e\left[\frac{\mu_c + 0.0375\pi\rho/\delta}{\tau}\right] + \frac{0.075\pi}{\delta}C_e = 0.075A\eta$$


$$C_e\left[\frac{\mu_c + 0.0375\pi\rho/\delta}{\tau}\right] + \frac{0.075\pi}{\delta}C_e = 0.075A\eta$$


(B.39)

$$C_e\left[\mu_c + \left(\frac{0.0375\rho - 0.075\tau}{\delta}\right)\pi\right] = 0.075A\eta\tau$$


$$C_e\left[\mu_c + \left(\frac{0.0375\rho - 0.075\tau}{\delta}\right)\pi\right] = 0.075A\eta\tau$$


(B.40)

$$C_e = \frac{0.075A\eta\pi}{\left[\mu_c + 0.0375\pi\left(\frac{\rho-\tau}{\delta}\right)\right]} C_e = \frac{0.075\,A\eta\tau}{\mu_c + 0.0375\,\pi\left(\frac{\rho - 2\tau}{\delta}\right)}$$

(B.41)

**APPENDIX B-5: Derivation of the multi-crop multi-farm minimum-cost machine width (for operation labour cost-included annual machinery cost)**

Some variables were converted to their width-containing form for easier differention.

$$AC_g=\mu w+\sum_{j}^{m}\sum_{i=1}^{n}\frac{10A_{ij}}{Swe}L+\sum_{j}^{m}\sum_{i=1}^{n}\frac{A_{ij}d\sigma}{2.66H_{ij}e}\left(C_{1ij}+C_{2ij}\frac{100C_e^{2}}{w^2e^2}\right)+\sum_{j}^{m}\sum_{i=1}^{n}\frac{\pi_{ij}d}{2.66\delta_{ij}}\left(C_{1i}\frac{Sw}{10}+C_{2i}\frac{100C_e^{3}}{w^2e^3}\right)$$

(B.42)

Differentiating the above expression went as follows:

$$\frac{d}{dw}AC_g=\frac{d\mu w}{dw}+\sum_{j}^{m}\sum_{i=1}^{n}\frac{d}{dw}\left(\frac{10A_{ij}}{Swe}L\right)+\sum_{j}^{m}\sum_{i=1}^{n}\frac{d}{dw}\left(\frac{A_{ij}d\sigma}{2.66H_{ij}e}\left(C_{1ij}+C_{2ij}\frac{100C_e^{2}}{w^2e^2}\right)\right)+\sum_{j}^{m}\sum_{i=1}^{n}\frac{d}{dw}\left(\frac{\pi_{ij}d}{2.66\delta_{ij}}\left(C_{1ij}\frac{Sw}{10}\right.\right.$$

(B.43)

$$\text{¿}\,\mu+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{26.6\delta_{ij}}C_{1ij}Sd\right)-\sum_{j}^{m}\sum_{i=1}^{n}\frac{10A_{ij}}{Sw^2e}L-\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{2.66\delta_{ij}}C_{2ij}d\frac{200C_e^{3}}{w^3e^3}\right)-\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{A_{ij}\sigma}{2.66H_{ij}}C_{2ij}d\frac{200C_e^{2}}{w^3e^3}\right)$$

(B.44)

$C_{1ij}Sd$ was replaced with its block representative notation $\rho_{ij}$ and the derivative equated to zero so as to solve for the minimum-cost width.

$$\left[\mu+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}\rho_{ij}}{2.66\delta_{ij}}\right)\right]w^3=\left[\sum_{j}^{m}\sum_{i=1}^{n}\frac{A_{ij}we^2}{20C_{2ij}Sd}L+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{2.66\delta_{ij}}C_e^{3}\right)+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{A_{ij}\eta_{ij}}{2.66}C_e^{2}\right)\right]\frac{200C_{2ij}d}{e^3}$$

(B.45)

The width variable $w$ in the labour containing term was changed to its field capacity ($C_e$) equivalent. Some groups of variables were replaced with block variable symbols to simplify the expression for further solution.

$$w^3=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(\frac{100A_{ij}C_ee}{C_{2ij}S^2d}L+75A_{ij}\eta_{ij}C_e^{2}+75\frac{\pi_{ij}}{\delta_{ij}}C_e^{3}\right)\frac{C_{2ij}d}{e^3}\right]}{\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{0.0375\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)} \qquad \text{(B.46)}$$

$C_{2ij}S^2d$ was replaced with its block representative notation $\varphi_{ij}$.

$$w^3=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(\frac{100A_{ij}C_ee}{\varphi_{ij}}L+75A_{ij}\eta_{ij}C_e^{2}+75\frac{\pi_{ij}}{\delta_{ij}}C_e^{3}\right)\frac{C_{2ij}d}{e^3}\right]}{\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{0.0375\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)} \qquad \text{(B.47)}$$

$$w=\sqrt[3]{\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(\frac{100A_{ij}C_ee}{\varphi_{ij}}L+75A_{ij}\eta_{ij}C_e^{2}+\frac{75\pi_{ij}}{\delta_{ij}}C_e^{3}\right)\right]\frac{C_{2ij}d}{e^3}}{\left[\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{0.0375\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)\right]}} \qquad \text{(B.48)}$$

**APPENDIX B-6: Derivation of the multi-crop multi-farm minimum-cost machine capacity (for operation labour cost-included annual machinery cost)**

Equation B.47 was multiplied with $\frac{S^3 e^3}{1000}$ to convert the width function $w^3$ to capacity function $C_e^3$. The resulting expression was rearranged to give the expression shown in Equation B.49. The implement fixed cost per width $\mu$ was also changed to its per capacity equivalent $\mu_c$.

$$\left[\mu_c + 0.0375 \sum_{j=1}^{m} \sum_{i=1}^{n} \left(\frac{\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)\right] C_e^3 = \sum_{j=1}^{m} \sum_{i=1}^{n} \left[\left(\frac{100 A_{ij} C_e e}{\varphi_{ij}} L + 75 A_{ij} \eta_{ij} C_e^2 + 75 \frac{\pi_{ij}}{\delta_{ij}} C_e^3\right) \frac{C_{2ij} S^3 d}{1000}\right]$$

(B.49)

Collecting like terms and dividing Equation B.49 by $C_e$ and replacing $C_{2ij} S^3 d$ with $\tau_{ij}$ gave Equations B.50.

$$\left[\mu_c + 0.0375 \sum_{j=1}^{m} \sum_{i=1}^{n} \pi_{ij} \left(\frac{\rho_{ij} - 2\tau_{ij}}{\delta_{ij}}\right)\right] C_e^2 - 0.075 \sum_{j=1}^{m} \sum_{i=1}^{n} A_{ij} \eta_{ij} C_e - 0.1 \sum_{j=1}^{m} \sum_{i=1}^{n} S A_{ij} e L = 0$$

(B.50)

$$a'' C_e^2 - b'' C_e - 0.1 c'' = 0 \qquad \text{(B.51)}$$

where:

$$a'' = \mu_c + \sum_{j=1}^{m} \sum_{i=1}^{n} 0.0375 \pi_{ij} \left(\frac{\rho_{ij} - 2\tau_{ij}}{\delta_{ij}}\right) \qquad \text{(B.52)}$$

$$b'' = -\sum_{j=1}^{m} \sum_{i=1}^{n} 0.075 A_{ij} \eta_{ij} \qquad \text{(B.53)}$$

$$c'' = -\sum_{j=1}^{m} \sum_{i=1}^{n} 0.1 S A_{ij} e L \qquad \text{(B.54)}$$

The above quadratic function of machinery capacity $C_e$ was solved using the formula method to yield Equation B.55

$$C_e = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \left(-b''_{ij}\right) + \sqrt{\sum_{j=1}^{m} \sum_{i=1}^{n} \left[\left(b''_{ij}\right)^2 + 4 a''_{ij} c''_{ij}\right]}}{\sum_{j=1}^{m} \sum_{i=1}^{n} 2 a''_{ij}} \qquad \text{(B.55)}$$

## APPENDIX B-7: Derivation of the multi-crop multi-farm minimum-cost machine width (for no operation labour cost scenario)

Some variables were converted to their width-containing form for easier differentiation.

$$AC_g = \mu w + \sum_{j}^{m}\sum_{i=1}^{n}\frac{A_{ij}d\sigma}{2.66H_{ij}e}\left(C_{1ij}+C_{2ij}\frac{100C_e^{2}}{w^2e^2}\right)+\sum_{j}^{m}\sum_{i=1}^{n}\frac{\pi_{ij}d}{2.66\delta_{ij}}\left(C_{1i}\frac{Sw}{10}+C_{2i}\frac{100C_e^{3}}{w^2e^3}\right) \quad \text{(B.56)}$$

Differentiating the above expression went as follows:

$$\frac{d}{dw}AC_g = \frac{d\mu w}{dw}+\sum_{j}^{m}\sum_{i=1}^{n}\frac{d}{dw}\left(\frac{A_{ij}d\sigma}{2.66H_{ij}e}\left(C_{1ij}+C_{2ij}\frac{100C_e^{2}}{w^2e^2}\right)\right)+\sum_{j}^{m}\sum_{i=1}^{n}\frac{d}{dw}\left(\frac{\pi_{ij}d}{2.66\delta_{ij}}\left(C_{1ij}\frac{Sw}{10}+C_{2ij}\frac{100C_e^{3}}{w^2e^3}\right)\right) \quad \text{(B.57)}$$

$$¿\,\mu+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{26.6\delta_{ij}}C_{1ij}Sd\right)-\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{2.66\delta_{ij}}C_{2ij}d\frac{200C_e^{3}}{w^3e^3}\right)-\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{A_{ij}\sigma}{2.66H_{ij}}C_{2ij}d\frac{200C_e^{2}}{w^3e^3}\right) \quad \text{(B.58)}$$

$C_{1ij}Sd$ was replaced with its block representative notation $\rho_{ij}$ and the derivative equated to zero and solved for the minimum-cost width as follows:

$$\left[\mu+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}\rho_{ij}}{2.66\delta_{ij}}\right)\right]w^3=\left[\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{\pi_{ij}}{2.66\delta_{ij}}C_e^{3}\right)+\sum_{j}^{m}\sum_{i=1}^{n}\left(\frac{A_{ij}\eta_{ij}}{2.66}C_e^{2}\right)\right]\frac{200C_{2ij}d}{e^3} \quad \text{(B.59)}$$

Some groups of variables were replaced with block variable symbols to simplify the expression for further solution.

$$w^3=\frac{C_{2ij}d}{\left[\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{0.0375\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)\right]e^3}\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(75A_{ij}\eta_{ij}C_e^{2}+75\frac{\pi_{ij}}{\delta_{ij}}C_e^{3}\right)\right] \quad \text{(B.60)}$$

$$w=\sqrt[3]{\frac{C_{2ij}d}{\left[\mu+\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{0.0375\pi_{ij}\rho_{ij}}{\delta_{ij}}\right)\right]e^3}\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\left(75A_{ij}\eta_{ij}C_e^{2}+\frac{75\pi_{ij}}{\delta_{ij}}C_e^{3}\right)\right]} \quad \text{(B.61)}$$

**APPENDIX B-8: Derivation of the multi-crop multi-farm minimum-cost machine capacity (for no operation labour cost scenario)**

Both sides of Equation B.59 was multiplied with $\frac{S^3 e^3}{1000}$ to convert the $w^3$ to $C_e^{\ 3}$. The implement fixed cost per width ($\mu$) was replaced with fixed cost per capacity ($\mu_c$) and further solution made.

$$\left[\mu_c+\sum_j^m \sum_{i=1}^n \left(\frac{\pi_{ij}\rho_{ij}}{2.66\delta_{ij}}\right)\right]C_e^{\ 3}=\left[\sum_j^m \sum_{i=1}^n \left(\frac{\pi_{ij}}{2.66\delta_{ij}}C_e^{\ 3}\right)+\sum_j^m \sum_{i=1}^n \left(\frac{A_{ij}\eta_{ij}}{2.66}C_e^{\ 2}\right)\right]\frac{200\,C_{2ij}S^3 d}{1000}$$

(B.62)

Collecting like terms gave:

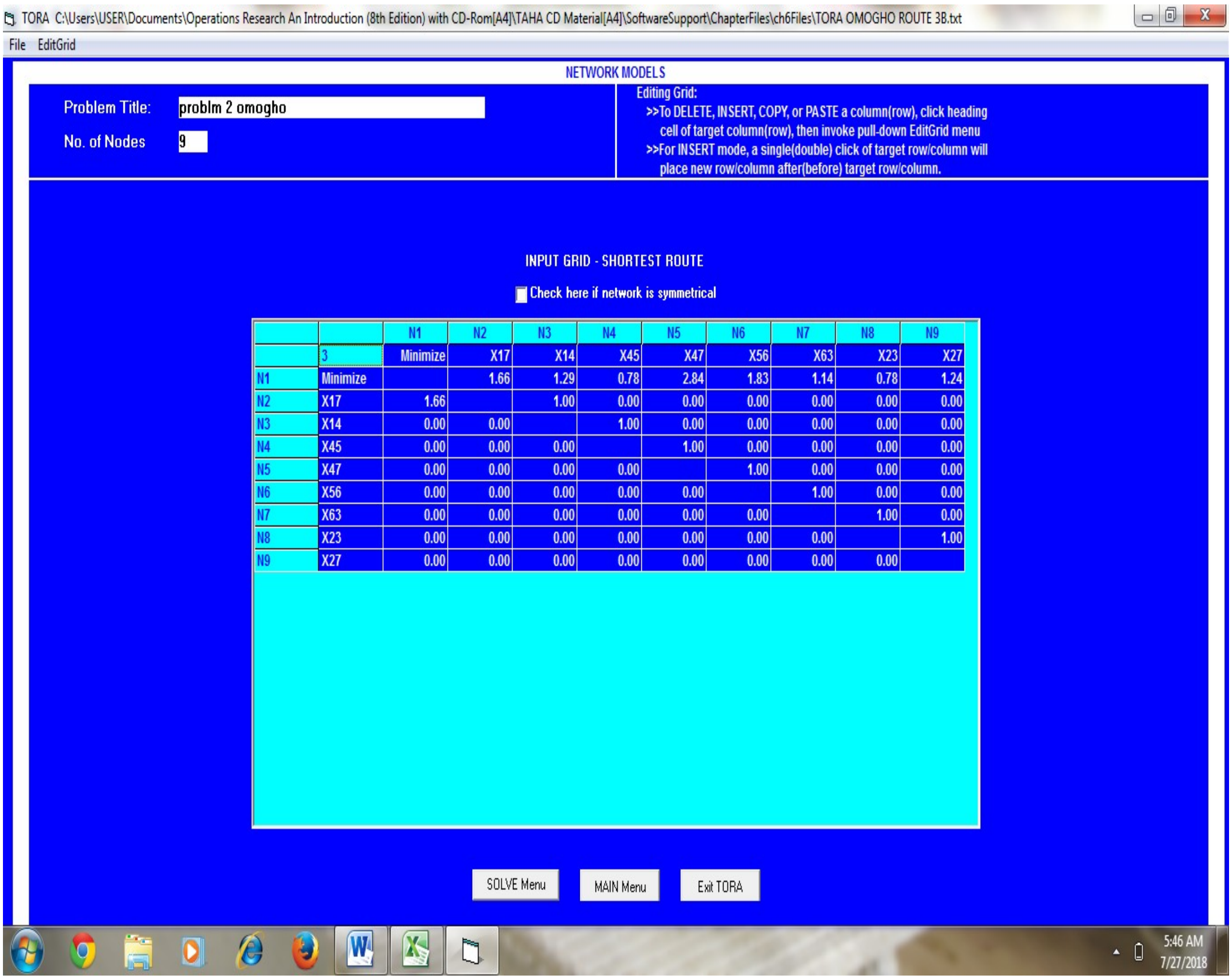
$$\left[\mu_c+\sum_j^m \sum_{i=1}^n \left(\frac{0.0375\,\pi_{ij}\left(\rho_{ij}-2C_{2ij}S^3 d\right)}{\delta_{ij}}\right)\right]C_e^{\ 3}=\sum_j^m \sum_{i=1}^n 75\,A_{ij}\eta_{ij}C_e^{\ 2}\frac{C_{2ij}S^3 d}{1000}$$

(B.63)

Dividing Equation (B.63) by $C_e^{\ 2}$and replacing $C_{2ij}S^3 d$ with $\tau_{ij}$ gave the minimum-cost capacity model as.

$$C_e^{\ 3}=\frac{0.075\sum_j^m \sum_{i=1}^n A_{ij}\eta_{ij}\tau_{ij}}{\mu_c+0.0375\sum_j^m \sum_{i=1}^n \frac{\pi_{ij}\left(\rho_{ij}-2\tau_{ij}\right)}{\delta_{ij}}} \qquad \text{(B.61)}$$

APPENDIX C: TORA model for solving the Dijkstra Algorithm




| | | N1 | N2 | N3 | N4 | N5 | N6 | N7 | N8 | N9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | Minimize | X17 | X14 | X45 | X47 | X56 | X63 | X23 | X27 |
| N1 | Minimize | | 1.66 | 1.29 | 0.78 | 2.84 | 1.83 | 1.14 | 0.78 | 1.24 |
| N2 | X17 | 1.66 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N3 | X14 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N4 | X45 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N5 | X47 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 | 0.00 |
| N6 | X56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 | 0.00 |
| N7 | X63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 | 0.00 |
| N8 | X23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 1.00 |
| N9 | X27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |

Source: Taha (2007)

**PLATES**

PLATE 1: The covered tractor shelter in Awkuzu Anambra State Nigeria

PLATE 2: Open shed implement shelter at the Anambra State agricultural ministry headquarters, Awka Nigeria