MACHINERY SYSTEM SELECTION AND
MANAGEMENT FOR CROP PRODUCTION
SUDAN (GEZIRA SCHEME)

By
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M.Sc. (Agric.) University of Khartoum 2001

A Thesis Submitted to the University of Khartoum
in Fulfillment of the Requirements for the
Degree of Doctor of Philosophy

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December 2004
To those who light for me candles of love
and support, my parents,
to my be loved brothers and sister,
to the kind hearted who provides generosity warmth, kind,
and encourage my dear husband (Magdi),
to my children with ever lasting love, Mohamed,
Huzyfa, Ahmed, Amera ,
and every one who contributed to the success of this effort.
I dedicate this work. ...
ACKNOWLEDGEMENT

First of all, I am grateful to Allah, for providing me with health and strength till I complete this work.

It gives me great pleasure to express my deep gratitude and everlasting thanks to my supervisor Dr. Mohamed Hassan Dahab for his keen interest, useful criticism and helpful guidance, his general assistance and continuous encouragement.

I have accumulated debt of gratitude to my Co-supervisor Dr. Abd Elmonen Elamin Mohamed for his great effort, helpful guidance and continuous encouragement.

Sincere thanks are due to Agric. Engineer Ahmed Mohamed Musa, Agricultural Engineering Dept., Gezira Board for his keen interest and unlimited help and support.

Special acknowledgement to Dr. Haitham Rajab El Ramlawi for his greater assistance in computer programming.

Thanks are also due to my colleagues at the Agricultural Bank of Sudan for their help and encouragement.

Special thanks and sincere gratitude are due to my colleagues at the Agricultural Engineering Department, Faculty of Agriculture, University of Khartoum.

Special thanks sincere gratitude are due to Miss. Bilghies for typing this work.

Finally, I would like to express my thanks to all those who helped me in any way.
ABSTRACT

It is believed that the improvement and increase of agricultural production can be warranted by developing better decision-aid planning tools. Hence, an algorithm has been developed. The crop production machinery system model (CPMSM) is an interactive computer model based on the concept of obtaining the total annual cost and cost per hour of tractor, implements and both of them together.

The model is a user-friendly program, which allows the person to interact with the program easily. The program was developed to enable the user easily obtain output using external files, thus gives options to choose the appropriate input, which suit his condition. The (CPMSM) was developed to predict the annual and hourly cost of a tractor as a source of power and also any of the attached implements in any operation according to the cultivated area. Also, the model can predict the cost a number of crops in specific crop rotation. This programming technique has been followed to achieve the maximum critical area allocated and the more profitable crops to be grown.

The sensitivity analysis of the model show that the different machines working parameters (e.g. speed, width of cut, field efficiency machine age and farm size) can affect the output and consequently selection is possible.
The computer model’s accuracy has been validated by taking different machinery cost analysis scenarios under the prevailing condition of Gezira scheme in Sudan.

Therefore, the model can be used for proper machinery management and decision-making successfully and with confidence.
لا يمكنني قراءة النص العربي المكتوب بالخط العربي. إذا كنت بحاجة إلى مساعدة في شيء آخر، فأنا هنا لمساعدتك!
# TABLE OF CONTENTS

Page

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ARABIC ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>CHAPTER ONE: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background and justification</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Problem definition</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Study objectiveness</td>
<td>5</td>
</tr>
<tr>
<td>CHAPTER TWO: LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>2. Farm machinery performance</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Power performance</td>
<td>6</td>
</tr>
<tr>
<td>2.1.1 Tractor for farm power</td>
<td>6</td>
</tr>
<tr>
<td>2.1.2 Tractor types and classification</td>
<td>7</td>
</tr>
<tr>
<td>2.1.3 Tractor construction component</td>
<td>8</td>
</tr>
<tr>
<td>2.1.4 Power generation in tractors</td>
<td>8</td>
</tr>
<tr>
<td>2.1.5 Power utilization system in tractor</td>
<td>9</td>
</tr>
<tr>
<td>2.1.6 Power requirements</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Machinery capacity performance</td>
<td>13</td>
</tr>
<tr>
<td>2.2.1 Machine capacity</td>
<td>13</td>
</tr>
<tr>
<td>2.2.2 Importance of field efficiencies</td>
<td>15</td>
</tr>
<tr>
<td>2.2.3 Factors affecting machinery field performance</td>
<td>15</td>
</tr>
<tr>
<td>2.2.4 Machinery matching with power sources</td>
<td>16</td>
</tr>
<tr>
<td>2.3 Economic performance</td>
<td>18</td>
</tr>
<tr>
<td>2.3.1 Machinery costing</td>
<td>18</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.6.2.1 Economic selection</td>
<td>38</td>
</tr>
<tr>
<td>2.6.2.2 Physical selections</td>
<td>39</td>
</tr>
<tr>
<td>2.6.2.3 Physio-economical selection</td>
<td>41</td>
</tr>
<tr>
<td>2.6.3 Timeliness</td>
<td>42</td>
</tr>
<tr>
<td>2.6.4 Computer modeling for farm machinery management</td>
<td>44</td>
</tr>
<tr>
<td>2.6.5 Technical packages of different crops in Gezira Scheme</td>
<td>50</td>
</tr>
<tr>
<td><strong>CHAPTER THREE: MATERIALS AND METHODS</strong></td>
<td>53</td>
</tr>
<tr>
<td>3.1 Characterization of the study area</td>
<td>53</td>
</tr>
<tr>
<td>3.1.1 General</td>
<td>53</td>
</tr>
<tr>
<td>3.1.2 The agricultural rotation</td>
<td>56</td>
</tr>
<tr>
<td>3.2 Model development</td>
<td>57</td>
</tr>
<tr>
<td>3.2.1 Programme main feature</td>
<td>57</td>
</tr>
<tr>
<td>3.2.2 Programme technical specifications</td>
<td>58</td>
</tr>
<tr>
<td>3.3 Programming technique and style</td>
<td>58</td>
</tr>
<tr>
<td>3.4 Programme limitations</td>
<td>61</td>
</tr>
<tr>
<td>3.5 Programme iterative logic</td>
<td>61</td>
</tr>
<tr>
<td>3.6 Calculation procedure</td>
<td>75</td>
</tr>
<tr>
<td>3.6.1 Tractor costs calculation</td>
<td>75</td>
</tr>
<tr>
<td>3.6.2 Machine cost calculation</td>
<td>79</td>
</tr>
<tr>
<td>3.6.2.1 Machine fixed cost</td>
<td>79</td>
</tr>
<tr>
<td>3.6.2.2 Machine running costs</td>
<td>81</td>
</tr>
<tr>
<td>3.6.3 Crop cost</td>
<td>83</td>
</tr>
<tr>
<td>3.6.4 Rotation cost</td>
<td>83</td>
</tr>
<tr>
<td><strong>CHAPTER FOUR: RESULTS AND DISCUSSION</strong></td>
<td>84</td>
</tr>
<tr>
<td>4.1 Model evaluation</td>
<td>84</td>
</tr>
</tbody>
</table>
4.1.1 Model verification 84
4.1.1.1 Verification of the tractor cost 85
4.1.1.1.1 Predicted and actual values for tractor costs 85
4.1.1.2 Machine cost 87
4.1.1.2.1 Predicted and actual values for cost of operations 88
4.2 Model validation 90
4.2.1 Model sensitivity tests 90
4.2.2 Effect of changing machine width 92
4.2.3 Effect of changing speed 93
4.2.4 Effect of changing efficiency 94
4.2.5 Effect of changing the cultivated area 95
4.2.6 Effect of changing tractor age 96
4.2.7 Effect of changing machine age 97
4.2.8 Comparison between operation cost in different areas 98
4.2.9 Comparison between crops cost on equal area 99
4.2.10 Comparison between crop patterns within rotation 100

Group I100

Scenario No. 1 100
Scenario No. 2 100
Scenario No. 3 100
Scenario No. 4 101

Group II 101

Scenario No. 5 101
Scenario No. 6 101
Scenario No. 7 102
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Tractors classification according to Culpin (1975).</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Effect of soil condition on machine performance</td>
<td>18</td>
</tr>
<tr>
<td>2.3</td>
<td>The successive timing of the agricultural operations in the Gezira.</td>
<td>52</td>
</tr>
<tr>
<td>3.1</td>
<td>Programme technical specifications.</td>
<td>59</td>
</tr>
<tr>
<td>4.1</td>
<td>Tractor cost analysis.</td>
<td>86</td>
</tr>
<tr>
<td>4.2</td>
<td>Comparison between predicted model cost and Gezira operation cost.</td>
<td>88</td>
</tr>
<tr>
<td>4.3</td>
<td>Comparison between predicted model cost and Gezira crops cost.</td>
<td>89</td>
</tr>
<tr>
<td>4.4</td>
<td>Effect of changing tractor purchase price.</td>
<td>91</td>
</tr>
<tr>
<td>4.5</td>
<td>Changing the machine width: using three blades disc and planter cost.</td>
<td>92</td>
</tr>
<tr>
<td>4.6</td>
<td>Changing speed: using ridger and green ridger cost.</td>
<td>93</td>
</tr>
<tr>
<td>4.7</td>
<td>Changing field efficiency: using ridger cost.</td>
<td>94</td>
</tr>
<tr>
<td>4.8</td>
<td>Changing the cultivated area: using three blades disc cost.</td>
<td>95</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>4.9</td>
<td>Effect of changing machine age on tractor cost: using ridger cost.</td>
<td>96</td>
</tr>
<tr>
<td>4.10</td>
<td>Changing machine age: using ridger cost.</td>
<td>97</td>
</tr>
<tr>
<td>4.11</td>
<td>Comparison between cost of operations in different areas.</td>
<td>98</td>
</tr>
<tr>
<td>4.12</td>
<td>Comparison between crops cost on the equal area.</td>
<td>99</td>
</tr>
<tr>
<td>4.13</td>
<td>Comparison between crop rotation.</td>
<td>103</td>
</tr>
</tbody>
</table>


## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Map of Gezira Scheme</td>
<td>53</td>
</tr>
<tr>
<td>3.2</td>
<td>Map of Gezira Scheme and Managil extension</td>
<td>54</td>
</tr>
<tr>
<td>3.3</td>
<td>The programme main flow chart</td>
<td>62</td>
</tr>
<tr>
<td>3.4</td>
<td>The programme detailed flow chart</td>
<td>63</td>
</tr>
</tbody>
</table>
MODEL CODING

1. TCA = Tractor cost analysis
2. MCA = Machine cost analysis
3. PP = Price purchase
4. IS = Tractor insurance
5. TS = Tractor shelter
6. TT = Tractor taxes
7. TD = Tractor interest
8. Ti = Tractor interest
9. TR & M = Tractor repair and maintenance
10. TFC = Tractor factor consumption
11. TCP = Tractor fuel price
12. TOC = Tractor oil cost
13. T. ann. hrs = Tractor annual hours of use
14. TPP = Tractor purchase price
15. TIC = Tractor insurance cost
16. TTC = Tractor taxes cost
17. TSC = Tractor shelter cost
18. T. Int. Sal. C = Tractor initial salvage cost
19. T. Sal. C. = Tractor salvage cost
20. T. Dep. C. = Tractor depreciation cost
21. TFC = Tractor fixed cost
22. T. Rnn C = Tractor running cost
23. T. ann. C = Tractor annual cost
24. T. hr C = Tractor cost
25. CF = Correct factor
26. Nos. C = Crops number
27. No. M = Machine number
28. MPP = Machine purchase price
29. MI = Machine insurance
30. MS = Machine shelter
31. MT = Machine taxes
32. M Dep. = Machine depreciation
33. M Nos. YW = Machine number of years work
34. Mi = Machine interest
35. MR & M = Machine repair and maintenance
36. A = Area
37. S = Tractor speed
38. W = Machine width
39. E = Efficiency
40. MFC = Machine fixed cost
41. MrunC = Machine running cost
42. M R&MC = Machine repair and maintenance cost
43. M ann.-h = Machine hour of use
44. M ann. C = Machine annual cost
45. MAC = Machine cost per area
46. M hr C = Machine cost per hour
47. OPC/area = Operation cost per area
48. OPC/h = Operation cost per hour
49. Cr C = Crop cost
50. MN = Machine name
51. CM = Crop name
52. OC/area = Operation cost per area
53. OOAAC = Operation overall area cost
CHAPTER ONE
INTRODUCTION

1.1 Background and justification

Machinery management has increased in importance in today farming operations because of its direct relation to the success of management in mixing land, labor and capital to return satisfactory profit. The importance of farm machinery in the total farming system is indicated by its costs in relation to the total costs of crop production.

The application of machines to agricultural production has been one of the outstanding developments in agriculture, hence machinery management is the study of selection, operation and replacements. This necessitates making the correct decision about the level of mechanization to be adopted and the selection of the proper and required machines to be used.

Machinery contributes a major capital input cost in most farm businesses, many factors are involved in the process of equipping a modern farm for carrying out field operations, and among the most significant factors is economic (Wan, 1998). Moreover, economic development, which is defined as: the means by which nations seek to increase the efficiency of meeting people’s demands and raising their standard of living, can not be achieved except through the proper utilization of resources and improvement of production efficiency of these countries.

As agricultural production in the less developed countries depends mostly on short duration rainfall and irrigation in limited areas, as such, this type of production is a risky business and requires careful decisions about the level of mechanization to be developed and the selection of the proper machines to be used in order to maximize the utilization of the short growing season. Moreover, these countries are frequently facing acute problems with regard to financing agricultural production operations. This necessitates making the correct decision, especially when high sums of money are to be directed for buying machines and implements to expand existing agricultural areas or to replace old equipment and machines. On the other hand, choosing of wrong type of machine or the wrong size of power unit, may lead to either over or under utilization of these valuable and expensive inputs, and may ultimately lead to a huge pile-up of unused scrap metal, and back-breaking financial debt. Under such a situation computer programmes are being may be used to assist farm manager in decision-making about how to manage their
machines or production operations and how to select their machinery requirements effectively based on the estimated total cost, land allocated for planning and number of crops to be grown.

Machinery management decisions are harder to pin down than most other decision related to farming.

Most machinery management problems may be solved through accurately estimating the total working time that is available for major field operations, proper determination of machines effective field capacities, matching of power units with machines capacities, and accurately predicting of any machine application costs.

No two farming operations are exactly the same and therefore, it is up to each manager to gather all possible information required to formulate the most effective and profitable machinery management program for each field operation and consequently for each farming system.

In recent years, information was collected to developed computer programmes to aid in arriving at machinery management decisions. Beside computers, the burden is still on the manager to provide a large part of input information must understand the principles and techniques of machinery management, which are now recognized to be more important in farming systems.

The success of many farm-level production systems depends on wise selection of machinery systems. The main aim of tractor and machinery selection studies is to complete a certain field operation during specific time and at minimum cost. The number of crops in a rotation, different land sizes for different crops in crop rotation, and the use of the same implement with different machinery.

Timeliness is an important machinery management concept and it has to be figured in a manner so that the equivalent losses can be determined in term of money per unit time or area. Although, timeliness is an important management factor, cash flow is even more important. Therefore, planning machinery system management decision a head of time will help in maintaining a good financial position. Combining of proper management procedures with accurate records will help in achieving proper decisions with confidence.

1.2 Problem definition

The selection of the level of farm mechanization is the most difficult problem in machinery management because it is complicated by the variety of machine types and sizes, capital investment, trained labour requirements, timeliness, farm size and possibility of using the
same equipment with different speeds, width and tractive efficiencies of machines and with different crops. Therefore, the future of farm management depends on the correctiveness of the decision taken.

Gezira Scheme is the largest agricultural scheme in the Sudan (area) and being at present (as it has always been) on top of all the agricultural schemes of the irrigated sector. It was designed to grow mainly the cotton crop. The area was extended to grow more than one crop in large areas. With time and due to many different problems, the areas cultivated by the main crops cotton, wheat, groundnut and dura rise and drop.

Mechanical power was first adopted in the scheme in 1920s and then during the Second World War and to produce more food, the area cultivated was increased and small to medium tractors were introduced.

With time many tractors and machines were introduced to the scheme to carry out different operations for the different crops cultivated and therefore a separate department was developed to supervise the large number of machinery in the scheme – Agric. Engineering Department (AED).

Due to improper planning and management, the number of different types of machines in the scheme dropped and many of them became scrap, without completing its life span. That was due to:

1- Poor maintenance, failure repairing of wearied parts and absence of programs for replacement besides the miss use of some machines.

2- Improper selection of required sizes and numbers.

3- Lack of finance at the required time resulted in shortage of spare parts and replacement of machinery at the required time.

After the computer technology becomes more appropriate and available, complexity of farm machinery management problems have led to develop several computer programs to assist farm machines
manager in decision-making about how to manage their available machinery efficiently and to select new ones efficiently and effectively.

1.3 Study objectiveness

The general purpose of this study is to develop a computer model, which can help in proper decision-making for farm machinery system management in the Gezira Scheme.

This will be achieved through:
1- Developing cost analysis computer model for tractors and a number of machines.
2- To use the computer model for linking different field operations in different farm sizes economically.
3- To evaluate the model under different machines working parameters (speed, width, area, machine age and field efficiency).
4- To verify the model with the actual data available from the field.
5- To use the model for investigating different machinery systems scenarios of management.
2. Farm machinery performance

Hunt (1979) mentioned that measures of agricultural machine performance are the rate and quality at which operations are accomplished. Quality as well as quantity must be considered when evaluating machine performance, such performance figures are usually called capacity.

2.1 Power performance
2.1.1 Tractor for farm power

Jones (1966) defined tractor by self propelled machine that can be used for supplying power for:

1- Pulling and/or mounting some farm machines.
2- Operating the machines either stationary or mobile by means of a belt, pulley or power takeoff shaft, and all tractors are now of internal combustion engines, which serves as the source of power. Liljedahl et al. (1979) reported that the early farm tractors, essentially a substitute for the draft horse, were first powered by steam engines. The interval-combustion engine came later to replace steam engines. The first tractors were large and cumbersome and were suited mainly for plowing and threshing. As time passed the tractor was developed for many purposes. Adaptations were made to use it as a motor cultivator, after which came the general purpose tractor to perform major farm operations.
2.1.2 Tractor types and classification

Jones (1966) stated that tractors can be classified as follows:

One) According to method of securing and self-propulsion:
1- Wheel tractors
2- Track-type tractors

Two) According to utility:
1- General purpose or utility
2- All purposes or row-crop type.
3- Orchard.
4- Industrial.
5- Garden.

Three) Also, may be classified according to model, make or even size (Table 2.1).

Table 2.1 Tractors classification according to Culpin (1975).

<table>
<thead>
<tr>
<th>Type</th>
<th>Power group</th>
<th>Approx. power range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market garden</td>
<td>Motor hoes</td>
<td>1 – 3</td>
</tr>
<tr>
<td>---------------</td>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td>Market garden</td>
<td>2 – wheels general purpose</td>
<td>3 – 10</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Wheeled 2-wheel drive</td>
<td>Small-medium</td>
<td>31 – 45</td>
</tr>
<tr>
<td>Wheeled 2-wheel drive</td>
<td>Medium</td>
<td>45 – 60</td>
</tr>
<tr>
<td>Wheeled 2-wheel drive</td>
<td>Large-medium</td>
<td>61 – 80</td>
</tr>
<tr>
<td>Wheeled 2-wheel drive</td>
<td>Large</td>
<td>81 – 100</td>
</tr>
<tr>
<td>Wheeled 2-wheel drive</td>
<td>Very large</td>
<td>Over 100</td>
</tr>
<tr>
<td>Wheeled 4-wheel drive</td>
<td>Large-medium</td>
<td>61 – 90</td>
</tr>
<tr>
<td>Wheeled 4-wheel drive</td>
<td>Large</td>
<td>81 – 100</td>
</tr>
<tr>
<td>Wheeled 4-wheel drive</td>
<td>Very large</td>
<td>Over 100</td>
</tr>
<tr>
<td>Track layers</td>
<td>Medium agricultural with linkage</td>
<td></td>
</tr>
</tbody>
</table>

### 2.1.3 Tractor construction component

Tractors construction could be categorized into eight systems according to Gene (1993) and Adigun (1987). Engine system,
transmission system, traction system, cooling system, electrical system, fuel system, hydraulic system and lubrication system. Liljedahl (1979) considered steering as a separate system with the other mentioned systems.

2.1.4 Power generation in tractors

Force is any action that changes or tends to change the state of rest or motion of a body. Common unit is newton in the SI system and pound in the customary systems.

Pull is the total force exerted upon the implement by the power unit. Draft is the horizontal component of pull, parallel to the line of motion. Unit draft is draft per unit width, usually, expressed as newton per centimeter (pound force per inch). Work is the product of force times the distance through which the force acts, and the common unit is joule in the SI system and foot/pound/force in the customary system.

Power is the rate of doing work measured in kilowatt in the SI system and horsepower in the customary system. One kilowatt is one kilojoule of work per second. One horsepower is 550 pound of work per second. Draw bar power (DBP), in relation to either a pull-type or mounted implement, is the power actually required to pull or move the implement at a uniform speed, which can be expressed by the following equation:

$$DBP = F \times S$$ … (2.1)

Where:
F = force measured in kN (lb)
S = forward speed in km/h (mph)
C = constant, 3.6 (375).

Kilowatt – hour (horsepower/hour) is the quantity of work performed in kilowatt and used for one hour (Kepner et al., 1982). Hunt (1977) reported that power is defined as the rate of doing work and reported work in a technical sense as the application of force through a distance.

Kilowatt is equivalent of 1.34 horsepower and one horsepower is equivalent to 745.7 watt.

Joule is one newton of force exerted through one meter of distance (J = N.m).

Kepner et al. (1982) reported that history indicates that the process of mechanization is dynamic, with no ultimate goal in sight. As larger and larger tractors are introduced, tillage tools must be designed for higher speeds or to be efficiently utilized than drawbar power so the traction is not a limiting factor.

2.1.5 Power utilization system in tractor

Tractors deliver power in several ways: pull or towed implements are powered through the traction of drive wheels and the pull or draft from the drawbar.

a) Engine power output
Is a function of the average pressure on the piston head and the engine speeds. The average pressure acting during the power stroke of the engine is referred to as the mean effective pressure.

b) Indicated power (IP)

It is theoretical power of the engine, which develops from the mean effective pressure existing at the piston head.

c) Brake power (BP)

It is measured at flywheel or crankshaft it is usually less than the indicated power due to losses.

d) Friction power (FP)

Is the numerical difference between IP and BP, which is the power absorbed by the engine in overcoming friction to run itself (Hunt, 1977).

e) Drawbar power (DBP)

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

\[ DBP = \frac{F S}{C} \]  \hspace{1cm} (2.2)

Where:

- DBP = drawbar power, kN
- F = force measured in kN.
- S = forward speed, km/h.
- C = constant.
2.1.6 Power requirements

Efficient machinery performance includes the selection of implements that neither over loaded nor failed to use adequately the power available from a tractor or self–propelled engine.

Power requirements for any operation is affected by some factors, and these are:

a) Effect of soil

Hunt (1977) concluded that power requirements depends on soil and crop condition, which are highly variable. In addition to soil type, tillage draft of plows is increased if the soil is either too wet or too dry.

Sherudin et al. (1988) reported that in case of disc plow the power required was greater in clay loam than in silt soil.

Gordon (1941) found that there was 40% increase in draft in clay loam soil, and 90% reduction in fine-loam soil when speed was increased from 1.34 to 2.68 m/s for disc plough of 45° disc angle and 18° to 20° tilt angle.

b) Effect of forward speed

Forward speed causes significant variations in plow draft. Quite often a force instead of a power requirement is reported to remove the effect of variations in forward speed. The variations due to different sizes of implements is removed by reporting draft per unit of effective width. Both speed and size variations are eliminated when terminal work or energy requirements are quoted. Hunt (1977) and
Bashford et al. (1991) concluded that for tandem disc and offset disc, changing speed resulted in small changes in draft.

The total draft of plow is increased as the tractor speed is shifted from lower gear to higher gear speed (Sheruddin et al., 1990).

Summers et al. (1986) reported that for a disc harrow dependency of the draft was linear with speed.

c) Effect of plowing depth

Gebresent (1992) stated that variations in plowing depth depend on:

a- Unevenness of the ground surface.
b- Soil strength variations.
c- Plowing speed variations.
d- Presence of stones and strong roots in the soil.

Baloach et al. (1991) concluded that draft requirement of an implement increased with depth of penetration in the soil.

d) Effect of implement type

Salokhe et al. (1992) reported that many scientists directed their efforts to optimize the disc plow design so that a minimum draft force was required for plowing.

During plowing, energy is expended both on useful work and on overcoming the parasitic forces of resistance due to friction of the tools on the soil, cohesion and stickiness of the soil and other factors. It is being possible for the parasitic resistance to reach half the total draft of the plow. Because of the limitation of controlling soil
parameters in the field, it is important to give due attention to reducing parasitic forces.

2.2 Machinery capacity performance

Machine performance is reported in form of quantity per time. Most agricultural field machines performance is reported as area per hour, harvesting and processing machines may be measured as tons per hour.

2.2.1 Machine capacity

The capacity of a machine is its rate of performance, and usually measured in terms of quantity per time, area per time or quantity per area.

Capacity when expressed only as area per time, is usually not sufficient indicator of machine’s true performance, particularly with harvesting machines. Differences in crop yields and crop conditions can mean that one machine may have a low area per hour capacity but a high mass per hour capacity when compared with an identical machine in a different field. In this case, a valid comparative capacity would be mass per hours.

One method for measuring machine capacity as given by Bowers (1987) and Hunt (1979) is the field capacity. It is measured in area per time or tons per time. The field capacity is determined by three factors:

a) Speed
b) Width
c) Efficiency
Efficiency is defined as the ratio between the effective and theoretical field capacities expressed as percent. It includes the effect of time lost in the field and the failure to utilize the full width of machine in the fieldwork (Kepner et al., 1978).

Theoretical field capacity of a machine or an implement is the maximum possible capacity obtained at a given speed assuming the machine is using its full width.

Effective field capacity is defined as the actual rate of field covered by machine based on the total field time and expressed as area per time (Kepner et al., 1978 and Hunt, 1979).

Field efficiency can be calculated as follows:

\[ E = \frac{EFC}{TFC} \quad \cdots \quad (2.3) \]

\[ TFC = \frac{SW}{F} \quad \cdots \quad (2.4) \]

\[ EFC = \frac{SWE}{F} \quad \cdots \quad (2.5) \]

Where:

\[ E = \text{field efficiency as decimal} \]

EFC = effective field capacity (ha/h)

TFC = theoretical field capacity (ha/h)

W = width of implement (m)

S = speed (km/h)

F = constant
Maclendon et al. (1987) stated that, higher capacities (ha/day) for chisel and moldboard plows were obtained by using a greater width of cut.

2.2.2 Importance of field efficiencies

The ability to improve field efficiency is important in developing machinery management skills. The machine may have low field efficiency due to lost-time such as: using partial capacity; unloading procedures; filling procedures and turning and field condition; unclogging machines, making adjustments, repairing breakdowns; servicing machines; stopping to rest; changing operator; checking machine performance and having unmatching machines. To maximize field efficiency time-lost for such operations should be reduced.

Time efficiency is a percentage reporting the ratio of the time a machine is effectively operating to the total time the machine is committed to the operation.

Any time the machine is not actually processing the field is counted as time waste.

2.2.3 Factors affecting machinery field performance

The following list describes the time elements that are associated with typical field operations, and that should be included when computing the capacities or cost of machinery related to the various farm enterprises:

1- Machine preparation time at the farmstead.
2- Travel time to and from the field.
3- Machine preparation in the field both before and after operations (includes daily servicing, preparation for towing, …etc).

4- Theoretical field time (the time of the machine is operating in the crop at an optimum forward speed and performing over its full width of action).

5- Turing time and time crossing grass waterway (machine mechanisms are operating).

6- Time to load and unload the machine’s container if not done on – the – go.

7- Machine adjustment time if not done on – the – go (includes unplugging).

8- Machine time (re-fueling, lubrication, chain tightening, …etc).

9- Repairing time

10- Operator personal time.

2.2.4 Machinery matching with power sources

Selecting machine size involves fitting the proper sized equipment to the amount of work for a given period of time. Lowering the field efficiency would decrease the effective capacity, on the other hand increasing capacities means a direct cost saving, so, always to be thinking of ways to improve field efficiency (Bowers, 1987). To determine how large a machine needs to be is necessary to determine capacity to complete the specific operation within the period available, and to estimate the correct working hours during that period.
However, keeping an accurate record of days and hours of work will help provide an average figure for planning operations.

When selecting power required there are some factors to be considered like engine type, power rating, soil resistance to machines, tractor size, and sizing for critical work (Bower, 1987).

The rating power source is obtained from the conversion of the energy contained in the fuel by combination process this rating power can be in form of draw bar pull, horizontal power for PTO relative power.

The drawbar has its maximum value normally at a certain combination of pull and forward speed (Persson, 1979).

Drawbar power is a function of pull and speed, and can be computed by the following formula:

\[
DBP = \frac{DS}{3.6}
\]  

... (2.6)

Where:

DBP = draw bar power in km.
D = pull (draft) in kN
S = speed in km/h

Size of implement would have to be related to the amount of soil resistance as (pounds per foot) of width as follows:

\[
Width = \frac{total
draft}{Draft
der foot of width} \quad or \quad \frac{total
draft}{draft
der unit area}
\]

... (2.7)
Bowers (1975) reported that when matching a tractor and implement, there are some important factors, which must be considered:

1- The tractor must not be over loaded or early failure of the compound will occur.
2- The implement must be pulled at the proper speed or the optimum performance can not be obtained.
3- The soil condition and its effects on machine performance must be considered as shown in Table 2.2.

Table 2.2 Effect of soil condition on machine performance

<table>
<thead>
<tr>
<th>Condition soil</th>
<th>Usable DB hp as % of maximum PTO hp</th>
<th>Ratio of maximum PTO hp to usable DB hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm</td>
<td>67%</td>
<td>1.5</td>
</tr>
<tr>
<td>Tilled</td>
<td>56%</td>
<td>1.8</td>
</tr>
<tr>
<td>Soft or sandy</td>
<td>48%</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Source: Bowers (1975).

2.3 Economic performance

2.3.1 Machinery costing

One of the important costs influencing profit of farming operations is the cost of owning and operating machinery. Accurate cost estimations play an important role in machinery management.
2.3.2 Machine life

ASAE (1983) defined the machine life as the useful service life of a machine before it become unprofitable for its original purpose due to obsolescence or wear.

Kepner et al. (1978) suggested ten years as obsolescence or wear-out life for various types of wheel type tractors, while 15 years for disc plow and disc harrow and 15 years for cultivators.

Darling and Green (1999) reported that when considering machine costs, perhaps the first issue to consider is cost structure.

Ownership costs include capital recovery (investment costs) as well as insurance, storage taxes and licensing. Operating costs include fuel, lubrication, repair and operator labour.

2.3.3 Fixed costs

This portion remains relatively constant, regardless of the annual use. These depend more on how long a machine is owned rather than how much it is used.

Kepner et al. (1982) stated that, fixed costs are inversely proportional to the amount of use.

O’Callaghan (1990) reported that, the two main components of fixed costs or ownership are the depreciation and interest of the capital invested in a machine. Fixed costs include depreciation, interest, insurance, taxes and shelter.

2.3.1 Depreciation

Depreciation cost is designed to reflect the reduction in value over a period of time (Kaul, 1985). Hunt (1979) stated that
depreciation measures the amount by which the value of a machine decreases with the passage of time weather used or not. The value declines because:

1- The parts of the machine become worn with use and can not perform efficiency. These parts are the economically irreparable mechanisms in a machine, for example, the basic frame may be worn or distorted.

2- The expense of operating the machine at its original performance increases as more power, labour, and repair costs for the same unit of output are required. Repair and adjustment can renew the machine but at an increased rate of cost.

3- Anew, more efficient machine or practice becomes available, when this situation develops the existing machine is said to be obsolete. The existing machine may be functionally adequate but because of new technology it is uneconomic to continue to operate it.

4- The size of enterprise is changed and the existing machine capacity is not appropriate for the new situation.

Hunt (1979) and Kepner et al. (1982) mentioned the following methods for common use in determining the annual value of depreciation:

**1- Estimated value method**

May be the most realistic determination of depreciation. The amount of 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.
Obviously, the validity of such a method depends on how responsibly the values are determined.

2- Straight-line method

The average annual depreciation is obtained by the following equation:

\[ D = \frac{(P - S)}{L} \]  

… (2.8)

Where:

\( D \) = annual depreciation (%).
\( P \) = purchase price (SD).
\( S \) = salvage value or selling price (SD).
\( L \) = time between buying and purchasing (year).

For general application in which the actual value of “S” is not known, 10% of the purchase price may be appropriately used (Witney, 1988).

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.

The relationship is expressed by the following equations:

\[ D = V_n - (V_n + 1) \]  

… (2.9)

\[ V_n = P(1 - \frac{X}{L})^n \]  

… (2.10)

\[ V_n + 1 = P(1 - \frac{X}{L})^{n+1} \]  

… (2.11)
Where:

\[ D = \text{amount of depreciation charged for year } n + 1. \]
\[ n = \text{number representing age of the machine in years at beginning of year in equation.} \]
\[ V = \text{remaining value at any time.} \]
\[ X = \text{ratio of depreciation rate used, normally between year 1 and 2 for used machines the maximum rate is } X = 1.5. \]

4- **Sum – of – years digits method**

The digits of the estimated number of years of life are added together. This sum is divided into the number of years of life remaining for the machine including the year in equation. Amount of depreciation charged each year is the functional part of the difference between purchase price and the salvage value.

\[ D = \frac{L - n (P - S)}{YD} \]  \( \text{...}(2.12) \)

Where:

\[ D = \text{annual depreciation.} \]
\[ YD = \text{sum – of the years digits} \]
\[ n = \text{age of the machine at the beginning of the year in equation.} \]
\[ L = \text{economic life in years.} \]
\[ P = \text{purchase price.} \]
\[ S = \text{salvage value or selling price.} \]

5- **Sinking – fund method**

This method considers the problem of depreciations as one of establishing a fund that will draw compound interest – uniform annual
payments to this fund are of such a size that by the end of the life of
the machine, the fund and their interest have accumulated to an
amount that will purchase another equivalent machine.

### 2.3.1.1 Depreciation and inflation rate

The replacement of any machine is based on the accumulated
values of depreciation for any reason of depreciation, but these values
may be not enough to purchase a new machine due to increase or
decrease in the inflation rate. It's found that if the inflation rate
increase by more than 10% it will be danger (Dahab, 2000).

Kaul and Mittal (1984) suggested an equation combining the
purchase price and the future price of a machine as follows:

\[ F = Pu(1 + I)^n \]  

... (2.13)

Where:

- \( F \) = future value.
- \( Pu \) = purchase price.
- \( I \) = constant inflation rate.
- \( n \) = machine life.

Also, they suggested the effect of the inflation on the straight
line method for determining depreciation as follows:

\[
Dn = \frac{n}{L} (Pu(I + I)^n - Sa) 
\]  

... (2.14)

\[
Cn = Pu(1 + I)^n - Dn 
\]  

... (2.15)

\[
Du = Dn - (Cn - 1) 
\]  

... (2.16)
Where:

\[ \text{Dn} = \text{accumulated depreciation to the year n} \]
\[ n = \text{number of years after the purchase price} \]
\[ \text{L} = \text{machine life in years} \]
\[ \text{Sa} = \text{salvage value of the machine} \]
\[ \text{Cn} = \text{remaining value of the machine after n years} \]
\[ \text{Du} = \text{the depreciation value of the machine at the n year} \]

2.3.2 Interest on investment

Hunt (1979) reported that interest on investment in a farm machine is usually included in operational cost estimates, since money to buy machine cannot be used for another productive enterprise. The suggested interest rate is 8%. The amount interested in a machine is greater during its early life than during later years similar to the depreciation.

O’Callaghan (1990), and Witney (1988) stated that, on calculating interest on a capital invested in the machine it is customary to choose a constant rate of interest over the life of the machine and to calculate interest charged on the average investment in the machine during each year of its life. This can be shown by the following equation:

\[ I = \frac{(P + S)}{2} \times i \quad \ldots (2.17) \]

Where:

\[ I = \text{annual interest charge.} \]
\[ i = \text{rate of interest.} \]
\[ P = \text{purchase price.} \]
S = salvage value or selling price.

This means to be homogenous if depreciation was estimated by using the straight-line method. If a variable depreciation rate is used, the interest charge for each year should be based on the remaining value of the implement at the beginning of the years (Kepner et al., 1982).

Lonnemark (1967) stated that, in developed countries with a stable national economy, it may be possible to borrow money for financing the purchase of farm machinery at interest rate of 6% to 8%. Whilst in developing countries with scarcity of capital and less credit facilities the interest rate may be as high as 15% or more. The Agricultural Bank of Sudan (2004) charged an interest rate of 15% for agricultural purposes.

2.3.3 Taxes

Hunt (1979) assumed that annual cost of taxes should be about 1.5% of the purchase price when spread overt a 10 years life. In Sudan, taxes are about 1.5% of the purchase price according to Ministry of Agriculture and Animal Resources (M.A.A.R) Khartoum State (1997).

2.3.4 Shelter

Liljedahl et al. (1979) found that suitable shelter can be constructed and maintained for about 1% annually of the original cost of the stored equipment.
ASAE (1983) suggested an annual rate of shelter cost as 0.75% of the purchase price. However, in Sudan, it is estimated at about 1% of original cost (M.A.A.R, Khartoum State 1997).

### 2.3.5 Insurance

Hunt (1979) assumed annual charge for insurance to be 0.25% of the original price. Liljedahl *et al.* (1979) assumed the annual charge for insurance would be 0.3% of the original cost. In Sudan, insurance is estimated at about 0.5% of the original cost (K.A.A.R, Khartoum State 1997).

ASAE (1983) stated that if the actual data of taxes, shelter and insurance are not known, the following percentages can be used: taxes 1%, shelter 0.75% and insurance 0.5% or a total of 2% of the purchase price.

### 2.3.6 Low annual use and fixed costs

When a machine is of low annual use, the fixed cost will be high and this will reduce the profit. Therefore, to a large extent, fixed cost in machinery controls the profit. An adequate amount of agricultural machinery is necessary to complete all the important jobs on time. But, it is important to keep fixed costs per unit time down by keeping machinery busy.

As the fixed cost varies slightly with the amount of annual use, reducing this fixed cost is easier and more important when there is a cash flow problem.

Fixed costs may be reduced without lowering the production at three conditions (Bowers, 1987):
1- To have the proper amount of equipment i.e. to have the most efficiently matched tractor and equipment.

2- Longer ownership of machinery by increasing the years of trading interval. So, in order to own the equipment longer a good repair and maintenance programme must be done, and this will help to realize higher returns.

3- Buying used equipment is a good way to lower fixed costs, particularly when there is a short in the finances, but greater care must be taken to be sure that repairs and down time will not be more than the offset of the saving.

2.4 Variable cost

Hunt (1983) stated that, these are costs that vary with use, and the actual estimation of them is usually based on hours of use. They include repair and maintenance, fuel, oil and labour costs. Kaul (1985) mentioned that, variable costs are meant to account for actual costs, including items such as fuel, oil, lubricants, labour and repair and maintenance costs.

2.4.1 Fuel consumption

Fuel costs vary with the use of the machine. Hunt (1979) reported that, the fuel consumption is measured or estimated and multiplied by its respective price to determine its cost. Culpin (1975) reported that, fuel costs will depend on the type of work done and tractor power and load. He suggested the overall fuel consumption of tractors as follows:

0.5 gal/h for 40 hp tractors
1.0 gal/h for 65 hp tractors
2.0 gal/h for 90 hp tractors

Dawelbeit (1997) reported that, disc plow consumed more fuel, due to the low working, Abdalla (1995) found that the disc plow has the least fuel consumption followed by chisel plow and finally moldboard plow, while Gordon (1991) found that the disc plow consumes more fuel compared to moldboard. Abuzaid (1999) found that chisel plow had the highest fuel consumption rate compared to disc plow, ridger and disc harrow.

The most accurate method for estimation of these costs are the actual records on similar machines, and operations. In case where such records are not available, its relatively simple to estimate these costs because fuel consumption is directly related to the amount of energy extended.

ASAE (1983) related the specific fuel consumption of a diesel engine to the power utilization ratio $X$, as follows:

$$Diesel\ fuel\ consumption = 0.52X + 0.77 - 0.04(73.8X + 173)^{1/2}$$ (2.18)

Where:

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

### 2.4.2 Oil and lubricant

ASAE (1980) defined oil consumption as the volume per hour of engine crankcase oil replaced as the manufacturer recommended. They gave the following equation for tractors:
Oil consumption \( (L/h) = 0.0059 \, P + 0.02169 \quad \ldots \quad (2.19) \)

Where:

\( P \) = the rated engine power in kW.

ASAE (1983) reported that, the oil consumption in gallon/hour is related to the rated engine power, \( (P \, \text{max.}) \) without any adjustment for engine loading. Lonemark (1967) and Kepner et al. (1982) reported that, for tractor and implements having engines, the total cost of oil and lubricants including filters can be taken as 15% of the cost of fuel used.

2.4.3 Repair and maintenance costs

Repair and maintenance costs are essential in one effect to guarantee a high standard of machine performance and reliability.

Hunt (1979) stated that, repair and maintenance costs are expected to vary from one part of the country to another, because of differences in soils, weather and crop conditions. He mentioned that, some variations are due to differences in the skill of machine operator and the value of machines.

Yang (1965) stated that, repair and maintenance covers a wide range of maintenance from minor adjustment to complete over hauling of a machine. These costs, like those of depreciation vary widely with operator skill and attitude, maintenance management, machine design feature, age of the machine and its condition and the amount of use, availability of replaceable spare parts at the appropriate time and the working condition.
Kepner et al. (1978) agreed with Fairbanks et al. (1971) and reported that, repair costs include maintenance (adjusting for wear, daily services and lubrication, …etc), as well as the cost of all parts and the labour to install them. Repair costs per hour of use increase with age but tend to level off, as a machine becomes older. The amount of change in repair rate (cost per hour) with age is influenced by the type of machine.

Hunt (1983) stated that, repair and maintenance costs are not constant over a machine’s life but increase from a very low value during the first year to some relatively constant value after a period of use.

Hunt and Fuji (1976) mentioned that these costs are highly variable from one part of a country to another for differences in soils, weather, and production systems.

O’Callaghan (1990) stated that, repair and maintenance costs are the most difficult costs to estimate for tractors and farm machinery, partly because failures calling for repair happen randomly.

There are some prediction models, which were developed to estimate repair and maintenance cost. The best model structure, which is well suited for prediction of repair and maintenance cost of machines was a power function of the farm (ASAE, 1989) as:

\[ Y = aX^b \]  

... (2.20)

Where:

- \( Y \) = total cumulative repair and maintenance cost.
- \( X \) = machine cumulative use in hours
a and b = constants, model parameters.


Ahmed et al. (1990) compared of Sudan standard prediction model with similar models estimated in some industrial and developing countries. The study revealed that the estimated repair and maintenance costs of the agricultural tractor in Sudan were significantly higher when compared with industrial countries. However, when compared with developing countries, there were no significant differences between that estimated for Sudan and those of other developing countries.

These costs are proportional to the amount of use of the machine and tend to increase steadily as a machine grows older, and are generally 10%, 15% of purchase price (Rotz, 1987).

2.4.4 Labour cost

Hunt (1979) defined operator cost as the labour rate multiplied by the expected hours of use for the machine. Fairbanks et al. (1971) found that, variable costs for tractors were about 64% of all costs, with the greatest single cost for labour.

Kepner et al. (1970) stated that, labour costs should be based upon prevailing wage-rate.
The labour cost per unit area is inversely proportional to the field capacity of the machine. The use of a larger implement for a given total area per year decreases the labour cost per unit area.

### 2.4.5 Annual total costs

Kepner (1978) stated that, the annual cost is generally given on either per unit area or unit production basis. The hourly cost is based on the total annual operating time for the tractor rather than annual use with the particular implement involved.

Culpin (1975) stated that, it is impossible to state with accuracy the annual or hourly cost of running a particular kind of a tractor, without first defining the tractor work cost clearly. This will depend on the amount and kind of work a tractor does, on the treatment it receives, on its fixed cost, its age and the method of charging depreciation. Hunt (1979) pointed out the possibility of combining the costs of depreciation, interest on investment, taxes, shelter, insurance and labour into a single percentage of the price called the annual fixed cost percentage (13%-17%).

The total cost per year for field machine can be calculated as follows:

\[
AC = FC\%P + \frac{CF.A}{100} (R \& M + O + L + T) \quad \ldots (2.21)
\]

Where:

\[
AC\% = \text{annual cost of operating machine.}
\]

FC\% = annual fixed cost percentage.

P = purchase price.
CF\% = correction factor, 10.
A = area used in hectare.
S = forward speed, km/h.
W = effective width of action of machine, m.
E = field efficiency, decimal.
R & M = repair and maintenance costs, decimal of purchase price.
L = labour cost rate, per hour.
O = oil cost, per hour.
F = fuel cost, per hour.
T = cost of tractor use by machine, per hour
   \( T = \text{zero, if self propelled}. \)

2.4.6 Custom work rate

Bowers (1975) reported that hiring custom operators is one important alternative to owning machinery. In some cases, using custom operators provides faster completion of work, provides the least-cost method, and do not require the capital needed for owning a machine. In other cases, doing additional custom work can help a farm operator justify ownership costs.

When considering hiring a custom operator, we have to consider the timeliness.

Al-Kadi (1989) reported that the custom operators should be firstly trained in the maintenance of equipment and improved agronomic techniques. Secondly, they should be introduced to farm
records keeping. Thirdly, a project of innovative financing of agricultural equipments should be introduced.

2.4.6.1 When to use a custom operator?

Determining when to use a custom operator is one of the most important decisions to be made in machinery management. The formula for calculating the number of (hectares, feddans) per year to justify machine ownership =

$$\frac{Average\ annual\ fixed\ costs}{Custom\ rate\ per\ hectar - operating\ costs\ per\ hectare} \quad \ldots \ (2.22)$$

Once, a machine is purchased, the only additional costs are fuel, oil, lubrication, labour and repairs. These costs, by themselves, are considerably lower than custom rates. Thus, each acre of annual use will provide additional money to buy off the ownership costs.

2.5 Operator performance

2.5.1 Operator skill

A manager must consider the type, amount and value of operator labour required when planning for mechanized agricultural production and must provide a safe environment (Hunt, 1995). So, the operator must understand and make use of all controls and instrumentation provided by the manufacturer, so the need for alertness increases with the size and complexity of machines. Small simple machines may require only steering activities from an operator, while large complex machines require only a little more attention to
steering but much more activity in monitoring the machines operations.

Control and protection of an operator from the noise, wind, dust and temperature of the field environment is not only thought to be human but economically worth while. However, the cab may often interfere with the operator’s monitoring efficiency.

So, Van Bargen analyzed field times for several operator-machine combinations. He defined the potential capacity of the combinations as based on operating times plus the time required for turns, for travel between fields, and for delays due to necessary machine support activities. Time for the operator, for machine maintenance, service repair, and for unadvisable delays were defined as idle or lost time. So, these studies do not permit definite conclusion about the type of labour required for high-performance machines.

2.5.2 Operator age

There is real indication that either age or experience have increased the performance. The factor of motivation and mental alertness are probably of greater significance but are difficult for a farm machinery manager to determine before hiring an operator (Hunt, 1995).

2.5.3 Amount of labour

The amount of labour required for production depends on the amount of mechanization and upon the size of implements (Hunt, 1995). As farm size increases the efficiency of labour use increases. Such, efficiencies are possible for large farms since high-capacity
equipment under the control of a single operator can be economically employed, on the other hand, multiple machines would not be expected to have greater labour efficiency since the additional machines require additional operators, this was reported by Union Agriculturist (1990).

2.5.4 Value of labour

The value of labour for machine operators can be determined in three ways as reported by Hunt (1995):

1- To portion out the cost of actual hired labour according to the hours of time spent in operating the equipment. Such, a method determines the value of farm labour by having it to match off-farm labour rates. It is a realistic way for evaluating hired labour, but it is not too pertinent a criterion for manager operator’s wage.

2- Meeting labour competition from other farm enterprises.

3- Considering labour for operating machines as an investment with opportunity for profit and not as expense. Therefore, the economic performance of machine operations should be undertaken only when they increase the value of a product. If the value is increased beyond the power and machinery costs, the difference may be assigned as a wage to the manager operator. So, the safety of farm machinery operations is a major concern for machinery managers.

2.6 Machinery management

2.6.1 Importance of management

Machine management has increased in importance in today’s farming operations because of its direct relation to the success
of management in mixing land, labour and capital to return a satisfactory profit.

The application of machines to agricultural production has been one of the outstanding developments in agriculture. Hence, machinery management is the study of selection, operation and replacement of farm machinery (Bowers, 1987). This necessitated making the correct decision about the level of mechanization to be developed and the selection of the proper and required machines to be used.

The adequacy of machinery management goal has a major impact on the farm profitability. Therefore, the economic goal of machinery management is achieved when the overall profitability of the farm business is maximized.

The optimization of the power and machinery requirements is achieved through a combination of the maximum tractor power demand and tractor fleet size for simultaneous operations.

Maximizing returns from machinery operations can be achieved by proper machinery management, and this may be done through: keeping records of field work done by the various machines and the number of working days available for the critical field operation by knowing the average machine capacity, knowing the accurate estimated costs for any machines and to combine these costs to have the total cost, improving the field efficiencies with machines to cut costs and complete more work in the available time, improve the equipment reliability by the elimination of the unnecessary down time, development of short and long range plan for farm operation including
the repair, purchase and trade – in of equipment, review the problems from time to time to speed up management decisions (Bowers, 1987).

Therefore, the cost can be kept to a minimum by proper matching of tractor with the machine through proper management.

2.6.2 Farm machinery selection

Selection of power matching with machines is one of the most important decision parameters of agricultural mechanization planning and machinery management. There are many factors affecting the selection such as: agricultural conditions, farming requirements of soil and crops, management scales and economic condition (Depneny et al., 1983).

2.6.2.1 Economic selection

Economic development, which is defined by Miller (1978) as: the means by which nations seek to increase the efficiency of meeting people’s demand through the proper utilization of resources and importance of production efficiency of these countries. Therefore, the mechanization will provide one of the outstanding tools for achieving the economical production of agricultural crops.

Agricultural production in the less developed countries depends mostly on short duration rainfall and irrigation in limited areas. As such, this type of production requires careful decision about the level of production to be adopted and the selection of the proper machines to be used, in order to maximize the utilization of the short growing season. This necessitates mainly the correct decisions, specially when high sums of money are to be directed for buying machines and
equipments to expand existing agricultural areas and replace old equipment and machines. If the decision of selection is based on few hours per year, large sized machine may be needed because the largest machine could used less time to complete the job but requires too much ready cash. So, the balance between the machine size and paid money is an important issue for proper and careful selection.

2.6.2.2 Physical selections

a) Selecting tractor size

Deciding the tractor size is to provide enough power to get all important field operations completed on time, and to provide sufficient annual use, so costs will be minimized. This can be done by listing all field operations according to energy requirements and to estimate the total time available.

Tractive force is usually used to predict the tractor power required to pull a machine. Engine horsepower is not usually used as the output needed to perform the work, because of the power losses. ASAE (1973) recommended the use of an equivalent power take-off (PTO) horsepower (Equiv-PTO) as a base for estimating draw bar horsepower (DBHP).

In order to determine the DBHP, Jones and Bowers (1977) suggested the use of the usable DBHP from the maximum engine power. The estimation of DBHP will facilitate the prediction of total draft required by implement as follows:

\[ F = \frac{DBHP}{S} \quad \ldots \quad (2.23) \]
Where:

\[ F = \text{total draft, per foot.} \]

\[ S = \text{speed, mph.} \]

Under known soil conditions and implement draft per width, the implement optimum width may be calculated as follows:

\[ W = \frac{F}{FW} \quad \ldots (2.24) \]

Where:

\[ W = \text{implement width, m.} \]

\[ F = \text{total draft, kN.} \]

\[ FW = \text{draft per unit width of implement, kN/m.} \]

b) Selecting machine size

The selection must be based on, selecting proper size machine for the proper unit, getting sufficient capacity to get the needed work to be done within the allotted time period, and getting the maximum net profit.

Therefore, selection of machine (width) can be estimated from the EFC as follows:

\[ W = \frac{EFC \times CF}{SE} \quad \ldots (2.25) \]

\[ EFC = \frac{\text{total area}}{\text{total available time}} \quad \ldots (2.26) \]

Where:

\[ EFC = \text{effective field capacity.} \]
When the speed is maximum (controllable), efficiency is a function of time loss (controllable), the width (W) will be the determining factor in selection of machinery, but must be done in an economical way. This depends on: the cost, labour, power, machine capacity and performance, area and working hours and time of operation.

2.6.2.3 Physio-economical selection

From the economic point of view, it is very important to calculate the relative costs in order to determine the enough power needed to get the important job to be done within the specific period of time, and to keep cost down and not to buy excessively large tractors and to determine the value of the time saved by using the large tractors. This can be achieved by planning ahead and considering the possibility of the size of the operations increasing in the future.

On the other hand, different values of width will give different values of costs. The width of the machine with the least cost can be obtained using the annual cost equation (Hunt, 1963) as follows:

\[ W = \sqrt[4]{\frac{CF \times A \times (L + T)}{FC\% \times Pw \times SE}} \]  \hspace{1cm} \cdots (2.27)

Where:

- \( W \) = least cost width/m.
- \( A \) = crop area in hectare.
- \( L \) = labour cost per hour.
T = tractor use cost per hour.
FC% = fixed cost of machine, %.
Pw = purchase price of the machine.
S = typical field speed of the machine (km/h).
E = field efficiency of the machine (decimal)

This width may not be the optimum width that may complete the operations within the required time, therefore, the timeliness factor must be considered.

2.6.3 Timeliness

Timeliness is defined as the ability of the machine to do the operations in the specific time qualitatively and quantitatively. The economic benefit of timeliness is evaluated by the cost being untimely working (losses). So, all field operations are sensitive to time but the degree of sensitivity varies from one operation to another.

\[
\text{Timeliness} = KVAY \quad \text{... (2.28)}
\]

Where:

- \( K \) = timeliness factor.
- \( V \) = value of the crop.
- \( A \) = area covered.
- \( Y \) = crop yield.

The selection may be categorized into the least cost approach of Hunt (1979) and the physical approach on the bases of tractive force as specified by the American Society of Agricultural Engineers (ASAE) in their standard Year Book (1973).
Hunt (1979) developed an equation from the first differential of the annual cost equation set equal to zero to obtain the optimum width of the machine as shown below:

\[ W = \left( \frac{CF}{FC\%} \cdot \frac{A \times L + T}{P \times SE} + \frac{KYVA}{(Sc)(nt)(Uh)} \right)^{0.5} \quad \ldots (2.29) \]

Where:

- \( W \) = optimum width of machine in meter, (m).
- \( C \) = constant = 10.
- \( FC \) = fixed cost of machine, (%).
- \( P \) = purchase price of the machine (SD).
- \( S \) = typical field speed of the machine, (km/h).
- \( E \) = field efficiency of the machine, (decimal).
- \( L \) = labour cost/hour.
- \( T \) = tractor use cost/h.
- \( K \) = timeliness factor, (1/day).
- \( Y \) = crop yield, (kg/ha).
- \( V \) = value of the crop, ($/kg).
- \( A \) = crop area in hectare.
- \( Sc \) = scheduling factor, (decimal).
- \( nt \) = number of times \( A \) should be divided because of dispersed optimum times.
- \( U \) = fractional utilization of total time, (decimal).
- \( h \) = hours of work per day

The physical approach is based on matching the tractor power to implement width by considering the soil condition, tractive force
and engine power and speed. Hunt (1973) recommended the use of an equivalent power - take off (equiv-PTO) as a base for estimating draw bar horsepower (DBHP) as given by the equation below:

\[
DBHP = \text{equiv. PTO} \times 0.96 \times TE
\]  

… (2.30)

Where:

- 0.96 = assumed tractor interval power transmission efficiency.
- TE = tractor efficiency rate of draw bar power to axial power.

**2.6.4 Computer modeling for farm machinery management**

Modeling is a simplified representation of a system with some but not all properties of real life. A model could be either static representing relations between variables, which do not involve time or dynamics describing the way in which a system changes over time.

Simulation in science is the reconstruction of a certain part of reality through the use of mathematical models to quantitatively reflect aspects of the real world as realistically as possible. Simulation aids in understanding the important aspects of a computer system in such away that its behaviour is visualized and a guide to its management is found. The simulation model is built up from one or more equations, which represent the relevant process of a system over a period of time and is expressed in a computer language.

Computer modeling and simulation (the assembling of data to give a complete yet compact, picture of a system), is a powerful technique with a broad range of application in research and analysis (Francis, 1963). It is a logical mathematical representation of a
concept for a system or an operation programme for producing solution through high-speed electronic computers. Thus, computer modeling used for the evaluation of a complex system is characterized by complicated probabilities, which may be associated with system’s reliability, the system effectiveness, events occurrence, functional operation time, and error measurements.

The selection and matching of farm machinery is, in fact, a complex problem. The complexity arises from the drivers decision-making inputs involved that include the wide range of farm machinery types and sizes, available capital and labour requirement, type of crop and crop rotation and timelines. Therefore, the presence of multi-factors and complexity have led to look at developed techniques like computer to assist in the development of decision-aid models dealing with how to select machinery efficiently and effectively (Burrow and Siemens, 1974; Hughes, 1974; Samsaa, 1976; Hunt, 1985 and Ozkan and Edward, 1986).

Generally, the machinery cost analysis model has an economical approach based on the estimation of the total annual cost analysis. The greater number of tractors and implements from which a manager can choose the field time available for operations to be carried out makes machinery selection difficult and needs more effort for problem solving and decision-making.

A computer model (MACHEL), which can be used as an aid to solve the problem of machinery selection was developed by Kletka and Sestak (1990). This model was used to select and evaluate alternative machinery complement for given farms, in addition, the
model was used to estimate fixed and variable costs for each alternative. This model involved an economical equation of machinery selection developed by Hunt (1963).

Datt (1988) developed a model to enhance the introduction of agricultural machinery in developing countries.

Isik and Sabansi (1993) developed a computer model to select optimum size of farm machinery and tractor power based on farm size, cropping patterns, soil properties and climatic conditions. The model was developed in order to minimize total cost of farm machines and tractors.

An economic analysis of farm machinery implements was studied by Lone et al. (1986) to determine optimum machinery implements for farm of different size and crop enterprise, and to examine the impact of alternative acquisition, financing and tax strategies in the least cost machinery implement decision. The model contained the basic components of annualization cost and crop returns. The model could also select the entire implements for all machinery operations from field preparation to crop harvest, and allocate the acres for use for each tractor-implement combination to maximize profits.

Liu et al. (1987) developed a computer model to study the economy of the big tractor system (BTS) in China’s state farm.

Giu and Siemens (1989) developed a programme to optimize the farm machinery system size, and replacements schedule, on the least cost basis.
Hetz (1986) validated a computer model to aid the selection of farm machinery for wheat production in Chile. The effect of cultivated area, tillage intensity and crop rotation upon machinery needs and production costs was analysed. It was concluded that as the area cultivated increased, the cost per hectare decreased, as tillage intensity increased the size of the machinery system and the cost per hectar also increased, and as the number of crops in the rotation increased and size of the machinery system and cost per hectare decreased.

Konaka (1987) developed a programme, using a personal computer in order to plan and design a farm mechanization system.

Lavoie et al. (1991) considered the revenue side of the machinery, which led to the development of linear models to maximize farm income considering the yield loss implication of different tractor sizes, and weather conditions.

Alam et al. (2001) developed a computer programme to select the proper level of agricultural machinery based on farm size, cropping patterns, cultural practices, crop yield, purchase price of machine and value of crop. The programme was designed in order to minimize the total costs.

The Machinery Advisory Service (MAS) used a computer programme called the Machinery Investment Programme (MIP), which was first developed at Haw Kesbury Agricultural College, Australia (Gramble et al., 1984). The MIP can help answer important questions such as: what is the real cost of buying a particular machine, should a new or second hand machine be purchased, how often should a machine be replaced, would it be cheaper to custom – hire
a machine rather than buy one, what sizes of machine (s) should be bought, what would be the cost of jointly buying or sharing a machine with other farmers.

Chondary and Brown (1983) used MIP and developed a new programme to select one of the following three options: (a) cost of ownership; (b) cost of a contractor; and (c) comparison of ownership with a contractor.

Faidley et al. (1975) developed computer model for selection and costing of farm machinery systems. The computer model was adapted from work done by Hughes (Hughes, 1973 and Hughes et al., 1973). The model begins by estimating horsepower needed for the cropping operations. The tractors are selected and assigned to field operations, machine size is matched to operation requirements, finally, yearly use, operation costs and fuel requirements are determined.

Ismail (1988) developed a model for crop production machinery system (PMS) at Michigan State University, USA to predict the machinery requirements and to determine the cost of production.

Stemens and Humburg (1988) developed a computer programme for determining the least cost machinery necessary for a farm of maize and soybean. The programme was both an educational tool and practical method for assisting farmers.

Aderoba (1989) developed a model to allow optimum selection of farm machinery for agricultural mechanization in developing countries.

Davila (1988) developed a methodology for selecting farm machinery for cultivation, drilling, fertilizer application and
harvesting of Paddy Rice. Particular attention was paid to determining the number of working days for which daily precipitation and soil condition play an important role. Cost analysis and breakeven point were included in a programme on a microcomputer.

He et al. (1989) developed a methodology system for agricultural machinery selection. The main part of the method considered a series of models with which farm production and economic results can be simulated when particular machinery was operated on the farm.

A crop production machinery system model was developed at Michigan State University, which is a computer interactive model developed on the concept of expert system, allows the user to interact with the programme, which consists of machinery selection model, which can be used to predict the size of tractors and implements required and to determine the compatibility of tractors and implements by properly matching the available tractor power. Also, it consist of a machinery cost analysis model, which can be used to determine the cost of the tractor and implements selection (Wan, 1998).

Mekalilie (1996) developed a model to obtain the optimum width of a machine using physical power of the tractor and implements or both.

Elhassan (2001) developed a cost analysis model capable of calculating the total annual cost of a tractor and a machine, and total cost of any operation. Also, the model can investigate the effect of changing the machine width, the speed, the field efficiency, the
cultivated area, and the machine age on the annual total cost of the operation, therefore, can help in quick decision-making.

Salih (2001) developed a model capable of calculating tractor and machine cost per hour. And predict the breakeven point by comparing the ownership cost with the contract charge rate.

It can be concluded that computer technology is now widely introduced in the field of farm machinery management and helping very much in proper decision making and selection of required machine inputs for agricultural production.

2.6.5 Technical packages of different crops in Gezira Scheme

1. Cotton

Soil preparation

The soil is prepared by one of the following ways:

One) The soil is ploughed by a disc harrow to a depth of 18-20 cm. Then it is ridged to 80 cm between ridges.

Two) Hard-pan soil: it is ploughed to a depth of 45-50 cm, by a subsoil, then a disc harrow is used to a depth of 10-15 cm to crush the clots.

Three) Infested soils by grasses: it is recommended to use the blade to a depth of 25 cm followed by a disc harrow to a depth of 10-15 cm to crush the clods.

Numbers of machines used for cotton crop according to each operation:

1- Land preparation: harrow, disc three blade and ridger.
2- Herbicides: using sprayer.
4- Sowing: using planter.
5- Fertilization: using fertilizer.
6- Green ridging: using ridger.

2. Wheat
1- Soil preparation: using ridger, harrow and leveller.
2- Sowing: using wide level disc or seed drill.

3. Groundnuts
1- Soil preparation: using ridger.
2- Sowing: using planter.
3- Watering: using ditcher for both Abu 20 and Abu 6.

4. Dura (sorghum)
1- Soil preparation: using ridger for first and second ridging.
2- Sowing: using planter.
3- Watering: using ditcher for both Abu 20 and Abu 6.

Table 2.3 shows the successive timing of the agricultural operations in the Gezira Scheme.
Table 2.3 The successive timing of the agricultural operations in the Gezira.

<table>
<thead>
<tr>
<th>Month</th>
<th>Agricultural operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>Beginning of vegetable and cotton sowing</td>
</tr>
<tr>
<td>August</td>
<td>Cotton sowing beginning of cotton thinning green ridging …</td>
</tr>
<tr>
<td>September</td>
<td>Cotton thinning –green ridging – start of pest control – vegetable sowing.</td>
</tr>
<tr>
<td>October</td>
<td>Beginning of dura and groundnuts harvest – wheat sowing.</td>
</tr>
</tbody>
</table>
| November | One) Pests and insects fighting campaigns (cotton).  
|         | Two) Continuity in wheat sowing  
|         | Four) Groundnuts and dura harvest. |
| December | One) Beginning of long staple cotton harvest.  
|         | Two) Continuity of vegetable harvest. |
| January | One) Continuity in cotton harvest.  
|         | Two) Fighting cotton and wheat pests.  
|         | Three) Beginning of cotton ginning.  
|         | Four) Cotton land preparation. |
| February | Cotton harvest and cotton land preparation. |
| March   | Continuity in cotton and wheat harvest and cotton land preparation. |
| April   | One) End of cotton harvest.  
|         | Two) Continuity of wheat harvest  
|         | Three) Cotton harvest preparation |
| May     | One) Uprooting and burring of cotton stalks  
|         | Two) Continuity in cotton land and vegetable land preparation for the coming season. |
| June    | One) Cleanup of cotton land and end of ginning.  
|         | Two) Sowing of groundnuts and sorghum. |

Source: Galal (1997).
3.1 Characterization of the study area

3.1.1 General

The name El Gezira that is “the Island” was originally given to all the country between the Blue Nile and the White Nile, without any defined limit to the south. For practical purposes, now it includes only the triangle lying North of Sennar-Kosti railway (Fig. 3.1 and 3.2).

The Gezira Scheme is considered as the largest scheme in the world under one administration having an area of 2.1 million feddans or one million hectares, however, this area covered about half the irrigated area in the Sudan.

The topography of the Gezira area has to a great extent facilitated surface irrigation operation after the construction of Sennar Dam in 1925.

The climatic conditions of the area vary, but generally the annual average rainfall is approximately 400-500 mm in the South, and this average drops gradually towards the North (Yousif, 1997).

The surface soil of the Gezira with high clay content, has the merit from an irrigation point of view that it is very impervious to water in its undistributed condition, and thus seepage and percolation losses from canal are low. But it contracts when dry and expands again when wetted and for this reason does not provide good foundations for irrigation structures and buildings. Soils are in general very good, their selfmunching characteristics is a great asset.

Fig 1
Fig 2
3.1.2 The agricultural rotation

The Gezira Scheme was devised primarily for the cultivation of cotton. Later, because of the value of the irrigated dura to the Sudan in years of drought, and the eagerness of the Sudanese farmer to grow his own food crop, area under dura was increased and it was greatly extended by the inauguration of the Sunnar Dam in 1925. Dura was included with Lubia and cotton in three years course rotation.

The second rotation is the four courses rotation in which the need for resting year before dura was taken into consideration. Hence, the yield of dura when sown in a three-course rotation after cotton is relatively low.

Also, lubia is harmful to cotton unless the land is allowed to rest at least one year after it.

The introduction of chemical fertilizers and pesticides has made a lot of changes in the agricultural rotation. The fallow land was reduced to the minimum. Land has become more fertile for crop production.

Also, water from the two dams (Sennar and Roseiris) helped a lot with the expansion of agriculture and the intensification of crops in the Gezira Scheme. From 1974 onwards, the area grown with wheat has doubled and so the area of groundnuts. The four-course rotation is as follows: cotton – wheat – sorghum – groundnuts – fallow. Then when it became of the five-course rotation the area for each crop decreased and some area was reserved for fodder production. The main objective of the five-course rotation was to integrate animal production. The five-course rotation as follows: cotton – wheat – sorghum – groundnuts – fallow – fodder.

A computer programme may be used to manage the production operations and to select the machinery requirement effectively based on the estimated total costs, land allocated for planning and numbers of crops to be grown.
3.2 Model development

3.2.1 Programme main feature

A computer programme was developed for machinery cost analysis in crop production system, it was constructed for a simple user and (direct producers) as a tool for cost analysis under diverse input variable and for quick decision-making. The programme was written in Pascal language to be used on a personal computer.

The programme main body consists of two options (tractor cost) and (machine cost) each option consist separate procedure. Most of these are dedicated to carry specific function. The detailed functions of each is as follows:

Option 1: tractor cost

The main programme elements are included in this part. Procedure for configuration and setting controls for the entire programme is organized and set up to serve use in both programme running configuration and exiting. In this part, the model calculates first fixed cost, running cost, total cost and the tractor cost per hour.

Option 2: machine cost

The main programme elements included in this basic part are the producers for calculating:

One) The machine cost, including the tractor cost per hour.
Two) Calculating the cost of a number of machines per hectare.
Three) Calculating the cost of an operation per hectare.
Four) Calculate a cost of each crop using a number of machinery per hectare.
Five) Calculate a cost of crops in rotation per hectare.
The main component of the model are shown in the main and detailed flow chart.

3.2.2 Programme technical specifications

The technical specifications of the computer programme are shown in Table 3.1.

3.3 Programming technique and style

Adhering to the logic of the modular programming, each part (unit) of the programme was broken down into small chunks (producers and functions). Modular programming was made easier to write and maintain by coding and testing each procedure or function independently of the main programme. Moreover, the programming modeling was increased by passing value parameters and variable into functions or procedure. However, by limiting the scope of the variables unwanted side effects were eliminated. In addition, modularity was improved by making both procedure and functions self-contained blocks of code to accept data through parameters.
Table 3.1 Programme technical specifications.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Programme language</strong></td>
<td></td>
</tr>
<tr>
<td>Programme flexibility</td>
<td>Prone to freeze</td>
</tr>
<tr>
<td>Programme type</td>
<td><strong>User friendly</strong></td>
</tr>
<tr>
<td>Programme dependability</td>
<td>Based on chunks (procedures)</td>
</tr>
<tr>
<td><strong>Units used</strong></td>
<td></td>
</tr>
<tr>
<td>Output available (displayed)</td>
<td>Available option</td>
</tr>
<tr>
<td>Output available (Printed)</td>
<td>Available option</td>
</tr>
<tr>
<td>Output available (Graphs)</td>
<td>Not available</td>
</tr>
<tr>
<td>Display type</td>
<td>EGA, VGA, SUGA</td>
</tr>
<tr>
<td>Minimum speed required</td>
<td>133 MHz</td>
</tr>
<tr>
<td>Mange activated menus</td>
<td>Not available</td>
</tr>
<tr>
<td>Minimum memory (RAM) needed</td>
<td>18.5 MB</td>
</tr>
</tbody>
</table>
The programme style was based on the principle of “making a place for everything and everything in its place”. To achieve this order, defined sections each to serve specific purpose was adopted. The major sections are programme heading, data section and code section.

The programming technique and style can be summerized as follows:

a) Programme heading
- Programme name.
- Compiler directives.

b) Data section
- User defined.
- Variable declaration.

Data declaration

(c) Code section
- Procedure
- Function

Code section

As given in the summary of programming style, compiler devices were used for the tasks of inputs output error alignment. This was made during programme build up by comparing the programme intermediate results with those calculated by (Excel) (spread sheet MS-Excel Ver. 6.0) examples.

The nature of data declarations employed in the programme are as follows:

i- Constant

One constant was used as defined by the code C.F = correction factor = 10.
ii- User defined types (records)

Use of many user-defined records was inevitable.

iii- Variables

Both global and local variable used where ever needed.

3.4 Programme limitations

The programme limitations, may be summarized as follows:

1- The programme is capable to predict the cost per hectare up to seven crops.

2- The programme is capable to calculate the cost per hectare up to 10 machines in an operation.

3.5 Programme iterative logic

The programme is designed to prompt the user to interactively enter relevant data via a sequence of driven menus. However, the user is free to execute each option separately or the whole model as one unit. The data entry was guided in a step by step process with explanatory notes to direct the user. Consequently, defined spaces in the form of blank areas appear to facilitate data entry. The setup of data was made to allow maximum freedom for the user to enter his own data.

The required data will be detailed in the calculation procedure of each option or sub-model as shown in the main and detailed flow chart (Fig. 3.3 and 3.4).
<table>
<thead>
<tr>
<th>Programme inputs</th>
<th>Processing</th>
<th>Programme output</th>
</tr>
</thead>
<tbody>
<tr>
<td>User input</td>
<td>Main programme (plan model exe)</td>
<td>Displayed on the console</td>
</tr>
</tbody>
</table>

Fig. 3.3 The programme main flow chart.
Detailed Flow Chart

Fig. 3.4 The programme detailed flow chart
TCA

Input parameters of fixed

Enter:
1. PP
2. TI%
3. TS%
4. TT%
5. TD%
6. T.No. × W hrs
7. Ti%

Input parameters of running cost

A
Enter:
TR & M%
TFC
TFP
TOC%
TLC
T. ann. hrs

Read:
TPP, TI, TS, TT,
TD, TC, T.No. WY

Read:
TR& M, TFC, TFP, TOC,
TLC, TC, T.ann hrs

A

B
TIC = TI * TPP/100

TTC = TT * TPP/100

TSC = TS * TPP/100

T Int. Sal [1] = TPP

T – Sal [1] = TPP *(1 – T. ann R)

\[ T – \text{Dep. [1]} = T + \text{Int Sal [1]} – T – \text{Sal [1]} \]

TFC = TIC + TTC + TSC + TiC + T Dep

TR & M/T. ann. ×TR & MC = (TPP \text{ hr})/100

FP×TFC = FC

0/100×TOC = TFC

(TR & M C = TFC ×T Run C = T. ann hr

C
Output

TFC
1. TIC =
2. TTC =
3. TSC =
4. TiC =
5. T Dep. C =

1. TR & MC =
2. TFC =
3. TOC =
4. TLC =
5. T RC/ann. =
6. T. ann. C =
7. T hr C =

D
Enter:
- CF
- Nos. Cr
- Nos. M
- T hr C

Data of crop

Type of machine

Data of machine

A
Input parameters of fixed cost

Enter:
1. T hr C
2. MPP
3. MIP%
4. MSP%
5. MTP%
6. MiP%
7. M Dep.%
8. MWY

Input parameter of running cost

B
Enter:
  M R&M%
  A
  S
  W
  E

Read:
MPP, MI, MT, MS, M Dep,
Mi, M Nos. WY

Read:
M R&M

C
MIC = MI \times \frac{MPP}{100}
MTC = MT \times \frac{MPP}{100}
MSC = MS \times \frac{MPP}{100}
M. int Sal. [1] = MPP
M. Sal. [1] = MPP \times (1 - M \text{ ann. R})
MiC = \frac{(MPP + M. Sal.)}{2}

MFC = MIC + MTC + MSC + MiC + M \text{ Dep. C}

M R&M C hr = \frac{(MPP \times M R&M)}{M \text{ ann. hr} \times 100}
M \text{ run. C} = M \text{ ann. hr} \times (M R&M C hr + T \text{ hr C})
M \text{ ann. C} = MFC + M \text{ Run C}
MAC = M \text{ ann.} / A
M hr C = M \text{ ann. C} / M \text{ ann. hr}
OPAC = \text{Sum. MAC for given crop}
Cr C = \text{Sum. OPAC}
CN: MFC
1. MIC =
2. MTC =
3. MSC =
4. MInC =
5. M Dep. C =

Your CN: FC is:

MN: MRC

MR & MC/hr is:

E
Your CN: TAC is:

Your MR & MC/Ann. is:

Your CN: TAC is:

Your MN Ann. C: are:
Your OC/area are:

Your MN C/hr: are:
Your OC/hr are:

F
F

Your MN: hr of use are:

Your OOAAC: are:

End
3.6 Calculation procedure

3.6.1 Tractor costs calculation

The annual average cost of the tractor used as a source of power may be calculated from the following equation:

\[ AC = TFC + \text{ann. Hrs of use} \ (R & M + F + O + L) \quad \ldots (3.1) \]

Where:

\[ AC\% = \text{annual TOTAL cost}. \]

\( TFC = \text{total annual fixed cost} \)
\( R & M = \text{repair and maintenance costs, } \% \text{ of purchase price}. \)
\( F = \text{fuel cost, per hour}. \)
\( O = \text{oil cost, per hour}. \)
\( L = \text{labour cost, per hour} \)

a) Fixed costs (FC)

The fixed costs (FC) include depreciation (D), interest (I), taxes (T), insurance (i) and shelter (S), as given by Hunt (1979).

i- Purchase price (PP)

It is the market value of the machine and is subjected to the current market prices.

ii- Interest on investment (I)

It is a direct expense on borrowed capitals even if cash is paid for purchase of machinery (Brower, 1987). It is calculated as follows:

\[ I_c = \frac{PP + SV}{2} \times i \quad \ldots (3.2) \]
Where:
Ic = interest cost.
PP = purchase price.
SV = salvage value at the end of the machine life.
i = interest rate.

iii- Taxes
It is used to be calculated as a percentage of the purchase price as follows:

\[ T \ cost = \frac{PP \times I\%}{100} \]  

... (3.3)

Where:
T = taxes cost.
PP = purchase price.
T\% = taxes percentage.

iv- Insurance
It is used to be calculated as a percentage of the purchase price as follows:

\[ I \ cost = \frac{PP \times I\%}{100} \]  

... (3.4)

Where:
I = insurance cost.
PP = purchase price.
I\% = insurance percentage.

v- Shelter
It is calculated as a percentage of the purchase price as follows:

\[ S \ cost = \frac{PP \times S\%}{100} \]  

... (3.5)
Where:

\[ S = \text{shelter cost.} \]
\[ \text{PP} = \text{purchase price.} \]
\[ S\% = \text{shelter percentage.} \]

The American Society of Agricultural Engineers (ASAE, 1983) stated that, if the annual data of taxes, insurance, and shelter are not known, 2% can be used (0.5% for insurance, 0.75% for shelter and 1% for taxes).

\textbf{vi- Depreciation (D)}

In this study the method used is the declining-balance, which reflects the actual value of depreciation of the machine at any age as follows:

\[ V_n = \text{PP} \times (1 - \frac{r}{L})^y \]
\[ D = V_n - V_n + L \]

Where:

\[ D = \text{annual depreciation value.} \]
\[ \text{PP} = \text{purchase price.} \]
\[ V = \text{remaining value of the machine at any time.} \]
\[ n = \text{age of the machine at the beginning of the year at which depreciation is determined.} \]
\[ r = \text{rate of depreciation.} \]
\[ L = \text{machine life.} \]
\[ y = \text{age at which depreciation is determined.} \]

Total fixed cost is calculated as follows:

\[ TFC = D + I + (TIS) \]

\[ \ldots (3.7) \]
b) Variable costs

These costs are calculated on per hour bases, and include the following items:

i- Repair and maintenance cost

It is one of the largest variable costs but is difficult to estimate and therefore computed as a percentage of purchase price as follows:

$$ R \& m\ cost/hr = \frac{R \& M\% \times PP}{100} \times \frac{1}{annual\ hrs\ of\ use} \quad \ldots (3.8) $$

Where:
R & M = repair and maintenance.
PP = purchase price.

ii- Fuel and oil costs (F + O)

Fuel and oil consumption are costs vary with the use of the machine, and the cost can be calculated as follows:

Fuel cost = fuel consumption (lit/h) \( \times \) fuel price/ lit

Oil cost = fuel cost \( \times \) \( \frac{10\ to\ 15\%}{100} \) \quad \ldots (3.9)

iii- Labour cost (LC)

Labour cost is computed as per hour and the charge is taken according to the running rate in the specific area.

The total variable cost (TVC) is calculated according to the following equation:

$$ TVC = annual\ hrs\ of\ use\ (R \& MC + FC + OC + LC) \quad \ldots (3.10) $$

Total annual cost (TAC) is computed as follows:

$$ TAC = TFC\ total\ fixed\ cost + TVC\ total\ variable \quad \ldots (3.11) $$
3.6.2 Machine cost calculation

The machine cost or the total operation cost includes the tractor (as a source of power) cost per hour and the machine fixed and variable costs. The calculations as follows:

3.6.2.1 Machine fixed cost

The fixed cost (FC) include the insurance (i), shelter (S), taxes (T), interest (I) and depreciation (D) as given by Hunt (1979).

**i- Insurance cost**

It is used to be calculated as a percentage of the purchase price as follows:

\[ i \, \text{cost} = \frac{PP \times i\%}{100} \]

Where:

- \( i \) = insurance cost
- \( PP \) = purchase price
- \( i\% \) = insurance percentage.

**ii- Shelter cost**

It is used to be calculated as a percentage of the purchase price as follows:

\[ S \, \text{cost} = \frac{PP \times S\%}{100} \]

Where:

- \( S \) = shelter cost
PP = purchase price
S% = shelter percentage.

**iii- Taxes cost**

It is used to be calculated as a percentage of the purchase price as follows:

\[
T \ cost = \frac{PP \times T\%}{100}
\]

Where:

- T = taxes cost
- PP = purchase price
- T\% = taxes percentage.

**iv- Interest on investment (I)**

It is a direct expense on borrowed capital, even if cash is paid for purchase of machinery (Bower, 1987). It is used to be calculated as follows:

\[
I \ cost = \left( \frac{PP + SV\%}{S} \right) \times i
\]

Where:

- I = interest cost.
- PP = purchase price.
- SV = salvage value at the end of the machine life.
- i = interest rate.
v- Depreciation cost

In this study the method of calculating the depreciation is the declining balance method, which reflect the actual value of the depreciation of the machine at any age of the machine life as follows:

\[ V_n = PP \times (1 - \frac{r}{L})^y \]

\[ D = V_n - V_{n+1} + L \]

Where:

- \( D \) = annual depreciation value.
- \( PP \) = purchase price.
- \( V \) = remaining value of the machine at any time.
- \( n \) = age of the machine at the beginning of the year ay which depreciation is determined.
- \( r \) = rate of depreciation.
- \( L \) = machine life.
- \( y \) = age at which depreciation is determined.

The American Society of Agricultural Engineering (ASAE) (1983) stated that, if annual data of taxes, insurance, and shelter are not known, 2% can be used (0.5% for insurance, 0.5-0.75% for shelter and 1% for taxes).

\[ Total\ fixed\ cost\ (TFC) = D + T + i + S \]

3.6.2.2 Machine running costs

These costs include the machine variable costs calculations and the machine hours of use calculation as follows:
i- Variable costs

These costs are calculated on per hour bases, and calculated as follows:

1. Repair and maintenance cost

It is one of the largest variable cost but is difficult to estimate and therefore, computed as a percentage of purchase price as follows:

\[
R \& m \text{ cost/hr} = \frac{R \& M\% \times PP}{100} \times \frac{1}{\text{annual hrs of use}}
\]

Where:

- R & M = repair and maintenance.
- PP = purchase price.

2. Machinery hour of use (Mhrs)

It is calculated as follows:

\[
M \text{ hrs} = \frac{CF \times A}{SWE}
\]  \hspace{1cm} \ldots (3.13)

Where:

- CF = correction factor, constant = 10.
- A = area in hector.
- S = forward speed, km/hr.
- W = effective width of machine, m

\[
\text{Machine running cost annually} = \frac{CF \times A}{SWE} (R \& M + TC)
\]  \hspace{1cm} \ldots (3.14)
Therefore, the total operation costs:

\[ TOC = TFC + \frac{CF \times A (R \& M+ TC)}{SWE} \] … (3.15)

### 3.6.3 Crop cost

The crop cost will be equal to the total operation costs of a number of machines used form different operations.

### 3.6.4 Rotation cost

Equal to the total crops cost cultivated in the rotation according to the crop pattern.

The unit used in this model as follows:

- Area = hector
- Correlation factor = 10
- Speed = lm/hour
- Width = meter
4.1 Model evaluation

According to Dent et al. (1979), model evaluation is a two-fold process. It involves model verification and evaluation.

4.1.1 Model verification

The objective of this study is to develop a machinery cost analysis model in crop production to evaluate the cost for the following:-

1- To predict tractor (as a source of power) total annual cost and cost per hour.
2- To predict machine total annual cost in an operation and cost per area.
3- To predict the total cost of an operation per area up to ten machines.
4- The total cost of each crop up to seven crops.
5- The total cost of any operation using tractor and machine or machines by changing the following:
   One) Machine width.
   Two) Forward speed.
   Three) Field efficiency.
   Four) Area.

Due to the modular nature of the model, model verification accepted by widely used models for each individual unit or sub-model. Testing the accuracy of each sub-model will be made in
relation to the scientifically accepted and popular models such as these developed from Hunt equation of cost analysis. The criterion for comparing each sub-model with the accepted ones will be based on statistical testing as follows:

4.1.1.1 Verification of the tractor cost

An estimation of the tractor cost as a source of power is one of the key criteria required for the planning, designing and operation of the agricultural schemes.

The accuracy of the computer model was tested using real input data from Gezira Board, Agricultural Engineering Department (AED) (Musa personal communication).

The results of the tractor cost predicted using the computer model showed no significant differences from those estimated from mathematical solved example. In addition, no differences between results predicted using the computer model and those estimated using Excel Programme.

4.1.1.1.1 Predicted and actual values for tractor costs

Comparing the tractor cost predicted by the model to actual cost from Gezira Scheme the results indicated that, the tractor cost per hour is less by a small value than the tractor cost per hour in Gezira by 45%. This is due to the fact that, the Gezira cost per hour is including the profit and other administration expenses. Therefore, the result showed some differences as shown in Table 4.1.
Table 4.1 Tractor cost analysis.

<table>
<thead>
<tr>
<th>Item</th>
<th>Tractor predicted values (SD)</th>
<th>Item</th>
<th>Gezira values (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase price</td>
<td>5,000,000</td>
<td>Purchase price</td>
<td>5,000,000</td>
</tr>
<tr>
<td>Insurance, 0.5%</td>
<td>25,000</td>
<td>Insurance, 0.5%</td>
<td>25,000</td>
</tr>
<tr>
<td>Shelter, 0.5%</td>
<td>25,000</td>
<td>Shelter, 0.5%</td>
<td>25,000</td>
</tr>
<tr>
<td>Taxes, 1%</td>
<td>50,000</td>
<td>Taxes, 0.5%</td>
<td>25,000</td>
</tr>
<tr>
<td>Interest, 8%</td>
<td>360,000</td>
<td>Interest, 15%</td>
<td>541,389</td>
</tr>
<tr>
<td>Depreciation, 20%</td>
<td>1,000,000</td>
<td>Depreciation, 15%</td>
<td>391,504</td>
</tr>
<tr>
<td>Repair and maintenance, h, 4%</td>
<td>200</td>
<td>Repair and maintenance, h, 29%</td>
<td>1,450</td>
</tr>
<tr>
<td>Fuel, h</td>
<td>350</td>
<td>Fuel, h</td>
<td>350</td>
</tr>
<tr>
<td>Oil, h</td>
<td>52.5</td>
<td>Oil, h</td>
<td>52.5</td>
</tr>
<tr>
<td>Labour, h</td>
<td>100</td>
<td>Labour, h</td>
<td>100</td>
</tr>
<tr>
<td>Annual hour of use</td>
<td>1000</td>
<td>Annual hour of use</td>
<td>1000</td>
</tr>
<tr>
<td>Fixed cost</td>
<td>1,460,000</td>
<td>Fixed cost</td>
<td>1,172,684</td>
</tr>
<tr>
<td>Running cost</td>
<td>702,500</td>
<td>Run cost</td>
<td>1,952,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,162,500</strong></td>
<td><strong>Total</strong></td>
<td><strong>3,125,184</strong></td>
</tr>
<tr>
<td>Tractor cost per hour</td>
<td>2,162</td>
<td>Tractor cost per hour</td>
<td>3,125</td>
</tr>
</tbody>
</table>
4.1.1.2 Machine cost

Machine cost is usually based on the estimation of the tractor cost per hour and the machine hours of use. The computer model predict the following machine costs: The fixed cost, variable cost, and total cost of the machine. The model predicts the following costs according to Hunt equation:-

1- Tractor cost.
2- Machine cost.
3- Operation cost per area.
4- Total operation cost for each crop.

The accuracy of the computer model was tested using real input data from AED (Musa personal communication) as follows:

1- Using unchangeable data like purchase price, insurance, depreciation rate, interest rate, shelter and taxes. Using the above input data the model predicts the annual fixed cost of the machine. Other data like repair and maintenance are used for the prediction of the variable cost of the machine.

2- Using changeable data (technical data):

These data include the width of the machine, area, speed and efficiency, which are used in the model for prediction of machine hours of use and calculates the variable cost of the machine.
4.1.2.1 Predicted and actual values for cost of operations

One) Comparing each operation cost per area predicted by the model with that of the Gezira values cost, the model cost is less by a small value. This is due to the fact that, the actual cost from Gezira is including profit and other administration expenses as shown in Table 4.2.

Table 4.2 Comparison between predicted model cost and Gezira operation cost.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Cost operation (SD)/ha</th>
<th>Gezira values</th>
<th>Model values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrowing</td>
<td>1666</td>
<td></td>
<td>1602</td>
</tr>
<tr>
<td>Disc three blade</td>
<td>3972</td>
<td></td>
<td>4421</td>
</tr>
<tr>
<td>Ridging</td>
<td>1428</td>
<td></td>
<td>1246</td>
</tr>
<tr>
<td>Planting</td>
<td>2380</td>
<td></td>
<td>1251</td>
</tr>
<tr>
<td>Fertilization</td>
<td>714</td>
<td></td>
<td>372</td>
</tr>
<tr>
<td>Field sprayer</td>
<td>833</td>
<td></td>
<td>329</td>
</tr>
<tr>
<td>Levelling</td>
<td>952</td>
<td></td>
<td>1243</td>
</tr>
<tr>
<td>Green ridging</td>
<td>1190</td>
<td></td>
<td>950</td>
</tr>
</tbody>
</table>
Two) Comparing each crop cost per area using different operations for each crop predicted by
the model to those costs estimated from Gezira also indicated that, the predicted model cost is
less by a small value than the cost from Gezira and also this is due to the fact that,
profit and other administration cost are included as shown in Table 4.3.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Crop cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gezira values</td>
</tr>
<tr>
<td>Cotton</td>
<td>12138</td>
</tr>
<tr>
<td>Wheat</td>
<td>4323</td>
</tr>
<tr>
<td>Sorghum</td>
<td>4998</td>
</tr>
<tr>
<td>G/N</td>
<td>4998</td>
</tr>
</tbody>
</table>

Table 4.3 Comparison between predicted model cost and Gezira crops cost.
4.2 Model validation

In order to test model adequacy, subjective assessment of the model should be made in relation to the model purposes (Dent et al., 1979).

4.2.1 Model sensitivity tests

As given in the specific objectives of this study, the programme main purpose is to be used as a planning tool through estimation of the tractor cost per hour as a source of power and a number of machines and the cost of crop operations in different rotation in order to manage the machinery system and do the selection from an economic approach by changing the area, machine width, speed and efficiency. However, to aid these qualitative indicators analysis will be employed. These indicators are:

a) Changing the purchase price:

According to the power required for different operations and different areas to be cultivated, the tractor purchase price can be changed as shown in Table 4.4. As the tractor purchase price is increase for more power requirement the cost per hour will increase, but accordingly the area cultivated can be more, and also the width of cut may increase, and the hours needed to complete the work will decrease and there will be more time available for other operations to be done and therefore, the cost per hour will decrease relatively, because the hours of use will be increase.

b) Changing the machine width, tractor forward speed and field efficiency, more area can be cultivated due to decreasing the cost.
Table 4.4 Effect of changing tractor purchase price.

<table>
<thead>
<tr>
<th>Item</th>
<th>Tractor cost (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Purchase price</td>
<td>5,000,000</td>
</tr>
<tr>
<td>Insurance, 0.5%</td>
<td>25,000</td>
</tr>
<tr>
<td>Shelter, 0.5%</td>
<td>25,000</td>
</tr>
<tr>
<td>Taxes, 1%</td>
<td>50,000</td>
</tr>
<tr>
<td>Interest, 8%</td>
<td>360,000</td>
</tr>
<tr>
<td>Depreciation, 20%</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Repair and maintenance, h, 4%</td>
<td>200</td>
</tr>
<tr>
<td>Fuel, h</td>
<td>350</td>
</tr>
<tr>
<td>Oil, h</td>
<td>52.5</td>
</tr>
<tr>
<td>Labour, h</td>
<td>100</td>
</tr>
<tr>
<td>Annual hour of use</td>
<td>1000</td>
</tr>
<tr>
<td>Fixed cost</td>
<td>1,460,000</td>
</tr>
<tr>
<td>Running cost</td>
<td>702,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,162,500</strong></td>
</tr>
<tr>
<td>Tractor cost per hour</td>
<td>2162</td>
</tr>
</tbody>
</table>
4.2.2 Effect of changing machine width

The model can predict the cost of a machine when changing the machine width. Increasing the machine working width from 0.9 m to 3.2 m caused a decrease in the machine running cost by 61.3%, and a decrease in the machine total annual cost by 26.3%. Also, a decrease in the hours of use by 71.8%, and accordingly an increase in the area to be cultivated within the allotted time by 73.5% = 177 ha, and the cost per area will be decreased by 69.76% as shown in Table 4.5.

So, this model can give right decision-making for good selection of the machine width supposed to be used.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width 0.9 m</td>
</tr>
<tr>
<td>Purchase price</td>
<td>350,000</td>
</tr>
<tr>
<td>Total annual fixed cost</td>
<td>85,400</td>
</tr>
<tr>
<td>Total running cost</td>
<td>238,292</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>323,692</td>
</tr>
<tr>
<td>Area cultivated (hectare)</td>
<td>50</td>
</tr>
<tr>
<td>Hours of use</td>
<td>102</td>
</tr>
<tr>
<td>Operation cost/h</td>
<td>3,169</td>
</tr>
<tr>
<td>Operation cost per area</td>
<td>6,473</td>
</tr>
<tr>
<td>120 hours cover area of:</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5 Changing the machine width: using three blade disc and planter cost.
4.2.3 Effect of changing speed

When increasing the forward speed from 6.4 km/h to 8.4 km/h, the total running cost was decrease by 19.1% and accordingly the total cost was decrease by 19.8%. Also, the hours of use will decrease by 24% and more area can be cultivated. Repair and maintenance cost per hour will increase, and the cost per area will decrease by 10.8%. But the total fixed cost for the operation was not affected as shown in Table 4.6.

Table 4.6 Changing speed: using ridger and green ridger cost.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed 6.4 km/h</td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>73,200</td>
</tr>
<tr>
<td>Total running cost</td>
<td>77,097</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>150,297</td>
</tr>
<tr>
<td>Hours of use</td>
<td>28.7</td>
</tr>
<tr>
<td>Cost/feddan</td>
<td>3,005</td>
</tr>
<tr>
<td>Cost/h</td>
<td>5,232</td>
</tr>
</tbody>
</table>
4.2.4 Effect of changing efficiency

When the field efficiency was decreased from 85% to 70% the running cost increased by 17.2%, and accordingly the total annual cost will increase by 8.85% and the cost per area also increased by 8.85% and the hours of use will be increased by 21.25%, and the cost per hour decreased by 21.25%. That is to say more time is needed for the work to be done as shown in Table 4.7. This indicated that for proper decision-making field efficiency should be improved.

Table 4.7 Changing field efficiency: using ridger cost.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
<th>Efficiency 85%</th>
<th>Efficiency 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Efficiency 85%</td>
<td>Efficiency 70%</td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>73,200</td>
<td>73,200</td>
<td></td>
</tr>
<tr>
<td>Total running cost</td>
<td>77,097</td>
<td>90,405</td>
<td></td>
</tr>
<tr>
<td>Total annual cost</td>
<td>150,297</td>
<td>163,604</td>
<td></td>
</tr>
<tr>
<td>Cost/area</td>
<td>3,005</td>
<td>3,272</td>
<td></td>
</tr>
<tr>
<td>Cost/h</td>
<td>5,232</td>
<td>4,690</td>
<td></td>
</tr>
<tr>
<td>Hours of use</td>
<td>28.7</td>
<td>34.8</td>
<td></td>
</tr>
</tbody>
</table>
4.2.5 Effect of changing the cultivated area

The model was valid for area to be changed using the same implements. The predicted cost indicated that as increasing the cultivated area the running cost will be increased by 833% and the total annual cost increased by 613%. Whereas, the operation cost per area decreased by 28.6%, and the operation cost per hour decreased by 28.6%. This is due to an increase in hours of use by 900% as shown in Table 4.8.

Table 4.8 Changing the cultivated area: using three blade disc cost.
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area 50</td>
<td>Area 500</td>
<td></td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>85,400</td>
<td>85,400</td>
<td></td>
</tr>
<tr>
<td>Total running cost</td>
<td>238,292</td>
<td>2,225,424</td>
<td></td>
</tr>
<tr>
<td>Total operation cost</td>
<td>323,692</td>
<td>2,310,824</td>
<td></td>
</tr>
<tr>
<td>Operation cost per area</td>
<td>6473</td>
<td>4621</td>
<td></td>
</tr>
<tr>
<td>Operation cost per hours</td>
<td>3169</td>
<td>2262</td>
<td></td>
</tr>
<tr>
<td>Hours of use</td>
<td>102</td>
<td>1021</td>
<td></td>
</tr>
</tbody>
</table>
4.2.6 Effect of changing tractor age

Increasing the tractor age from 1<sup>st</sup> to 5<sup>th</sup> years caused a decrease in the depreciation cost by 59%, but the repair and maintenance cost per hour will be increased by 54.2%, and accordingly the tractor running cost increased by 182.9% and the total annual cost also increased by 40%, and the tractor cost per hour increased by 39.9% as show in Table 4.9.

So, proper repair and maintenance cost should be taken into consideration.

Table 4.9 Effect of changing machine age on tractor cost: using ridger cost.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; years age</td>
</tr>
<tr>
<td>Repair and maintenance cost</td>
<td>4%</td>
</tr>
<tr>
<td>Annual depreciation cost</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>1,460,000</td>
</tr>
<tr>
<td>Repair and maintenance per hour</td>
<td>200</td>
</tr>
<tr>
<td>Total running cost</td>
<td>702,500</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>2,162,500</td>
</tr>
<tr>
<td>Operation cost per hours</td>
<td>2,162</td>
</tr>
</tbody>
</table>
4.2.7 Effect of changing machine age

This model can predict the depreciation cost of a tractor and a machine for any age up to 20 years.

Increasing the working life of the machine from 1\textsuperscript{st} to 5\textsuperscript{th} year the depreciation cost was decreased by 47.79%, and accordingly the fixed cost was decreased by 22.5%.

The repair and maintenance cost was increased as the age of the machine increased by 74%, and accordingly the running cost increased by 85.4% and the total operation cost also increased by 32.8%. The total cost per area increased by 32.8%.

In order to decrease the fixed costs of the machine we have to prolong the ownership of machinery by increasing the years of trading-interval, and assuming proper repair and maintenance for its direct effect on changing this factor as shown in Table 4.10.

Table 4.10 Changing machine age: using ridger cost.
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st years age</td>
</tr>
<tr>
<td>Repair and maintenance cost</td>
<td>5%</td>
</tr>
<tr>
<td>Tractor cost per hour</td>
<td>2,162</td>
</tr>
<tr>
<td>Annual depreciation cost</td>
<td>450,000</td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>73,200</td>
</tr>
<tr>
<td>Repair and maintenance per hour</td>
<td>5222</td>
</tr>
<tr>
<td>Total running cost</td>
<td>77,097</td>
</tr>
<tr>
<td>Total operation cost</td>
<td>150,297</td>
</tr>
<tr>
<td>Operation cost per area</td>
<td>3,005</td>
</tr>
<tr>
<td>Operation cost per hour</td>
<td>5,232</td>
</tr>
</tbody>
</table>

4.2.8 Comparison between operation cost in different areas

The cost of every operation decreased as the area cultivated increased as shown in Table 4.11. According to the availability of machines proper selection for the operation to be done can be decided easily and the area to be cultivated accordingly can be chosen and the type of crop to be grown can be decided correctly.
As observed from Table 4.11 the least width of the machine caused high percent increase in the cost per area.

**Table 4.11 Comparison between cost of operations in different areas.**

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cost (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ridger</td>
</tr>
<tr>
<td>50</td>
<td>3,005</td>
</tr>
<tr>
<td>30000</td>
<td>1,244</td>
</tr>
<tr>
<td>Increase %</td>
<td>58.5</td>
</tr>
</tbody>
</table>
4.2.9 Comparison between crops cost on equal area

As shown in Table 4.12 different crops in the same area show different costs according to the number of operations done for each crop.

Although, the highest cost is for cotton crop, but can be chosen in the crop rotation for other parameters (expected yield per area and the price of the crop yield).

Table 4.12 Comparison between crops cost on the equal area.

<table>
<thead>
<tr>
<th>Area/ha</th>
<th>Cotton (SD)/ha</th>
<th>Wheat (SD)/ha</th>
<th>Sorghum (SD)/ha</th>
<th>G/N (SD)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>5,332</td>
<td>3,441</td>
<td>3,441</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>5,294</td>
<td>3,416</td>
<td>3,416</td>
</tr>
<tr>
<td>50,000</td>
<td>9,753</td>
<td>5,283</td>
<td>3,407</td>
<td>3,407</td>
</tr>
</tbody>
</table>
### 4.2.10 Comparison between crop patterns within rotation

All predicted cost in (SD) per hectare.

**Group I**

Crop rotation = two crops = scenario No I

Crop pattern as follows:

#### Scenario No. 1

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cotton</th>
<th>Wheat</th>
<th>Total cost/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>5,332</td>
<td>15,484</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>5,294</td>
<td>15,067</td>
</tr>
<tr>
<td>60,000</td>
<td>9,753</td>
<td>5,283</td>
<td>15,036</td>
</tr>
</tbody>
</table>

#### Scenario No. 2

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cotton</th>
<th>Sorghum</th>
<th>Total cost/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>3,441</td>
<td>13,593</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>3,416</td>
<td>13,189</td>
</tr>
<tr>
<td>60,000</td>
<td>9,753</td>
<td>3,407</td>
<td>13,160</td>
</tr>
</tbody>
</table>

#### Scenario No. 3

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>Total cost/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>5,332</td>
<td>3,441</td>
<td>8,773</td>
</tr>
<tr>
<td>40,000</td>
<td>5,294</td>
<td>3,416</td>
<td>8,710</td>
</tr>
<tr>
<td>60,000</td>
<td>5,283</td>
<td>3,407</td>
<td>8,690</td>
</tr>
</tbody>
</table>
### Scenario No. 4

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Sorghum</th>
<th>G/N</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>3,441</td>
<td>3,441</td>
<td>6,882</td>
</tr>
<tr>
<td>40,000</td>
<td>3,416</td>
<td>3,416</td>
<td>6,832</td>
</tr>
<tr>
<td>60,000</td>
<td>3,407</td>
<td>3,407</td>
<td>6,814</td>
</tr>
</tbody>
</table>

### Group II

Crop rotation = three crops

Crop pattern as follows:

### Scenario No. 5

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cotton</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>Total/ha cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>5,332</td>
<td>3,441</td>
<td>18,925</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>5,294</td>
<td>3,416</td>
<td>18,483</td>
</tr>
<tr>
<td>60,000</td>
<td>9,753</td>
<td>5,283</td>
<td>3,407</td>
<td>18,443</td>
</tr>
</tbody>
</table>

### Scenario No. 6

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cotton</th>
<th>Wheat</th>
<th>G/N</th>
<th>Total/ha cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>5,332</td>
<td>3,441</td>
<td>18,925</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>5,294</td>
<td>3,416</td>
<td>18,483</td>
</tr>
<tr>
<td>60,000</td>
<td>9,753</td>
<td>5,283</td>
<td>3,407</td>
<td>18,443</td>
</tr>
</tbody>
</table>
### Scenario No. 7

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Cotton</th>
<th>Sorghum</th>
<th>G/N</th>
<th>Total/ha cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>3,441</td>
<td>3,441</td>
<td>17,036</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>3,416</td>
<td>3,416</td>
<td>16,605</td>
</tr>
<tr>
<td>60,000</td>
<td>9,753</td>
<td>3,407</td>
<td>3,407</td>
<td>16,567</td>
</tr>
</tbody>
</table>

### Scenario No. 8

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>G/N</th>
<th>Total/ha cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>5,332</td>
<td>3,441</td>
<td>3,441</td>
<td>12,214</td>
</tr>
<tr>
<td>40,000</td>
<td>5,294</td>
<td>3,416</td>
<td>3,416</td>
<td>12,126</td>
</tr>
<tr>
<td>60,000</td>
<td>5,283</td>
<td>3,407</td>
<td>3,407</td>
<td>12,097</td>
</tr>
</tbody>
</table>

### Group III

Crop rotation = four crops

Crop pattern as follows:

### Scenario No. 9

<table>
<thead>
<tr>
<th>Area</th>
<th>Cotton</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>G/N</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>10,152</td>
<td>5,332</td>
<td>3,441</td>
<td>3,441</td>
<td>22,366</td>
</tr>
<tr>
<td>40,000</td>
<td>9,773</td>
<td>5,294</td>
<td>3,416</td>
<td>3,416</td>
<td>21,899</td>
</tr>
<tr>
<td>50,000</td>
<td>9,753</td>
<td>5,283</td>
<td>3,407</td>
<td>3,407</td>
<td>21,850</td>
</tr>
</tbody>
</table>
The results obtained from the different groups of two rotations, three rotations and four rotations for the different crop patterns for the 9th scenarios were as follows:

1- The cost of the cultivated crops within a crop rotation decreased as the area cultivated by the same crops in the rotation increased.

2- Changing the crop pattern within the rotation affects the cost according to the crop cost and the decision-making will depend on the yield per area and the crop price.

4.2.11 Comparison between rotations

As the crop rotation increases i.e more crops to be cultivated, the total cost increased by 19% as shown in Table 4.13. Therefore, as the total cost of the crop decreases according to the increase in the cultivated area, decision can be made in order to cultivate the more profitable crop in the largest area.

<table>
<thead>
<tr>
<th>Area</th>
<th>Group II 3 crops</th>
<th>Group III 4 crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cotton + wheat + sorghum</td>
<td>cotton + wheat + sorghum + GN</td>
</tr>
<tr>
<td>30,000</td>
<td>18,925</td>
<td>22,366</td>
</tr>
<tr>
<td>40,000</td>
<td>18,483</td>
<td>21,899</td>
</tr>
<tr>
<td>60,000</td>
<td>18,443</td>
<td>21,850</td>
</tr>
</tbody>
</table>

Table 4.13 Comparison between crop rotation.
4.3 Model application

Following Dent et al. (1979) recommendations model application need to be viewed in terms of model involvement in research process and for decision-making.

It is clear that generally and through the computer model variables may be changed (i.e. machine width, speed, field efficiency, area and machine age) and their effect on the cost of using farm machinery may be detected without going to the field and making the experiment, therefore, a lot of research studies related to machinery management may be carried out in order to sufficient database.

On the other hand, as shown in the ninth scenarios for the case of Gezira Scheme and the results, if each scenario to be tested in real life, large amount of resources (money and time) and risk (infrastructure and people) will be required.

Depending on decision-maker objectives various conclusions can be drawn from each scenario. To illustrate the utility of the scenarios as a research tool the ninth scenario was made into three groups.

As given before (section 4.2.10) the groups were analyzed with objective to look into options to improve pre-season planning by matching crops to be cultivated and area according to the cost.

The model can be used as a decision-making tool for the case of Gezira Scheme. As the model can predict the cost for a tractor as a source of power and the cost of an operation and of crops. So, the decision-making for selection of the number of crops within the
rotation and the crop pattern according to the cost will depend on three parameters:

1- The expected yield of the crop per area.
2- The price of the yield.
3- The availability of other resources for crop production.

According to the model prediction for crop cost its possible to carry out benefit analysis for the season planing through the selection of the number of crops within the rotation and the crop pattern can be taken according to the cost and the other parameters in the Gezira Scheme.
CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall view of this study can be summarized as follows:

1- The machinery cost analysis model can predict the total annual cost and the cost per hour for a tractor as a source of power.

2- Also, the crop production machinery system model (CPMSM) can predict the total annual cost of each machine in an operation.

3- The model is able to compute the total cost of an operation using tractor as a source of power and a number of machines up to ten machines and for up to 7 crops.

4- The CPMSM enable the user to predict the hours of use for any type of machine used in the operation. Also, can calculate the interest cost, the annual total depreciation cost at any age of machine up to 20 years.

5- The model can quickly be used to investigate the effect of changing the machine width, machine age, field efficiency and area on the annual total cost of the operation and therefore, can help in quick decision-making.

6- One of the advantages of the CPMSM is the possibility of choosing the number of crops in the rotation and the crop pattern within the rotation according to the cost estimated.
5.2 Recommendations

1- As the CPMSM can be employed as a pre-seasonal planning tool to predict the area to be cultivated and the type of crop to be cultivated according to the yield of the crop per area and the price of yielded crop and the availability of the resources in Gezira Scheme.

2- The crop production machinery system model can be used as a tool for research and as a tool for decision-making for machinery selection and management in the Gezira Scheme and other irrigated schemes.
REFERENCES


simulation. Trans. of ASAE, 30(5): 1259-1265, St Joseph, M.I., USA.


