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Testing and evaluation of agricultural machinery and equipment

Principles and practices

FAO AGRICULTURAL SERVICES BULLETIN

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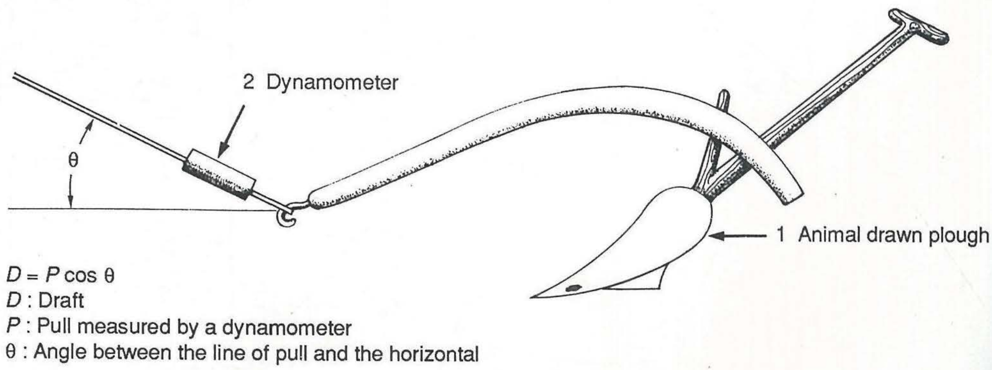

MEASURING PULL AND CALCULATION OF DRAFT

Food and Agriculture Organization of the United Nations

Testing and evaluation of agricultural machinery and equipment

Principles and practices

by
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FOREWORD

Formal testing of agricultural machinery was instigated during the industrial revolution at the turn of the century, but it was only with the wide adoption of engine powered equipment that testing began to make a serious and valuable contribution to manufacturers and users of agricultural machinery. Testing, in which the engineering parameters of a machine are determined, has, without doubt, received the greatest attention. The evaluation of machines, in which their characteristics of handling and performance, their economic impact, as well as their engineering parameters, are determined, came at a much later stage in development, despite the greater potential benefits provided to the user and manufacturer by these activities. There is no universal terminology which can be used to distinguish the activities of testing and evaluation.

Because of misconceptions associated with testing and evaluation of agricultural machinery, FAO decided that its Panel of Experts on Agricultural Engineering should discuss the topic at its Eleventh Session in October 1992. One of the Panel recommendations was the preparation of two AGS Bulletins: one directed towards testing and evaluation stations, universities and students in developing countries, and one directed towards governments, policy makers, entrepreneurs and managers of testing and evaluation centres. This Bulletin is the former of the two.

This Bulletin has been produced by the Overseas Division of the Silsoe Research Institute, U.K. working under an FAO contract.

Adrianus G. Rijk
Chief
FAO Agricultural Engineering Service

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This Manual is the fruit of an enterprise that was initiated in 1990 with the preparation and delivery of a practical course on farm machinery evaluation for scientists of the Mexican National Forestry and Agriculture Research Institute (INIFAP). Since 1990 the material has been developed further during similar practical workshops in Cuba, Honduras and Chile. Financial help from the UK Government's Overseas Development Administration and the British Council enabled these workshops to take place and is gratefully acknowledged.

A penultimate version of the Test Procedures presented in the second part of the Manual was prepared for the Eleventh FAO Panel of Experts on Agricultural Engineering which met in Rome in October 1992. At that meeting it was recommended that the Procedures be edited and supplemented and that practical guidelines should be included. This recommendation was adopted by FAO and resulted in the present document.

Many colleagues have reviewed drafts and have made valuable comments which have enhanced our understanding of the project. Among these we would like to single out for special thanks:

Frank Inns; Ulrich Viebig; Derek Sutton; Jim Ellis-Jones; Steve Twomlow; Graeme Rainbird; Adrianus Rijk; Terry Lester.

We owe a special debt to Sue Robinson who battled with manuscripts and typed many drafts of the final text. We also recognise the cheerful and constructive efforts of Rosemary Briars; Maria Knaggs; Bob Wardell and Roger Cover of Silsoe Research Institute Graphics Department who produced the illustrations.

Despite the contributions from all those who have collaborated the views contained in the Manual are those of the authors; likewise we are responsible for all omissions and errors.

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CONTENTS

SECTION A PRINCIPLES AND PRACTICES 1

1 INTRODUCTION 1

2 MEASUREMENTS 5

2.1 Basic Measurements 5

2.1.1 Time 5
2.1.2 Mass 6
2.1.3 Dimensions 6
2.1.4 Revolutions 8
2.1.5 Temperature 9
2.1.6 Electrical 9

2.2 Derived Measurements 9

2.2.1 Area 9
2.2.2 Volume 10
2.2.3 Force 11
2.2.4 Pressure 14
2.2.5 Speed 14
2.2.6 Torque 15
2.2.7 Work and Power 16
2.2.8 Rate of Work 17
2.2.9 Rate of Flow 19
2.2.10 Fuel Consumption 23
2.2.11 Rate of application 23
2.2.12 Output 24

3 CALIBRATION OF TEST EQUIPMENT 25

4 APPLICATION OF MEASUREMENT TECHNIQUES TO TESTING PROCEDURES . . . 28

4.1 Selection of material for tests 28
4.2 Soil conditions 28

4.2.1 Soil texture 28
4.2.1.1 Field estimation 28
4.2.2 Bulk Density 30
4.2.2.1 Field estimation of bulk density 30
4.2.2.2 Sampling strategy for bulk density measurements 31
4.2.2.3 Dry bulk density and porosity 32
4.2.3 Moisture Content 32
4.2.3.1 Measurement method 32
4.2.3.2 Estimation by feel method 33
4.2.4 Mean Clod Diameter 33
4.2.5 Soil Strength 35
4.2.5.1 Cone Index 35
4.2.5.2 Shear Strength 36

4.3 **Measurement of power** ... 37

4.3.1 Rotary power ... 37
4.3.1.1 Engine ... 37
4.3.1.2 Power take-off ... 38
4.3.1.3 Machines ... 39
4.3.1.4 Electric Motors ... 39
4.3.2 Linear ... 39
4.3.2.1 Animal ... 39
4.3.2.2 Tractor ... 40
4.3.2.3 Machine ... 42
4.3.3 Hydraulic ... 42
4.3.3.1 Oil ... 42
4.3.3.2 Water ... 43

4.4 **Performance of hand tools** ... 43

4.4.1 Performance tests ... 43
4.4.2 Ergonomic assessments ... 44

4.5 **Animal performance** ... 44
4.6 **Machine performance** ... 47

4.6.1 Cultivators (primary and secondary) ... 47
4.6.1.1 General ... 47
4.6.1.2 Draft measurement ... 47
4.6.1.3 Machine capacity and field efficiency ... 48
4.6.1.4 Soil Inversion ... 48
4.6.1.5 Surface evenness ... 50
4.6.2 Seeders and planters ... 50
4.6.2.1 General ... 50
4.6.2.2 Laboratory tests ... 50
4.6.2.3 Field tests ... 50
4.6.3 Fertiliser distributors ... 52
4.6.4 Knapsack Sprayers ... 54
4.6.5 Field Sprayers ... 58
4.6.6 Manual pumps ... 59
4.6.7 Power operated pumps ... 61
4.6.8 Grain Threshers and Shellers ... 61
4.6.9 Combine harvesters ... 62
4.6.10 Animal carts ... 66

5 ERGONOMICS APPRAISAL OF AGRICULTURAL EQUIPMENT ... 67

5.1 **Introduction** ... 67
5.2 **Human characteristics** ... 67

5.2.1 Body size ... 67
5.2.2 Body strength ... 69

5.3 **Energy demands** ... 71

5.3.1 Static workload ... 72
5.3.2 Dynamic workload ... 74

5.4 Environmental factors 76

5.4.1 Thermal stress 76
5.4.2 Air quality 77
5.4.3 Noise 77
5.4.4 Vibration 77

5.5 Safety and comfort 77

6 ECONOMICS 80

6.1 Calculation of costs and benefits 80
6.2 Partial Budgets 83
6.3 Net Present Values and Future Cash Flows 85
6.4 Variability, risk and sensitivity analysis 87
6.5 Equilibrium point partial budget 87

SECTION B: TEST PROCEDURES 95

7 POWER MEASUREMENT 96

8 PROCEDURE FOR EVALUATING DRAFT ANIMAL PERFORMANCE 110

9 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR PRIMARY CULTIVATION 121

10 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR SECONDARY CULTIVATION 131

11 PROCEDURE FOR EVALUATION OF HAND HOES 142

12 PROCEDURE FOR EVALUATION OF SEEDERS AND PLANTERS 148

13 PROCEDURE FOR EVALUATION OF FERTILISER DISTRIBUTORS 170

14 PROCEDURE FOR EVALUATION OF KNAPSACK SPRAYERS 181

15 PROCEDURE FOR EVALUATION OF FIELD SPRAYERS 192

16 PROCEDURE FOR EVALUATION OF MANUALLY-OPERATED PUMPS 200

17 PROCEDURE FOR EVALUATION OF POWER OPERATED PUMPS 207

18 PROCEDURE FOR EVALUATION OF GRAIN THRESHERS 216

19 PROCEDURE FOR EVALUATION OF MAIZE SHELLERS 225

20 PROCEDURE FOR EVALUATION OF COMBINE HARVESTERS 235

21 PROCEDURE FOR EVALUATION OF ANIMAL CARTS 255

22 REFERENCES 264

ANNEX 1 INSTRUMENTATION AND EQUIPMENT 269

ANNEX 2 CONVERSION FACTORS TO SI UNITS 272

SECTION A: PRINCIPLES AND PRACTICES

1 INTRODUCTION

Farm mechanisation is one component of agricultural engineering which can be described as the application of all aspects of engineering technology to rural and agricultural development. In many industrialised countries the fruits of research in agricultural sciences have made it possible for agricultural production to exceed national food requirements, and complementary advances in agricultural engineering (especially farm mechanisation) have helped to make the application of these fruits a technical reality.

The situation in too many developing countries is quite the reverse. Millions of impoverished farmers labour at near subsistence level and do not have access to the technical improvements which would allow them to improve land and labour productivity and raise net farm incomes.

In the last few decades considerable effort has been expended by many research groups both national and international on the design and development of "improved" equipment for small and medium sized farms. Unfortunately farmer adoption, and therefore the impact on standards of living, has been well below the level hoped for. The numerous "improved" ploughs; tool carriers; equipment powered by pedals, steam, biogas, wind, solar energy or animals; driers; shellers and threshers; pumps and much more as well as "tractorisation" projects, either with conventional tractors or specially designed small farm models, have failed, in many cases in spite of an impeccable programme of technical development of the technology.

A farm mechanisation innovation will only be accepted by farmers if it provides a solution that the farmer is actively seeking, to a problem keenly felt by the farm family. This means that it must be compatible with the farming system and the needs of the farm family taking technical, social and economic factors into account.

Whilst recognising this complex of factors, the aim of this manual is to focus on procedures which have been developed for testing and evaluating farm machinery, and on the criteria for testing small farmer oriented technology.

Improvement in the quality of equipment evaluation procedures in national or regional testing programmes will be of benefit to various groups. These may include the following:

- local agricultural implement manufacturers.
- extensionists in rural development projects.
- decision makers in rural credit banks that extend credit lines to small scale producers.
- programmers and decision makers in the agricultural and industrial sectors.

In addition the fundamental ingredient of discipline in scientific evaluation develops an aptitude for observation and precise measurement, important aspects in training agricultural engineers.

TESTING AND EVALUATION

The term "testing" is usually used in connection with an analysis of the behaviour of a machine compared with well defined standards under ideal and repeatable conditions (Johnson, 1985).

In contrast "evaluation" involves measurement of machine performance under real farm conditions. For example: the behaviour of a plough in soils with different textures and moisture contents and a range of vegetative covers (e.g. weeds, stubble, grass).

Testing

Test procedures and standards for agricultural tractors have been established in several industrialised countries for many years. The eventual coincidence of North American (ASAE, 1980) and European (OECD, 1970) test procedures and the universal adoption of the International Standards Organisation code (ISO, 1983) will mean international standardisation and will avoid the need to perform a tractor test in more than one country.

Official tractor tests are designed to provide reliable and repeatable information, they do not include tests under agricultural conditions as these would be impossible to reproduce precisely. In consequence the official tests only cover measurement of parameters which are not affected by ground conditions, for example:-

- complete tractor specifications
- engine power and fuel consumption
- power and capacity of the hydraulic system
- turning area and turning circle
- smoke emission
- centre of gravity
- noise levels
- drawbar power
- brake performance
- resistance of protective structures (safety cabs).

In order to enable test results from different test sites to be compared, drawbar power is measured on a special concrete track. The drawbar pulls achieved are, therefore, greatly in excess of those that could be expected under normal field conditions.

In addition to tractor performance test procedures, several countries have defined standards for a wide range of technical aspects of specifications (materials, dimensions and geometry) for tractors and agricultural implements (e.g. Society of Automotive Engineers in the USA and British Standards in the UK). Adherence to these standards (e.g. drawbar height and three point linkage geometry) allows compatibility of common parts and attachments. Again the move is towards world wide homogeneity with the publication of ISO standards for tractor and many agricultural machinery component specifications (ISO, 1983).

Evaluation

The purpose of obtaining information by testing is to compare a device or machine with the requirement which it was developed to fulfil (Crossley and Kilgour, 1983). In the interests of comparability this aim may be lost and tests may not be as valuable to users as other methods of assessment. As has been discussed, tests performed under ideal conditions may be irrelevant to agricultural situations (e.g. drawbar pull of a tractor on a concrete track).

Although tractor testing has the potential of being uniform internationally, the differing working environments and levels of sophistication of agricultural implements mean that standard test procedures are difficult to produce at an international level. With few exceptions (e.g. fertiliser distributors; potato planters; grape harvesters - ISO, 1983) little has been achieved.

National organisations (notably the British National Institute of Agricultural Engineering - NIAE - before 1969, and the Canadian Prairie Agricultural Machinery Institute - PAMI, amongst many others) have produced test codes adapted to their local conditions. The relatively sophisticated procedures of the industrialised countries usually require expensive equipment and instrumentation and are often inappropriate for developing country test centres.

As a response, many developing countries and regions have developed their own agricultural machinery test codes. Notable examples are: India, East Africa (Commonwealth Secretariat, 1981 & 1982) and Asia (RNAM, 1983), which require less sophisticated test equipment.

In practice all assessment procedures for agricultural equipment include a section done under controlled and repeatable conditions (tests); and a section of field evaluations. For the remainder of this paper the term "test procedure" is taken to include both types of assessment.

Categories of Tests

The type of test procedure selected as appropriate will be influenced by:-

- the stage of development of the equipment to be tested
- the potential beneficiaries of the test report

a) The Stage of Development

Whether the test is required at the design, prototype development or manufacturing stage will affect the type of procedure that should be applied.

At the design stage, even before engineering drawings have been made, it is very important to justify the proposed innovation. The procedure involves the identification and quantification of the need for the innovation in technical, social and economic terms. Any negative effects (e.g. on the labour demand or the need for new inputs or processes) must be included in the analysis.

The stage of prototype development will include practical tests of the prototypes and their components, mechanisms and processes, under laboratory and field conditions. The aim is to verify whether the prototype functions as expected, effectively, economically and safely. Almost always this process results in modifications which must, in turn, be tested.

Testing and evaluation at the manufacturing stage are aimed at measuring the quality of the product, its durability and efficiency. They also permit comparisons between different models or makes of the machine. At this stage user experience surveys can be included which will yield additional information on reliability, durability and the most common causes of breakdown. This information is generally very valuable for extension purposes.

Frequently in industrially developing countries, the quality of fabrication is not always uniform between manufacturers. Series tests, in which several makes of a machine type are tested under similar conditions, enable the most appropriate machine to be selected from the alternatives available. Matthews (1969) describes the advantages of series tests in India where they served as the first step in improving the "breed" of a machine type. Research areas were identified more easily and it was possible to draw to the attention of manufacturers those aspects of mediocre equipment which could be improved.

b) The Potential Beneficiaries

An appropriate test procedure can only be selected if the use of the information to be produced is well defined. There is a range of possibilities:-

Test reports can help potential users of a machine to compare the performance of alternatives and select the model most suited to their needs (Stevens, 1982). Nevertheless, as Johnson (1985) points out, in most countries where this type of information is available, it generates very little interest. The most important factor for a potential user is the reputation of the manufacturer or distributor.

Information from tests can be used to control imports of tractors and implements with a view to assuring quality and service for the user. One of the first examples was the Nebraska tractor tests (Barger et al., 1963). Since 1920 it has been a state legal requirement for all tractors for sale in Nebraska to have been officially tested and that replacement parts are available.

The fundamental goal of OECD tests has been to provide reliable information for governments and users in all the member countries to reduce barriers to international trade (Manby and Matthews, 1973). The same authors mention a series of secondary aims and underline the importance of presenting the information in an educational form to enable extensionists and students to understand the importance of aspects of design of tractors and implements.

One of the motives frequently put forward by developing country governments to justify a national testing programme is to protect the economy against a mis-use of foreign exchange. It is maintained that, by means of a test programme, only machinery appropriate to the country's conditions is made available to farmers. This strategy has often proved to be impractical as machinery manufacturers change specifications in the normal course of product development and so it may not be possible to supply machinery to the specification "as tested" (Johnson, 1985). However, evaluation to assess a machine's suitability to local conditions is potentially beneficial both to the user and to the national economy if modifications can be incorporated before widespread dissemination.

Increasingly important are tests for safety and environmental impact. Certain features of a machine which affect the user's comfort and health, or that may contribute to environmental degradation, can be measured objectively (Matthews, 1977). Examples are:- Protective cab tests; operator vibration; noise; smoke and toxic fumes (ISO, 1983).

Confidential and impartial testing can be of benefit to manufacturers for product development. A test centre may have the capital equipment and the expertise to carry out tests more cheaply than individual manufacturers.

SCOPE OF THE MANUAL

The aim of this manual is to give a guide to the aspects of a machine's performance that can be evaluated and the procedures given in Section B give this information for a range of equipment.

The aim is not to offer inflexible test procedures, quite the opposite. Whilst the procedures include many of the characteristics which could be tested, it is emphasised that the user of the test information must only select for test those aspects of the procedure which are of particular interest and which will yield usable information.

In many situations, access to a full range of testing facilities is a rarity and test personnel may not always have the depth of experience required to interpret fully the procedures given. Therefore the manual also gives guidelines (in Section A) on how to apply them in practice.

In some cases (for example: engine speed and torque; sound pressure level; implement draft force)) some instrumentation is necessary and in these cases the correct application of available equipment is described together with sources of supply. In other cases where the principles are clearly understood it will be possible to design adequate equipment with frequently available resources without prejudicing the quality of the information gathered. Examples could be: "Patternators" for sprayer distribution assessment; engine fuel consumption measurement; soil properties assessment.

Two topics not dealt with in detail in Section B are ergonomic and economic evaluation of farm equipment. The themes are developed in Section A to the extent that a general coverage of the principles involved is given for the respective appraisals. It will be appreciated that each of the topics could merit a complete manual, the aim here is to emphasise the need for a complete appraisal of farm equipment from the technical, ergonomic and economic viewpoint and not to foster the notion that a machine need only be technically efficient and effective to be acceptable to potential adopters.

POTENTIAL USERS

The potential users of this manual are expected to be those involved in the evaluation of machinery primarily directed towards users on smaller farms. Evaluation of farm equipment may be appropriate at any stage in its development process, from first prototype to batch and series produced. Consequently the users of the manual will be machinery designers and developers; test engineers producing technical information for comparative decision making purposes; university level technical training staff and students.

2 MEASUREMENTS

An essential part of any procedure for the mechanical evaluation of an item of farm equipment is the measurement of parameters which will determine the performance characteristics. The level of accuracy of the measurements will depend on the particular procedure used and the sophistication of the measuring equipment available. For example, it is generally true that the smaller the measurement to be made, the greater accuracy required of the measuring equipment (e.g. the length of a seed compared with the length of a field plot).

To compare results of tests on similar models and types of machine, it is useful to have the data presented in consistent units. The use of Système International (SI) units has now been universally accepted and has been used throughout the test procedures in Section B. However, other units are often used and where this is the case, they have been incorporated into the test procedures. Annex 3 gives tables of conversion factors for SI units.

In many cases, the desired parameters are expressed in basic units, however, frequently other units are derived from these. The following paragraphs give details of the basic units used and those which are derived.

The more useful multiples and sub-multiples of the units of measurement are formed by the following prefixes.

Factors by which the unit is multiplied	Prefix	Symbol
1000 000	mega	M
1 000	kilo	k
100	hecto	h
10	deca	da
0.1	deci	d
0.01	centi	c
0.001	milli	m

2.1 Basic measurements

2.1.1 Time

Short periods of time are measured in seconds (s) and are generally used with other functions such as revolutions, distance, volume and pulses. Calibrated mechanical stop-watches have the required accuracy for this function, however electronic quartz based timers are generally inexpensive, very accurate over long periods and can be incorporated into other multi-functional measuring instruments.

For longer periods of time such as when carrying out field tests, durability trials and trials on farmers fields, the times are measured in hours (h). If the tests are not under constant supervision, some type of hour recorder should be used. Electronic versions are available for fitting to power units and tractors, usually running from the battery charging circuits.

For general use a recorder which operates from vibration is perhaps the most useful. In addition to an hour counter, a chart mechanism can be added to such a unit, giving precise information of times of machine operation over long periods (Fig 2.1).

Figure 2.1 Vibration type time recorder attached to a manually operated sprayer

2.1.2 Mass

The basic unit of mass measurement is the gram (g) which is generally used for test samples of grain, seeds, soils and fertiliser, etcetera. The weighing of such samples usually takes place in the laboratory where very accurate balances are held (Fig 2.2). Spring type balances may be used for field work if lower levels of accuracy can be tolerated. Where greater quantities of material or machines require to be weighed, the multiple unit of the gram, the kilogram (kg) is used which is the SI unit. For weights of materials such as bulk quantities of seed, fertiliser or grain, spring type balances, electronic strain gauged tension links or portable platform weighing machines may be used. Larger fixed weighing platforms will be required for tractors and field machinery. Portable electronic strain gauged wheel or axle weighers are available and are useful when testing machines or trailers in the field.

2.1.3 Dimensions

The metre (m) or its multiples are the basic units used for dimensional measurements. Rules and callipers graduated in millimetres (mm) and centimetres (cm) are used for accurate measurement of machine details, ranges of adjustment and materials (Fig 2.3). Field measurements of working width and depth of soil engaging implements can be carried out accurately by using a specially made graduated rule (Fig 2.4), travel distances are marked by pegs and measured by suitable measuring tapes. The setting up of markers for travelling speed measurement and for defining working plot areas is also usually carried out using measuring tapes. Sufficient accuracy may be obtained in the field by the use of a pace marker.

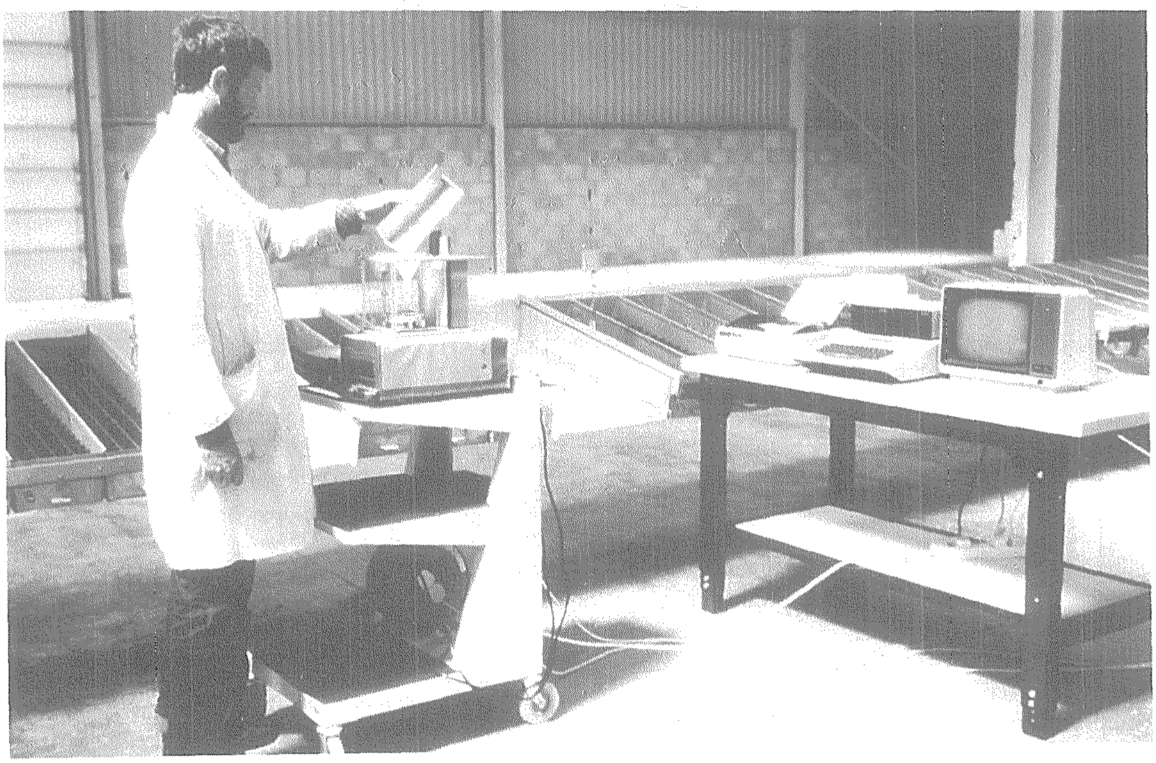


Figure 2.2 Laboratory balance for accurate weighing of samples

Figure 2.3 Use of calipers to measure seed dimensions

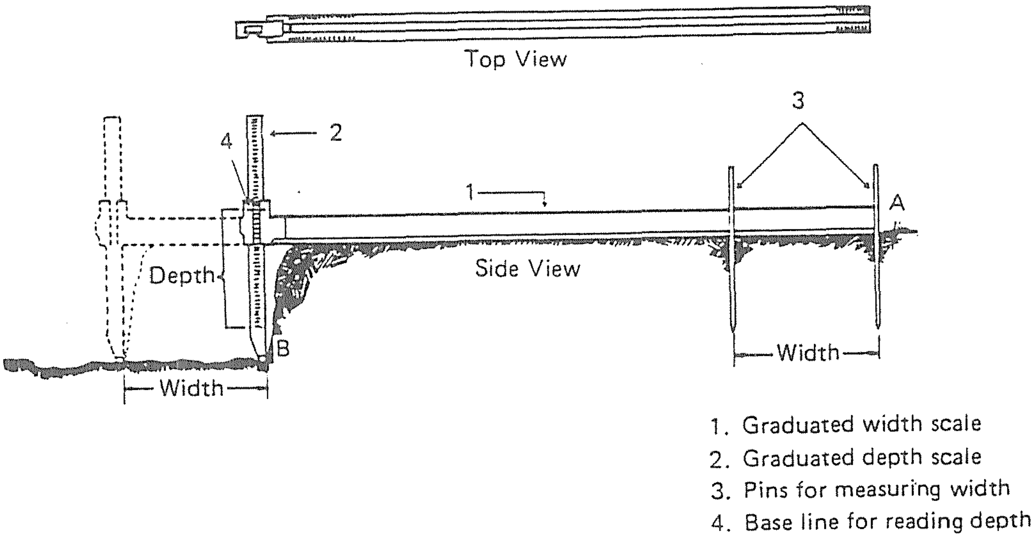


Figure 2.4 Graduated rule for measurement of furrow width and depth
Source: RNAM, 1983

The marker (Fig 2.5) made of wood or light tube, is one metre between the tips and is swung around while walking allowing metre distances to be marked off quickly.

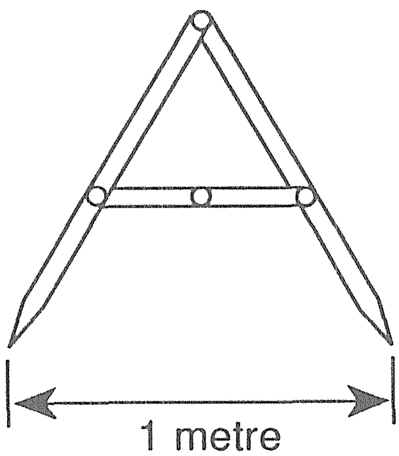


Figure 2.5 Pace marker for measuring plot size
Source: Crossley and Kilgour, 1983

2.1.4 Revolutions

The measurement of the number of revolutions is simply a counting procedure. The number of revolutions of land engaging wheels on tractors and machines on test rigs and in the field and pedals and handles of machines such as small threshers, grinders and water pumps, can be counted by eye. For shafts turning at higher speeds, some form of counting apparatus is required. Where the end of the shaft is accessible, a mechanical, electrical or electronic counter may be used driven directly from the end of the shaft. However, if the shaft is connected at each end, an electronic counter can be used which incorporates a light emitter and a sensor working from a reflective strip attached to the rotating part. Some shaft torque measuring devices have integral revolution counters to enable direct power readings to be obtained.

2.1.5 Temperature

The measurement of temperatures may also require equipment to cover a wide range from ambient air values to those of the exhaust gasses from internal combustion engines. The SI unit of temperature is the Kelvin (K), degree Celsius (°C) is also recognised for use in conjunction with the SI and has the same datum and value as the Kelvin. Measuring equipment is usually graduated in degrees Celsius.

Mercury-in-glass thermometers may be adequate for some ambient and fuel measurement, however, the thermocouple type of measuring device has a large temperature range and is commercially available and widely used. The electrical device can be built into a hand-held unit (Fig 2.6) or coupled to additional monitoring or recording equipment.

Figure 2.6 Hand held electrical thermometer

2.1.6 Electrical

During tests of machines incorporating electrical equipment, it is often necessary to measure the units of electric potential (volt), current (ampere) and resistance (ohm).

Standard commercial instruments are available with meters adequately covering ranges and units suitable for direct current (DC) and alternating current (AC) supplies. It is recommended that measurements on electrical equipment should only be made by experienced personnel.

2.2 Derived Measurements

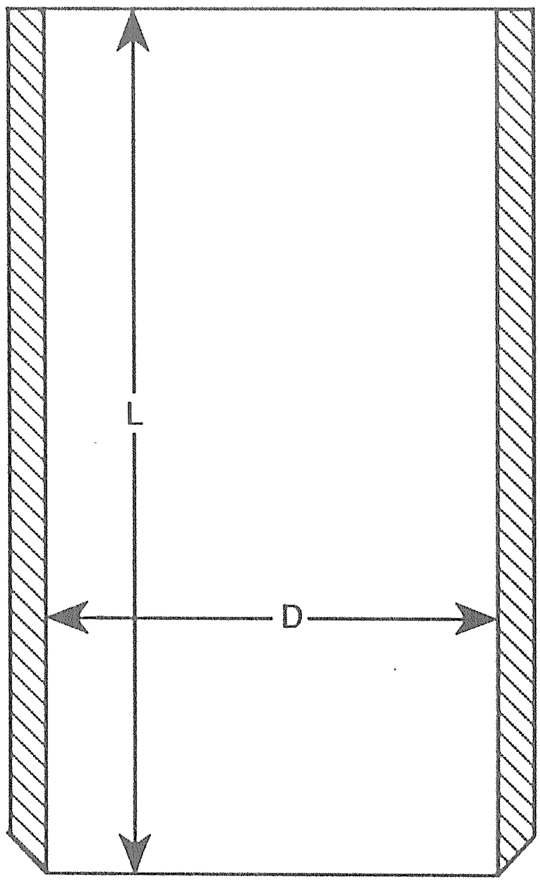
2.2.1 Area

The square metre (m^2) is the recommended unit of area and is used for calculation of plot size. Measurement is by calibrated tapes or pace markers as in Section 2.1.3. Larger field areas are usually quoted in hectares (ha) equal to 10 000 square metres. Smaller multiples such as the square centimetre (cm^2) are used for plot sampling areas such as straw collection for combine tests or weed areas for cultivation work. Sizes of small components such as pump pistons are expressed in square millimetres (mm^2).

2.2.2 Volume

The standard unit of volume is the cubic metre (m^3) with smaller multiples of cubic centimetre (cm^3) and cubic millimetre (mm^3). However, the litre (l) with a value of 1000 cm^3, is still in common use for specifying the volume of liquids and granular material (eg hopper capacity).

Cylinders of known volume required for the field sampling of soils can be manufactured from steel tubes of various sizes (Fig 2.7). When checking specifications, the volume of tanks and containers on machines such as sprayers, seeders and spreaders can be calculated from internal dimensions or by filling with measured quantities. During performance tests, the total output or the distribution of sprayer nozzles is measured using proprietary made calibrated cylinders, either singly (Fig 2.8) or in a row as in the distribution measuring "Patternator" described in Section 4.6.4. Larger volumes can be measured using previously calibrated buckets or tanks.



$$\text{Volume of cylinder} = \frac{\pi \times D^2}{4} \times L$$

Figure 2.7 Construction of steel cylinder for soil density determination

The measurement of fuel consumed by power units and tractors over periods of field work can be obtained by measuring the volume of fuel required to top up the tank after each work period. The use of more sophisticated fuel measuring devices is discussed under Section 2.2.9 (Rate of flow).

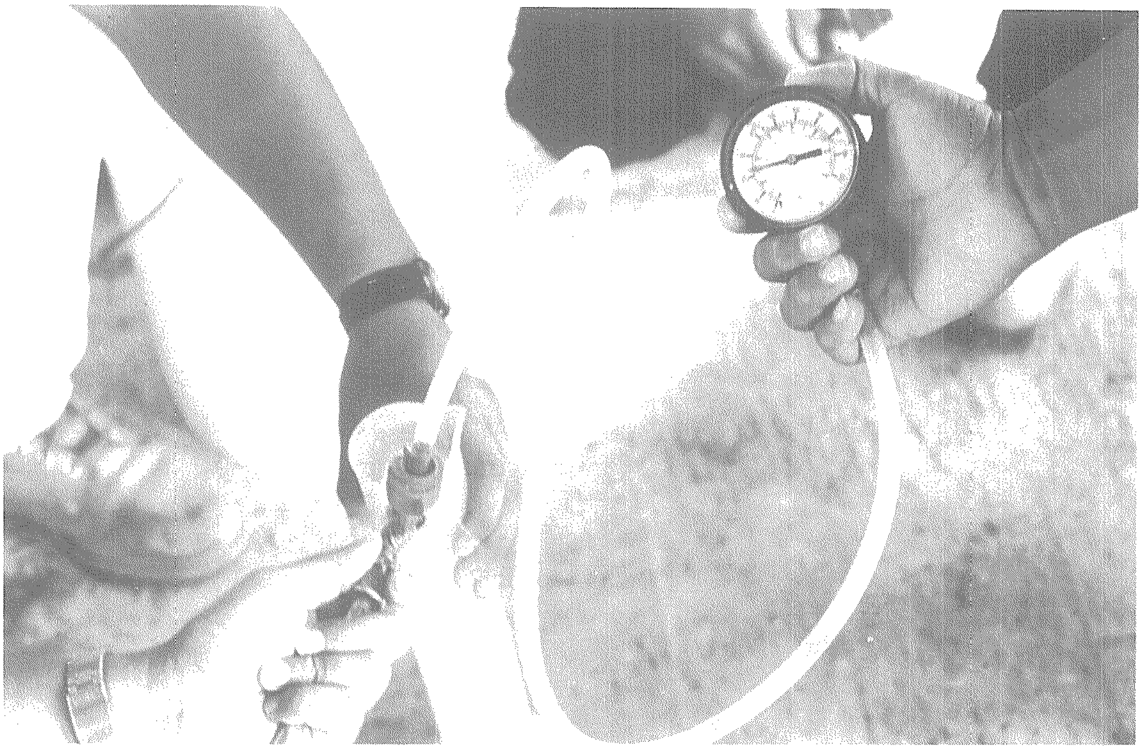


Figure 2.8 Sprayer nozzle output measured with graduated cylinder

2.2.3 Force

The newton (N) is the SI unit of force which is defined as the force which, when applied to a body of one kilogram mass, gives it an acceleration of one metre per second squared (kgm/s^2). The kilogram force (kgf) is the force that when applied to a body of mass of one kilogram gives it the standard acceleration due to gravity ($9.8067\ m/s^2$). Therefore $1\ kgf = 9.8067\ kg\ m/s^2 = 9.8067\ N$. It can be seen, therefore, that it is possible to calculate forces from results obtained by using the same equipment as that used for measuring mass (Section 2.1.2).

Spring type balances may be used for measurement of force on hand tools and light implements drawn manually or by animals. However, under field conditions because of lack of damping, they may be difficult to read with accuracy.

Draft forces of tractors and machines may be considerably greater than the capacity of these weighing units and Figure 2.9 shows an arrangement using a system of levers which could be used.

Hydraulic dynamometers using calibrated pressure gauge indicators (Fig 2.10) are available to measure heavy draft loads but these have generally been superseded by electronic strain gauged tension links (Fig 2.11). These units, with their indicators can be purchased in various sizes to measure draft forces of the smallest manual machine to those of the largest tractor or field machine. The units are easily calibrated, portable and can be battery powered for field use. They can also be connected to suitable recording or analyzing equipment. In the case of machines with fixed draw poles some modification may be necessary to accommodate the measuring device. Fig 2.12 gives two examples.

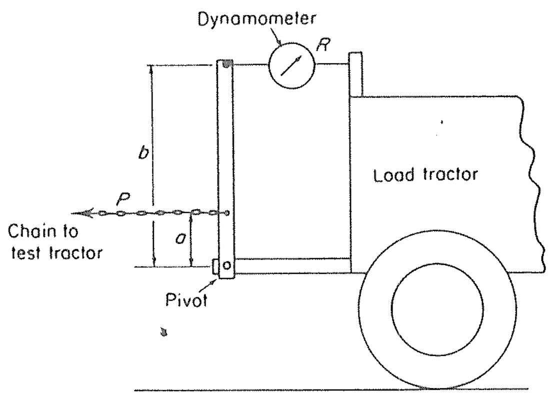


Figure 2.9 Method for increasing the capacity of weighing unit. Taking moments about the pivot:

$$P \times a = R \times b$$

$$\therefore \quad P = \frac{R \times b}{a}$$

Source: Crossley and Kilgour, 1983

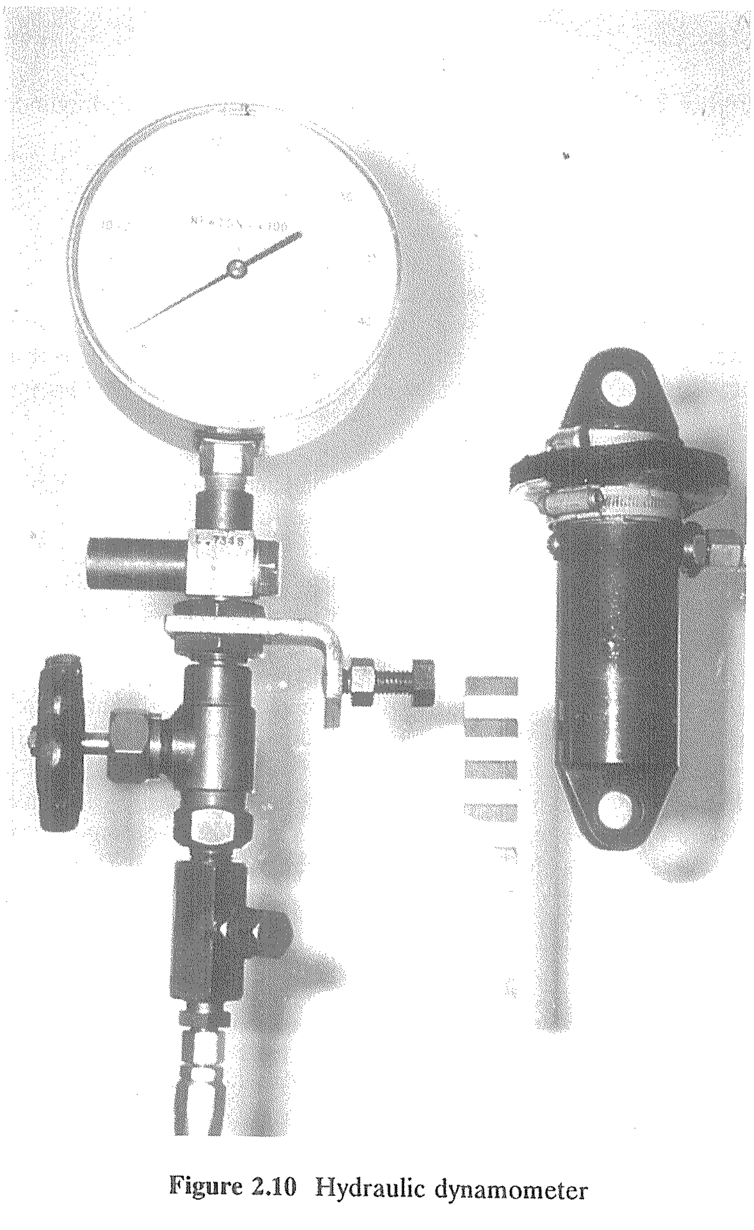


Figure 2.10 Hydraulic dynamometer

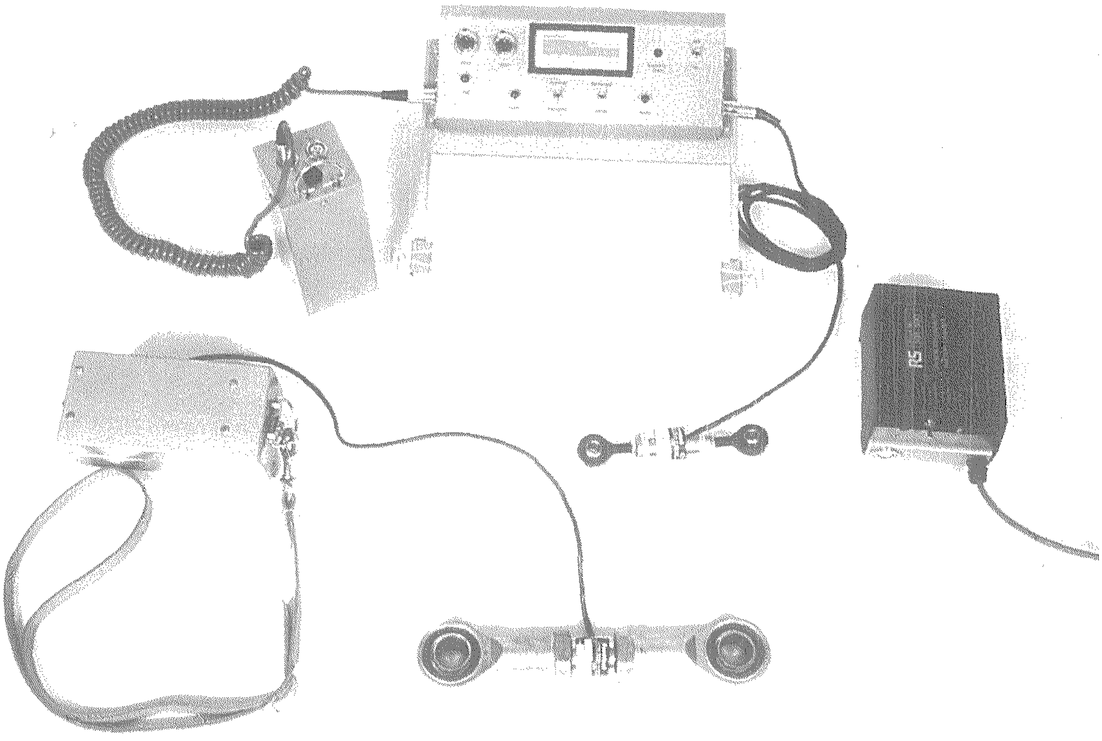


Figure 2.11 Strain gauge tension links with signal processor, battery and charger

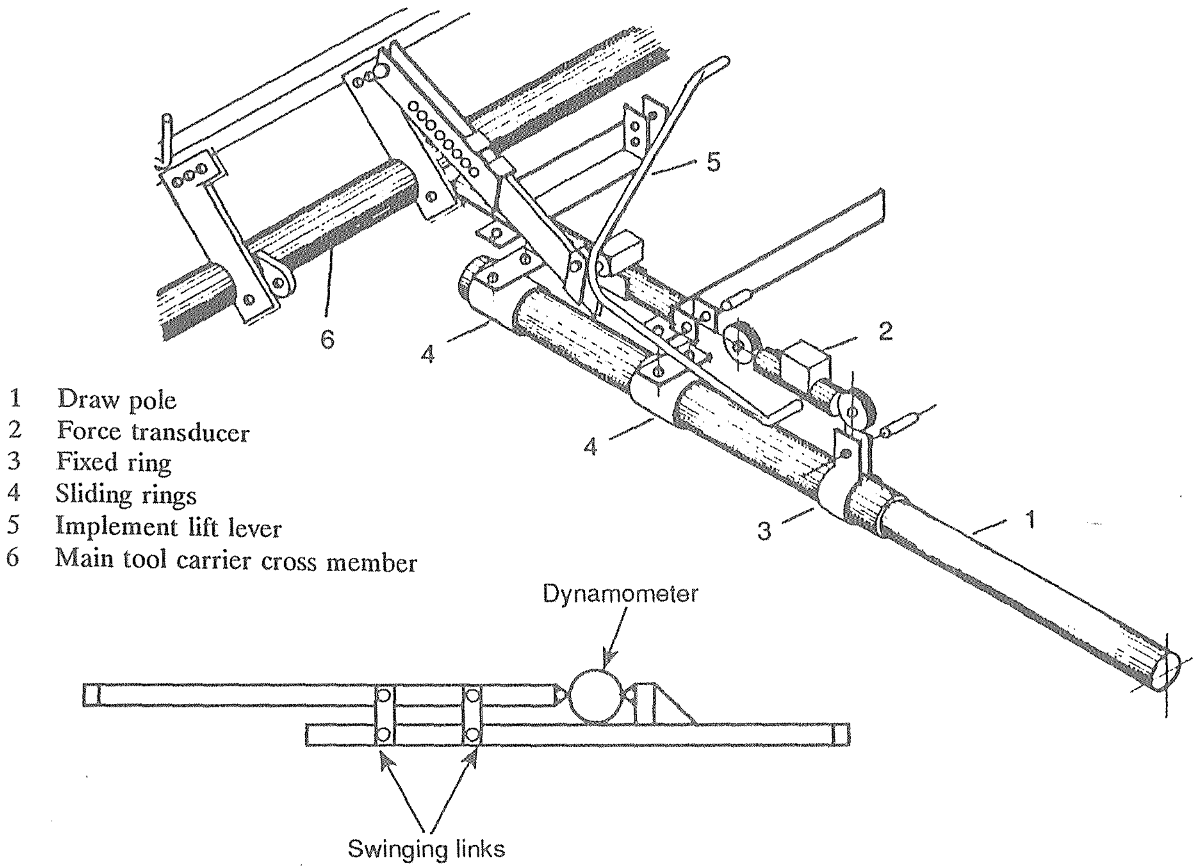


Figure 2.12 Two methods of draft measurement for implements with rigid draw poles.
(a) for an animal drawn wheeled tool carrier. (Source: Sims, 1987) (b) a universal system.

2.2.4 Pressure

Pressure measurements are required to be made in tests of power units, tractors, sprayers and water pumps. These cover a wide range and can be positive or negative.

Lower levels such as depressions in engine inlet manifolds and in water pump suction pipes can be measured using simple water or mercury filled manometers. In this case, the pressure in the system is calculated using the difference in height of the liquid column.

Pressure and vacuum gauges are manufactured in various ranges and graduated and scaled in units such as bars, kilograms force per square centimetre (kgf/cm^2), Pascals (Pa) or Newtons per square metre (N/m^2), this latter unit being preferred by the SI. Electronic systems using pressure sensors may be obtained together with their associated display and recording equipment.

2.2.5 Speed

The SI unit of speed of rotation is radians per second (rad/s), this unit is used for calculation of power from machines such as engines and tractors. Test measurements are made in revolutions (2π radians) for a given time, per minute (rev/min) or per second (rev/s).

Mechanical revolution counters and totalisers will require time to be measured by stopwatch. Electrical and electronic units automatically count the number of revolutions over a period of time and the results are displayed and continually updated (Fig 2.13).

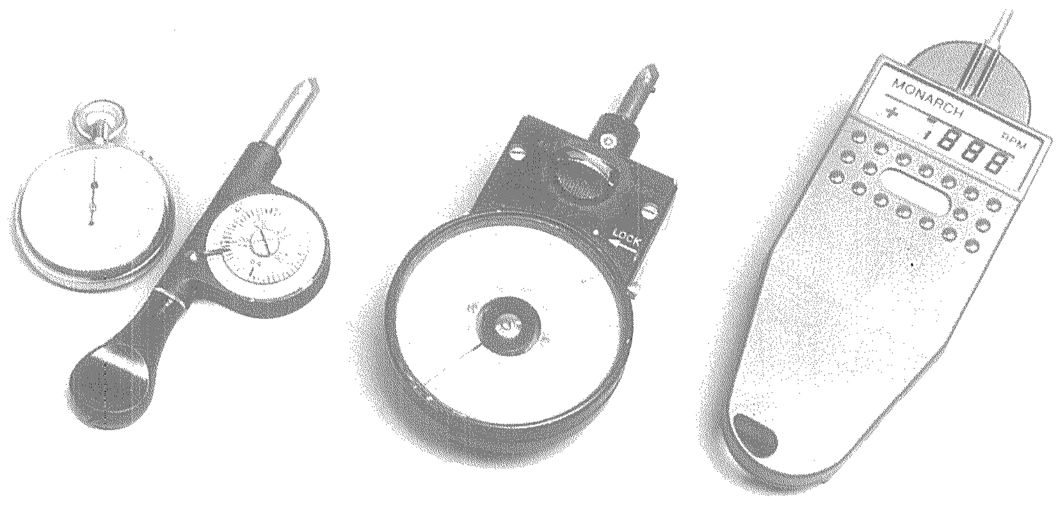


Figure 2.13 Range of mechanical and electronic revolution counters

The unit of linear speed is the metre per second (m/s). However, the unit normally used when presenting the travelling speed of tractors and machines is the kilometre per hour (km/h) which is derived by calculation.

A method of measuring travel speed during field trials of machines is to set up marker poles across the width of the work at say 20m apart to form a rectangle. An observer will then be able to sight across the poles and measure the time taken for the machine to travel the known distance (Fig 2.14).

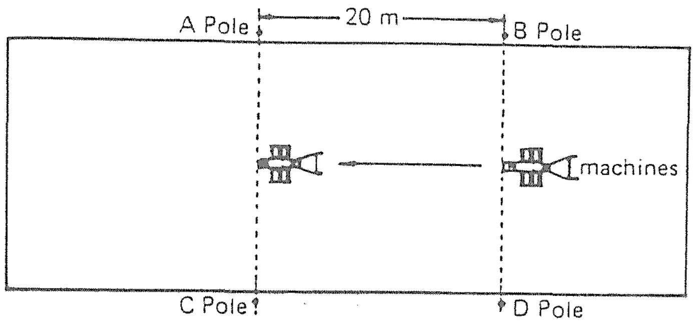


Figure 2.14 Field measurement of forward speed
Source: RNAM, 1983

When drawbar tests and slip measurements are being made in the field, the distance for a tractor or machine to travel for a number of wheel revolutions is measured. If the travel time is also recorded, the travel speed may be calculated (Fig 2.15).

Figure 2.15 Field measurement of tractor wheelslip during forward travel

2.2.6 Torque

Torque is defined as force x moment of application, the SI unit is the newton metre (Nm). Dynamometers for engine and tractor testing are basically devices which apply a measured and variable torque to a rotating shaft (engine crankshaft, pto shaft, etc). Friction loads applied mechanically, hydraulically or electrically within the dynamometer act upon an arm of known length attached to a load measuring device.

Selected torque values may be applied to the drive shaft by variation of the internal loading. In most proprietary machines the length of the arm is designed to give constants of whole numbers in the power calculations.

Transmission dynamometers that can be fitted into an engine/machine or tractor power take-off/machine drive line (Fig 2.16) are available to cover a large range of torque and speed requirements. These units are portable and comprise an internal strain gauged shaft or tube with suitable monitoring and read-out equipment, they can be mains or battery operated.

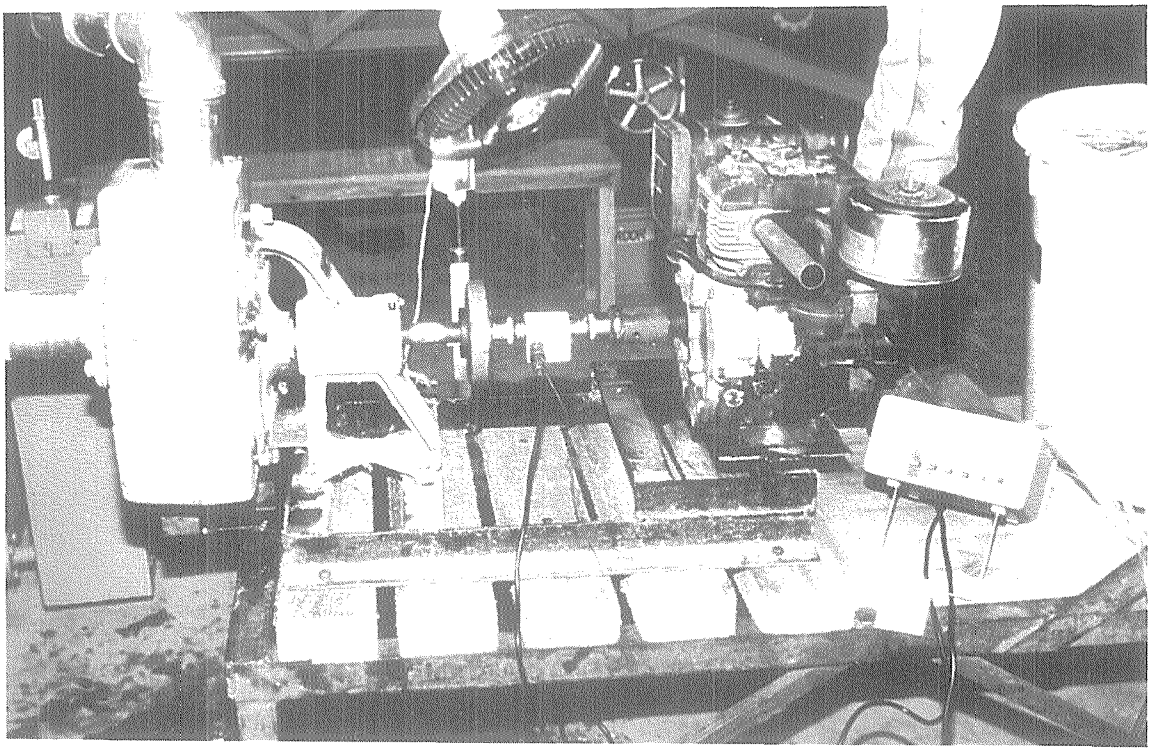


Figure 2.16 Torque meter fitted into the driveline between an engine and water pump

2.2.7 Work and Power

The SI unit of energy and work is the joule (J) which is defined as the work done when a force of one newton acts through a distance of one metre in the direction of the force. The joule (J) is equivalent to one newton metre (Nm). The unit of power is the watt (W) which is equal to one joule per second (J/s) or one newton metre per second (Nm/s). The unit most commonly used is the kW which is equal to one kilo newton metre per second (kNm/s).

For measurement of linear power, for a tractor drawbar test for example, the following equation is used:-

$$\text{Power (kW)} = \frac{\text{Force (kN) x distance (m)}}{\text{Time (s)}}$$

$$= \text{Force x velocity}$$

For rotating mechanisms such as engines,

$$\text{Power (W)} = \text{Torque (Nm)} \times \text{Speed of rotation (rad/s)}$$

If the speed of rotation is measured in revolutions per minute (R) and since there are 2π radians in one revolution then:-

$$\text{Power (kW)} = \text{Torque}\left(\frac{\text{Nm}}{1000}\right) \times \text{Speed of rotation}\left(\frac{2\pi R}{60}\right)$$

For measurement of power of tractor hydraulic systems, the following formula is used:-

$$\text{Power (kW)} = \text{Flow}\left(\frac{m^3}{s}\right) \times \text{Pressure}\left(\frac{N}{m^2}\right) \times \frac{1}{1000}$$

However, a formula in common use is:-

$$\text{Power (kW)} = \text{Flow}\left(\frac{l}{\text{min}}\right) \times \text{Pressure (bar)} \times \frac{1}{600}$$

For water pumps the equation is again modified to include the suction and pressure head (see section 4.6.7) and density of the liquid to give the pressure function.

$$\text{Power (kW)} = \text{Flow}\left(\frac{m^3}{s}\right) \times \text{Head (m)} \times \text{Density of liquid}\left(\frac{kg}{m^3}\right) \times \frac{1}{102}$$

For machines driven by electric motors, power requirement may be established by fitting a torque measuring device in the drive line and measuring speed of rotation.

If this is not possible, a good approximation can be obtained by measuring the input voltage (V) and current (A) to the motor and calculating the average power in watts (W).

For this, the relationship power (W) = voltage (V) x current (A) is used. However, it is possible to obtain various types of watt meters which when connected between the supply and the motor will give direct power readings (Figs 2.17 and 2.18). The diagram gives connections for circuits up to approximately 5A, if higher power ratings are required, a transformer is needed in the current measuring circuit and should be wired in accordance with the meter manufacturers' instructions.

It should be understood that measuring the power in the drive line will give the exact requirement of the machine. The watt meter measures the electrical power input to the motor and the efficiency of the motor to transmit that power to the machine should be taken into account. The motor efficiency valves will depend on the level of loading and will range from approximately 70% to 90%.

2.2.8 Rate of Work

This measurement is concerned with the output of machines in field evaluations. Rate of work is defined as area worked in square metres (m^2) for a unit of time, say one hour (h), giving the equation:-

$$\text{Rate of Work} = \frac{\text{area } (m^2)}{\text{time (h)}}$$

For field work, the number of square metres may be very large so the hectare (ha) equal to 10 000 m^2 is used, giving the expression hectare per hour (ha/h). The total work time used for this calculation includes time taken for turning at the headlands, rests and any breakdowns or adjustments.

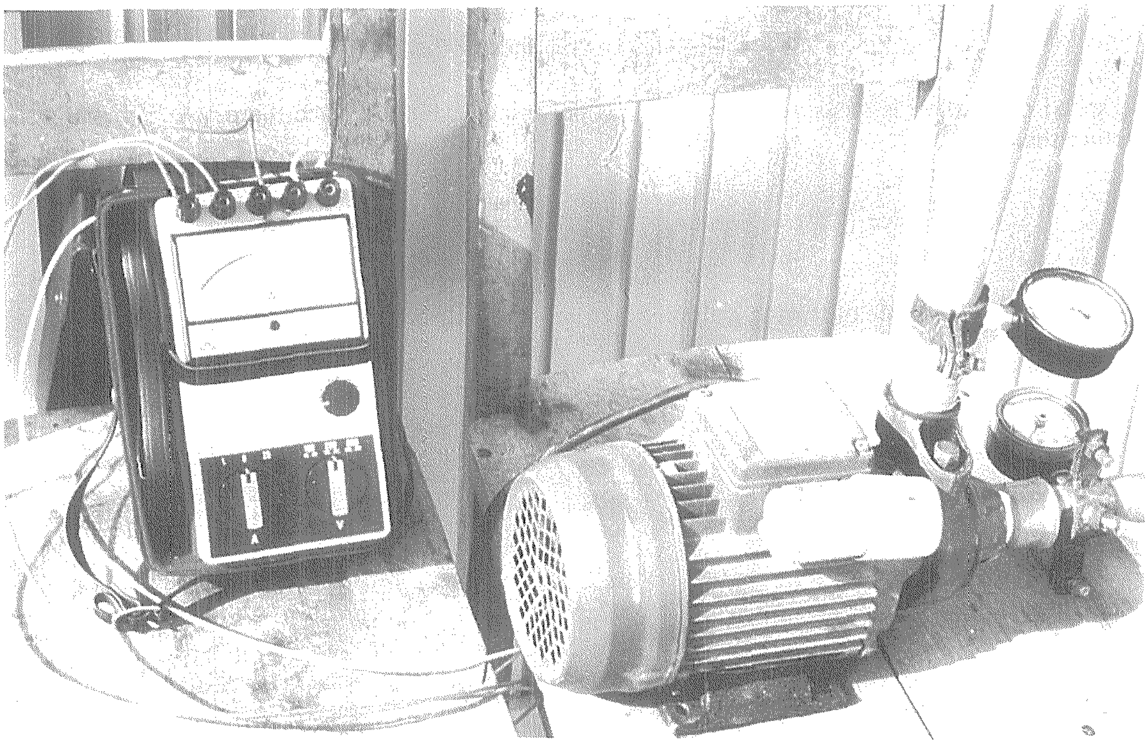


Figure 2.17 Wattmeter connected to electric motor

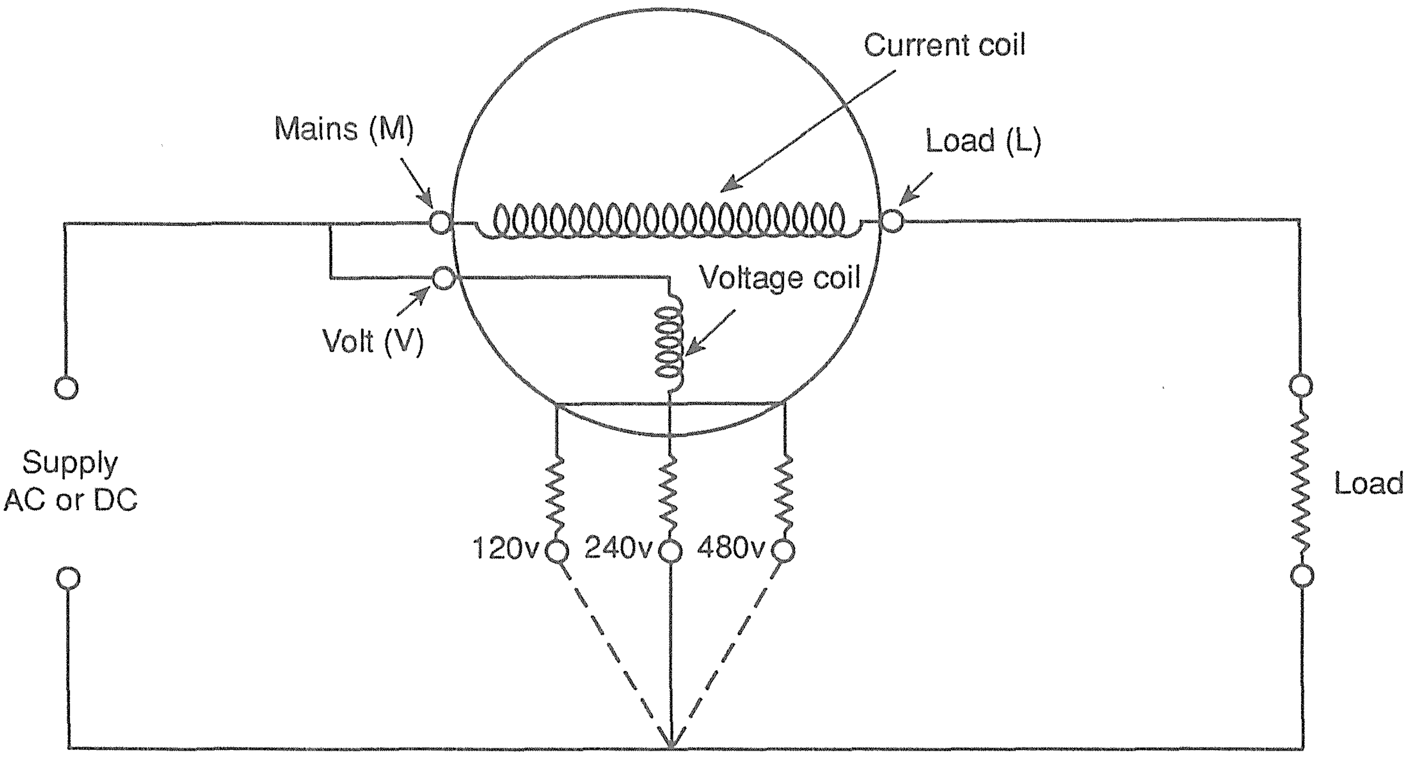


Figure 2.18 Diagram of basic connections to wattmeter for single phase supply up to 5A

2.2.9 Rate of Flow

Volume of flow is measured to establish the fuel consumption of petrol and diesel engines, and the output of sprayers and pumps. The basic function for flow rate, volume per unit of time is used in each case.

Fuel consumption of engines is measured in millilitres or litres per second (ml/s or l/s). For stationary engines a simple apparatus can be constructed (Fig 2.19). The vertical clear tube forming the fuel column should have a capacity of approximately 0.5 l and the scale calibrated. After filling the column from the separate supply, the tap is closed and operation of the three-way valve will divert the supply to the engine from the main tank to the column. After measuring time for a given volume, the sequence is reversed, refilling the column (Fig 2.20).

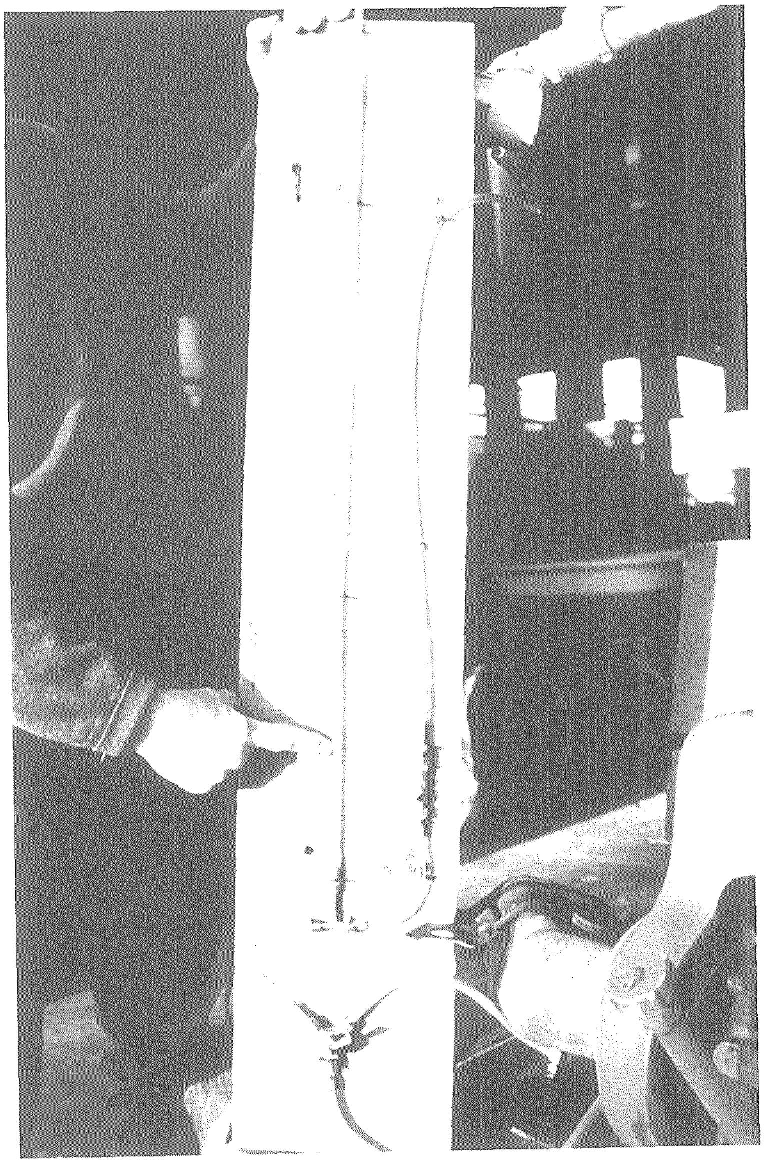


Figure 2.19 Low cost apparatus for measuring engine fuel consumption

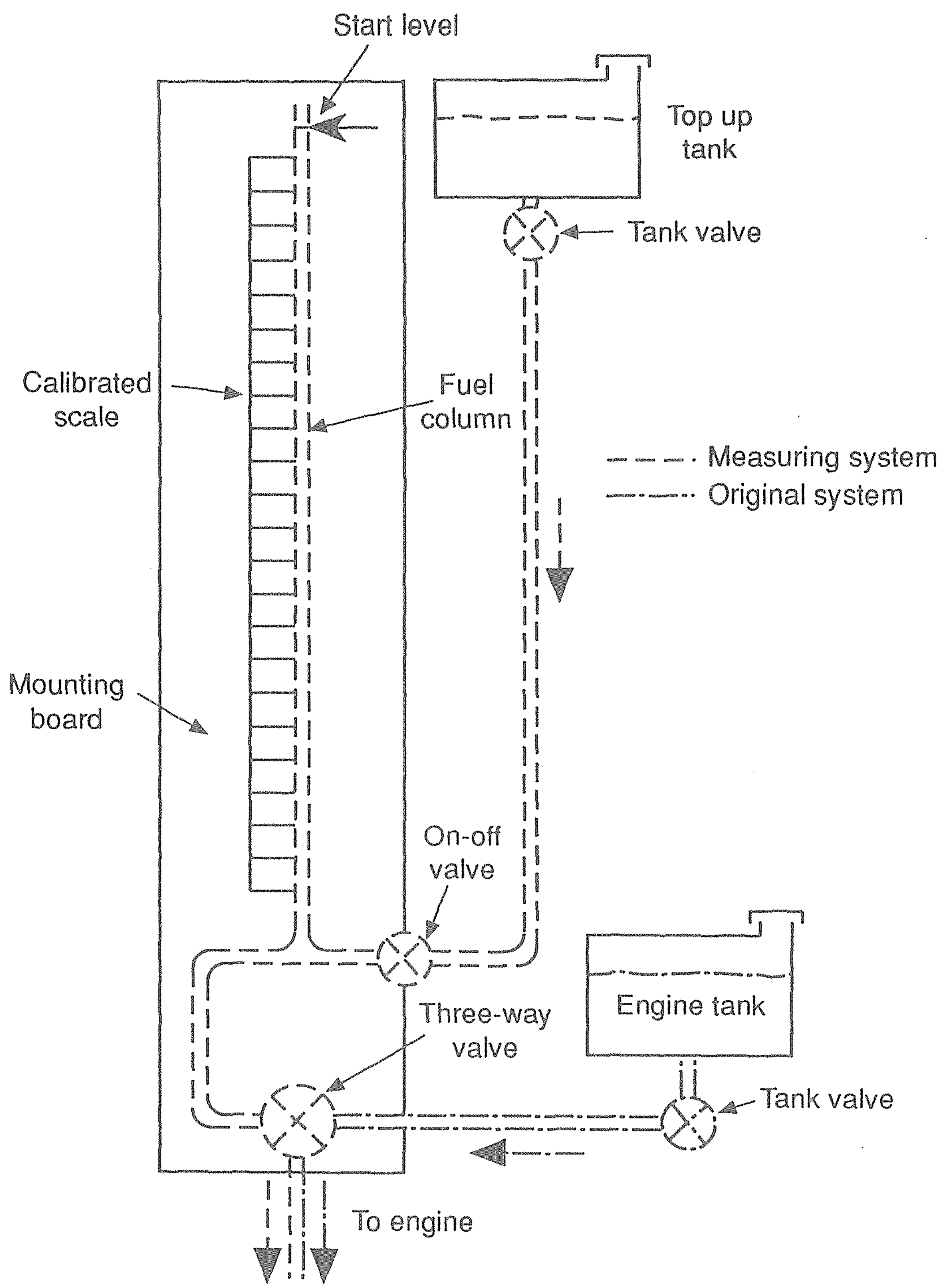


Figure 2.20 Construction of fuel measuring apparatus for petrol or diesel engines

Fig 2.21 shows a totalising flow meter fitted into a tractor fuel system. Various types of meter are available incorporating some form of rotor driving a counting mechanism for mechanical or electrical read-out. A three-way valve is fitted into the excess fuel return line to the tank to enable the flow to be diverted back into the main feed system after the meter, when measurements are being made (Fig 2.22). This type of meter is particularly suitable for measuring fuel flow over longer test periods.

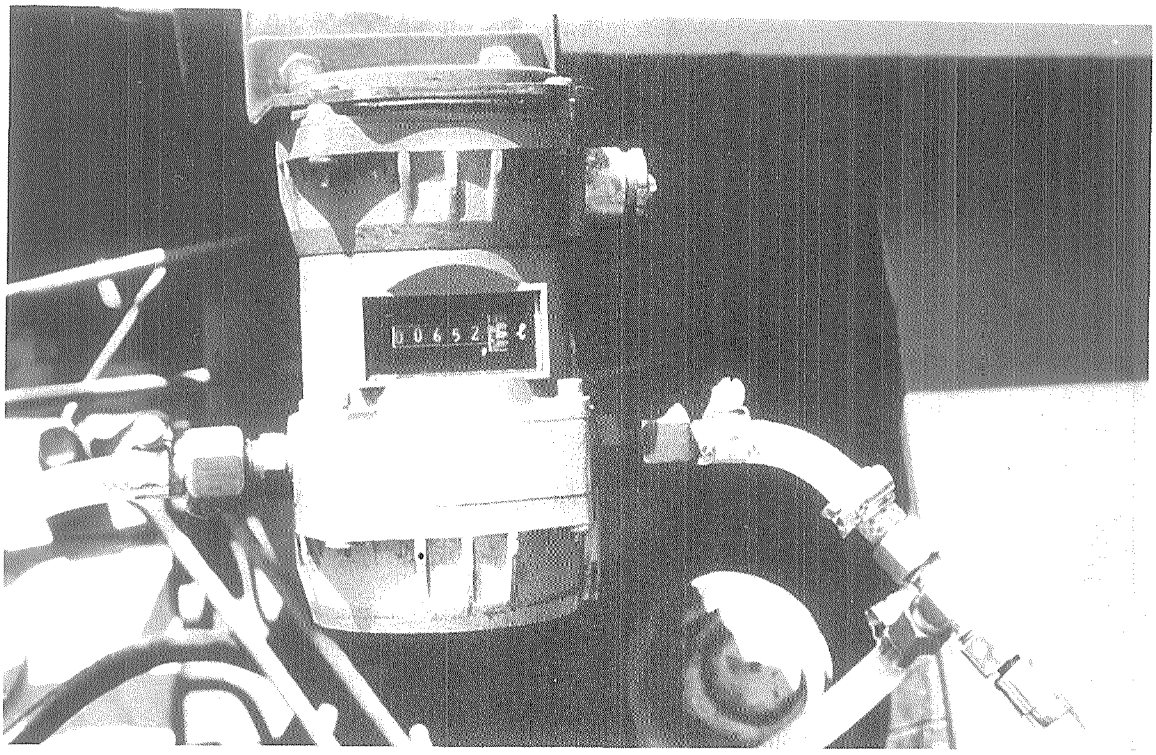


Figure 2.21 Totalizing flowmeter fitted to tractor fuel system

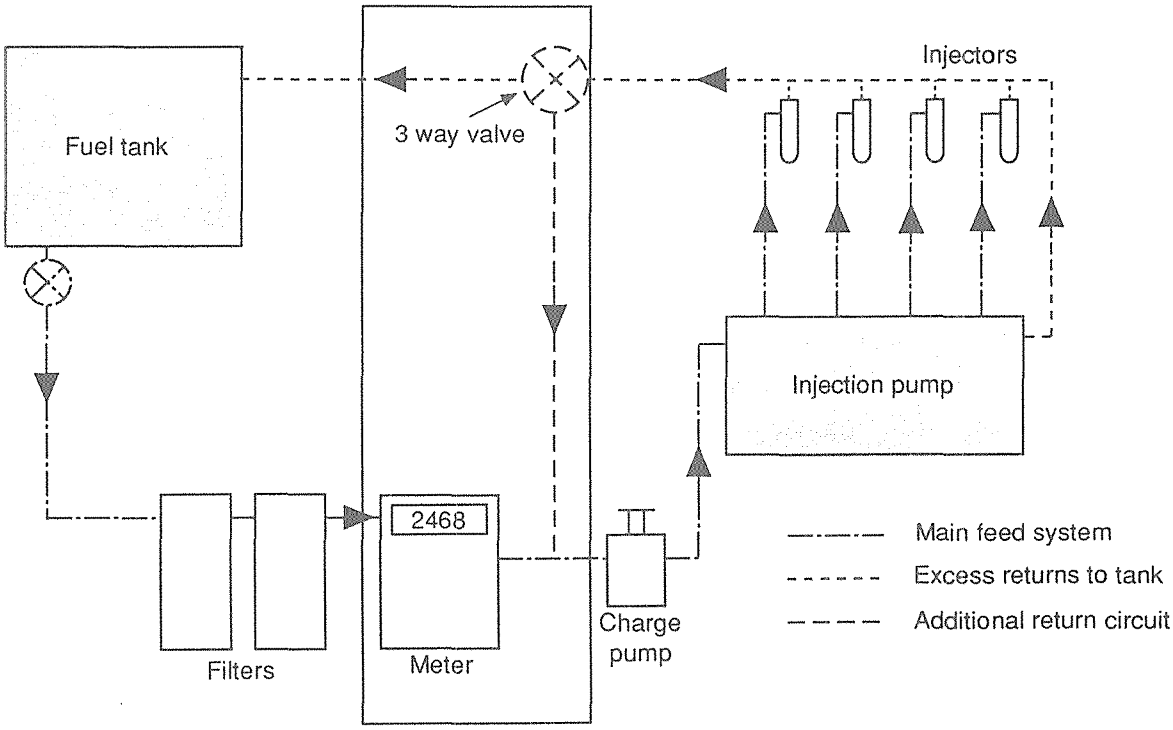


Figure 2.22 Meter fitted to typical tractor fuel system

Proprietary meters giving direct read-out of flow rate are used for tests on hydraulic systems. Fig 2.23 shows how a meter is fitted into the flow line of a tractor hydraulic system. In cases of tractors with "closed-circuit" systems, the meter must be of a type to withstand the pressure of the boost pump supply into which the return flow is connected. Before fitting test equipment to this type of tractor hydraulic circuit, information on testing methods should be sought from the tractor manufacturer.

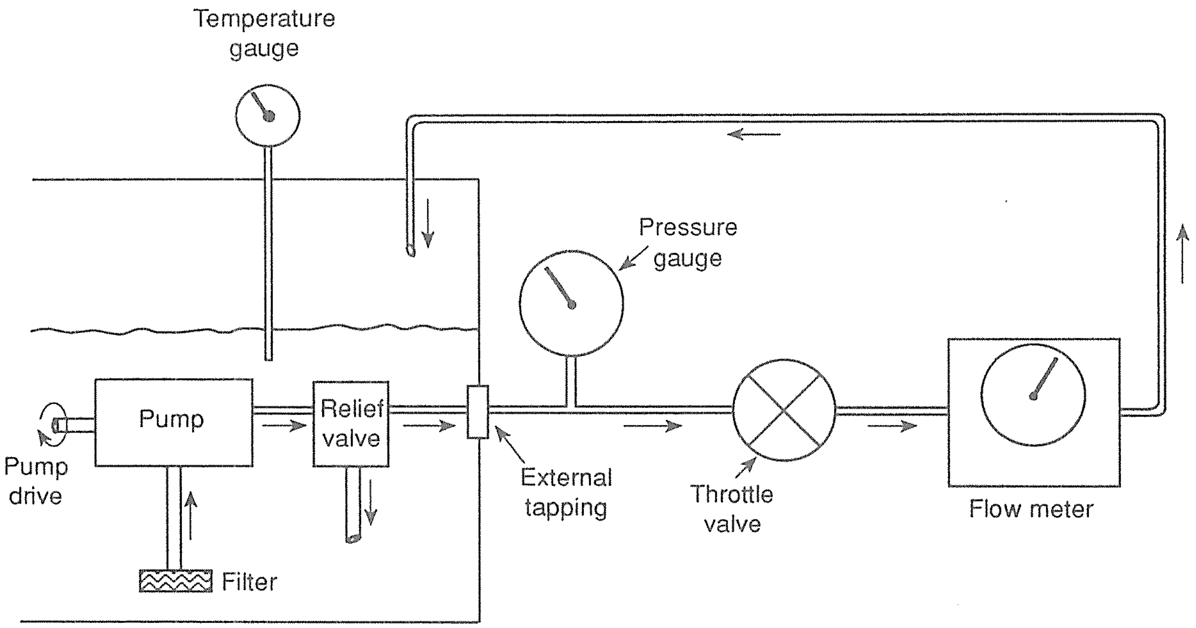


Figure 2.23 Arrangement for power test of tractor hydraulic system

Suitable flow meters may also be fitted into water pump outlets in preference to measuring the time to fill tanks of known volume. A further technique for measuring larger amounts of liquid flow is to use a 'V' notch fitted into the flow channel (Fig 2.24). This consists of a plate with a 90° 'V' notch across the line of flow through which the liquid flows. There is a relationship between the height of the liquid level above the lowest part of the notch and the top surface of the liquid flow. The expression for a true 90° notch is:

$$\text{Rate of flow, } Q = k \times \sqrt{2g} \times \frac{8}{15} \times H^{2.5}$$

where
Q = rate of flow (m^3/s)
g = acceleration due to gravity (9.8067 m/s^2)
H = height of liquid level (m)
k = plate coefficient

For each notch, the coefficient k must be determined by experiment to give the correct relationship between rate of flow and liquid height. This information may be supplied by a plate manufacturer.

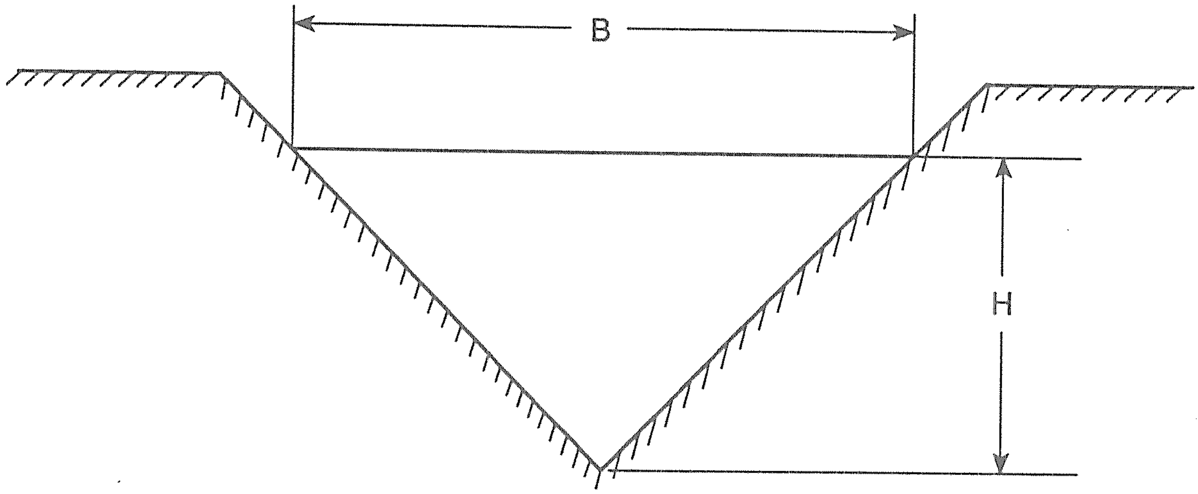


Figure 2.24 V-notch for rate of flow measurement

90° Flow (Q) m^3/sec $= k \times \sqrt{2 \times g} \times \frac{8}{15} \times H^{2.5}$

Not 90° $= k \times \sqrt{2 \times g} \times \frac{4}{15} \times B \times H^{1.5}$

2.2.10 Fuel Consumption

When considering the fuel consumption of engines, the ability of an engine to convert fuel into useful work will vary with engine type and design and with speed and loading. The measured fuel consumption should be related to the power output and expressed as "specific fuel consumption" in litres per kilowatt hour (l/kWh).

Fig 2.25 gives an example of curves of torque covering the operating speed range of an engine on to which have been added lines of constant power and specific fuel consumption.

It can be seen that for the same power output, the specific fuel consumption, and hence the fuel consumption, decreases with speed. For example, at 75% of maximum power, the consumption will fall about 7% when the speed is also reduced to 75% of rated speed. At 50% power, a fall in consumption of about 15% is achieved with a speed of 75% of rated speed.

This typical example shows how measurement of specific fuel consumption can be used to highlight areas of higher fuel efficiency in terms of power and speed. It shows, generally, that for tractor operation, it is more economical to work in the highest gear ratio possible, adjusting the throttle to maintain the required load and forward speed.

2.2.11 Rate of application

The volume or weight (mass) of insecticide, fertiliser or seed applied related to crop or field area is the most useful expression of rate of application. It is measured in litres per hectare (l/ha) or kilograms per hectare (kg/ha). If these terms are multiplied by the rate of work in hectares per hour (ha/h), the application rates per hour can be achieved.

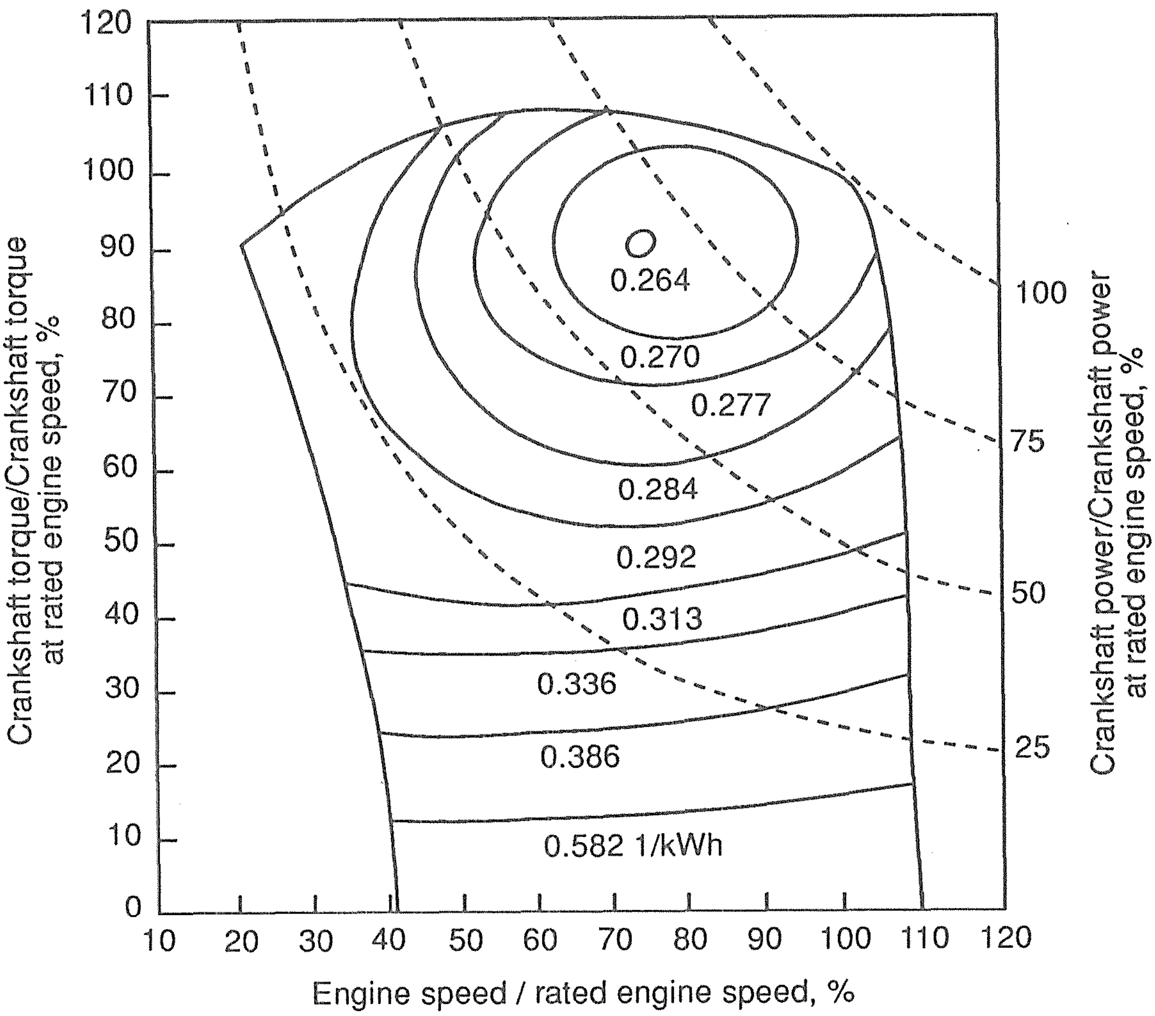


Figure 2.25 Fuel economy measured over operating range of an engine
Source: Crossley and Kilgour, 1983

2.2.12 Output

For stationary threshers and shellers and combine harvesters, rate of output is one of the main factors in determining the performance of the machine. In all cases, samples of threshed grain collected over the period of the test run are weighed and the results expressed in kilograms per hour (kg/h). For tests of combine harvesters, this result may be divided by the rate of work in hectares per hour (ha/h) to give a result in kilograms per hectare (kg/ha).

3 CALIBRATION OF TEST EQUIPMENT

The reliability of data from measurements made during tests and evaluations will depend on the accuracy of the instruments used. This supposes that the use of such equipment is understood by testing personnel and operated correctly with accurate data recording. The level of accuracy will depend on the purpose of the test, greater accuracy is generally required for smaller quantities (eg engine fuel consumption or dimensions of small components). Such accuracy is not required for larger quantities, eg field size. Instruments with high levels of accuracy will generally be more expensive.

The range of the measuring equipment used should be consistent with the range expected during the test (eg expected draft forces of up to 5 kN should be measured with a tensile link of 5 kN rated load).

All proprietary measuring equipment will be produced and supplied calibrated to known standards and limits of accuracy over suitable measuring ranges. Instrument accuracy will depend on such factors as: hysteresis; non-linearity; repeatability; creep and temperature. Simple measuring devices such as rules, tapes, and graduated cylinders and thermometers will not require regular calibration as changes due to damage and wear will be obvious and the units are relatively inexpensive to replace.

Much of the mechanically based test equipment has now been superseded by electric and electronic measuring devices which can be mains or battery operated and are suitable for laboratory or field use. Testing engineers without suitable knowledge to understand all the basic processes of the new systems will need to have total reliance on the continued accuracy of the equipment. Because of this reliance on accuracy, all test measuring equipment should have periodic calibration checks especially if there are any doubts about the results of measurements. Manufacturers may include standards for calibration within the equipment such as a standard noise source for sound level meters and means for measuring frequency of light for revolution counters.

Many checks can be made within the testing organisation using "standard" equipment for comparison. Graduated cylinders may be used to check the volume or output of fuel measuring devices and the capacity of various containers, pressure gauges, balances and timers can be checked against further units of the same type. However, these should only be used for "spot" checks and instruments should be returned to the manufacturer or to a suitably equipped standard test laboratory.

Fig 3.1 shows a laboratory set-up for testing a pressure gauge where the pressure in the system is provided by known standard weights acting on a very accurately machined piston and cylinder. The reservoir and pump are fitted to ensure that the system is full and that the piston is supported by the liquid column when measurements are made.

Strain gauge devices used on engines, tractors and machines in the field are particularly vulnerable to damage and adverse conditions and will require more frequent checks. A well equipped laboratory may have a specially designed machine for calibrating compression or tension links. However, standard weights of sufficient quantity may be used as shown in Fig 3.2 for calibrating a tension link used for draft force measurement.

A set-up for applying loads when calibrating a torque meter is shown in Fig 3.3. One end of the meter drive shaft is attached to the test stand and a torque arm is attached to the other. A weight tray and weights are added to the arm at a suitable distance which is accurately measured and defined. For accuracy, the torque arm should be as light as possible and balanced before weights are added.

All test equipment and instrumentation should be stored in a clean environment and records kept of periods of use, frequency of calibration and any breakdowns or repairs.

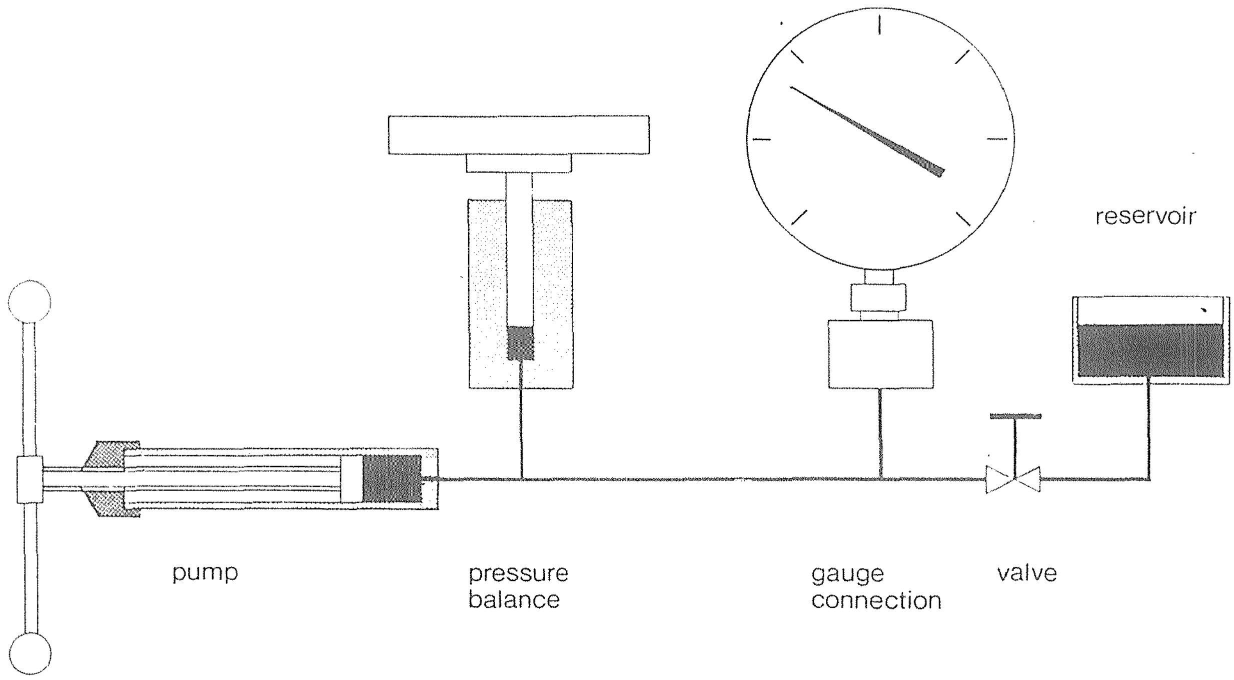


Figure 3.1 Rig for pressure gauge calibration
Source: Budenberg Gauge Co Ltd

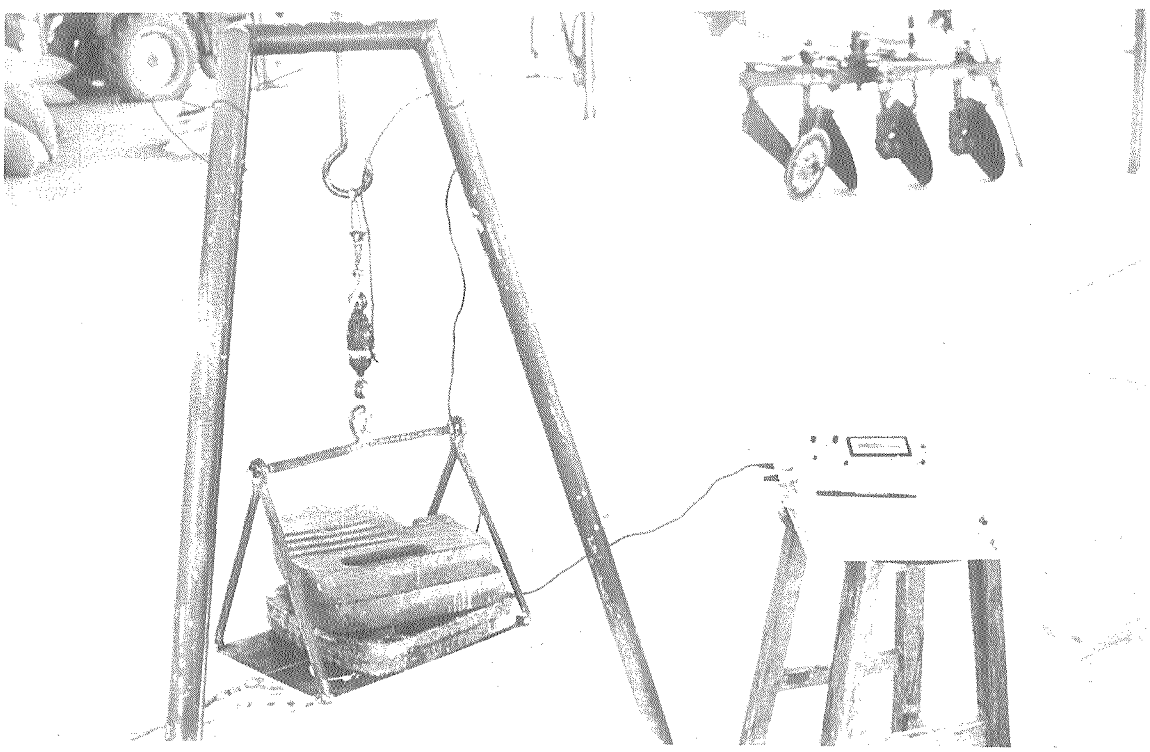


Figure 3.2 Calibration of strain gauge tension link

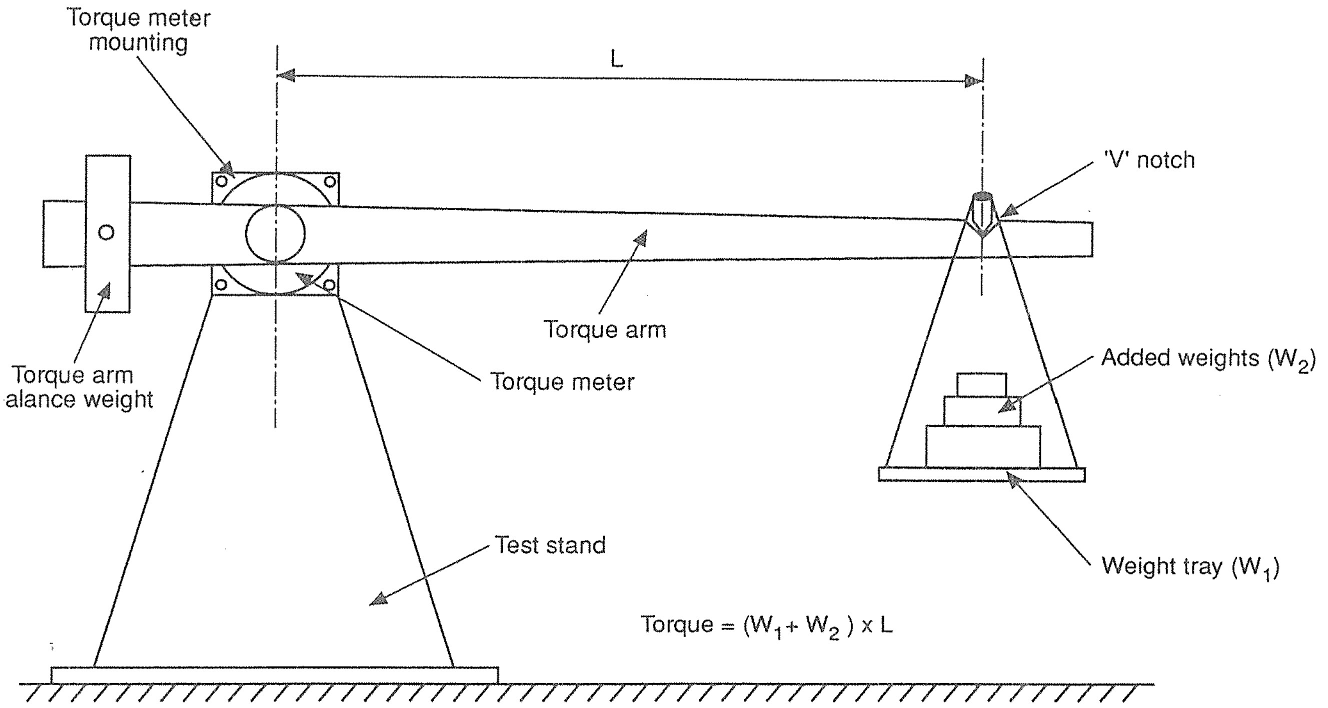


Figure 3.3 Mechanical arrangement for torque meter calibration

4 APPLICATION OF MEASUREMENT TECHNIQUES TO TESTING PROCEDURES

4.1 Selection of material for tests

During evaluations, machines are assessed on their ability to meet certain design criteria. Fertiliser distributors, seeders, planters, threshers and harvesters are specifically designed to process particular types of bulk material. The material selected for the tests should be in accordance with the design criteria of the machine and should be adequately checked and specified in the test report. This is particularly important where various types of machines are being compared for performance.

Granular fertiliser should be specified by name, type and shape. The flow of material in the hopper and the passage through the elements of the machine will be affected by the size distribution of the granules and the moisture content. The density of the material will be related to the volume applied by the machine per hectare, and hence the capacity of hoppers and feed mechanisms.

The metering and feed components of any seed drill or planter will be designed for seeds of particular shape, dimension and weight. Bulk seed for tests should be sampled for measurement and the weight of 1000 grains (standard grain specification weight) established. Damage to the seed when passing through the machine is one of the important aspects to be assessed. The sample used for tests should not contain any damaged seeds so that any damage caused by the machine can be measured. Where a germination method is used to assess machine performance, the germination rate of the original sample will need to be established.

Threshers and shellers are assessed on their ability to separate grains from straw or cobs without damage. In addition to specifying the type and variety, moisture content, size and density of the original material, the average ratio of grain/straw and grain/cob should be established.

The type and condition of the crop will considerably affect the performance of combine harvesters. The main output tests should be made with crops in "average to good" condition which means that the majority is standing with a minimum amount of weeds and at the desired moisture content. Where investigations are made under poor conditions (laid or weedy crops), these should be adequately specified.

4.2 Soil conditions

For tests on soil engaging implements and machines, there are parameters which can be established to describe soil conditions before and after work has been carried out. These parameters will enable assessment of the quality of the work and the ability of the implement or machine to satisfy desired criteria.

4.2.1 Soil texture

Particle size analysis, also referred to as mechanical analysis, determines the percentage of the three mineral fractions: sand, silt and clay in the soil and hence its textural class. The texture of a soil is its most permanent characteristic and directly influences a number of other soil properties (see Table 4.1) such as: structure, soil water regime, permeability, infiltration rate, run-off rate, erodibility, workability, root penetration and fertility etc. and as such it is a basic parameter which should always be determined.

Measurement of soil particle size distribution requires very accurate equipment and is normally undertaken in a suitably equipped soils laboratory. The method is by sedimentation (British Standard Institution, 1975). Fig 4.1 shows percentages of clay (below 0.002 mm), silt (0.002 - 0.06 mm) and sand (0.06 - 2.0 mm) in the basic soil textural classes. The sub-divisions reflect the various combination of particles present.

4.2.1.1 Field Estimation

If details of the soil type are not available using the particle size and distribution method, the type may be estimated using the following sampling procedure and manual method (Fig 4.2).

Table 4.1 Average Soil Physical Characteristics (ranges shown in parentheses) for undisturbed sites

Textural class	Bulk density (D_b)	Total pore space (V_p%)	Field Capacity (vol %)	Wilting point (vol%)	Available water by volume (AWC%)	Air capacity at FC (Va%)
sandy	1.65 (1.55-1.80)	38 (32-42)	15 (10-20)	7 (4-10)	8 (6-10)	23
sandy loam	1.50 (1.40-1.60)	43 (40-47)	21 (15-27)	9 (6-12)	12 (9-15)	22
loam	1.40 (1.35-1.50)	47 (43-49)	31 (25-36)	14 (11-17)	17 (14-20)	16
clay loam	1.35 (1.30-1.40)	49 (47-51)	36 (31-41)	17 (15-20)	19 (16-22)	13
silt clay	1.30 (1.25-1.35)	51 (49-53)	40 (35-46)	19 (17-23)	21 (18-23)	11
clay	1.25 (1.20-1.30)	53 (51-55)	44 (39-49)	21 (19-24)	23 (20-25)	9

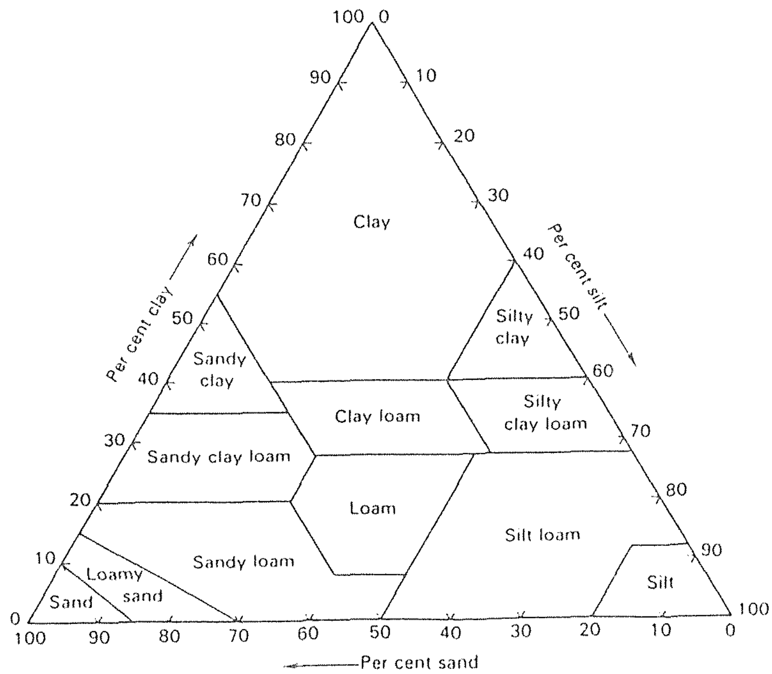


Figure 4.1 Soil textural triangle
Source: Russell, 1973

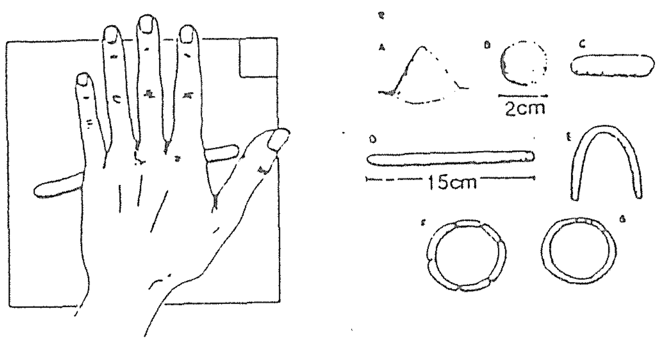


Figure 4.2 Manual tests to estimate the textural class of a soil
Source: Zambia, 1990

Ideally, samples for tillage studies should be taken at intervals of 0.1 m or less, throughout the cultivation layer, e.g. surface (0-0.05 m), 0.05-0.15 m, 0.15-0.25 m and possibly to 0.10 m below the layer of intended depth of cultivation. The minimum sample size taken at each depth is 200 g and should be replicated at least three times throughout the test area to give a representative estimate of soil texture for the area.

A ball of about 2.5 cm diameter is formed of fine soil. Water is slowly dripped onto the soil until it approaches the sticky point ie: the point at which the soil just starts to stick to the hand. The extent to which the moist soil can be shaped by hand is indicative of its texture.

Textural Class

A	Sand	the soil remains loose and single grained and can only be heaped into a pyramid.
B	Loamy sand	the soil contains sufficient silt and clay to become somewhat cohesive and can be shaped into a ball that easily falls apart.
C	Silt loam	as for loamy sand but the soil can be shaped by rolling into a short thick cylinder.
D	Loam	because of about equal sand, silt and clay content the soil can be rolled into a cylinder about 150 mm long that breaks when bent.
E	Clay loam	as for loam, although the soil can be bent into a U, but no further, without being broken.
F	Light clay	the soil can be bent into a circle that shows cracks.
G	Heavy clay	the soil can be bent into a circle without showing cracks.

When dry, loam or silt will give off fine powdery dust if scratched or blown upon, but a clayey soil will not; a silt is extremely powdery because of its' very low clay content. A loam when wet feels soapy and more or less plastic; when rubbed between the fingers until dry it leaves dust on the skin, clay does not.

When ploughed or augured, a clay that has a slightly moist condition displays a shining surface, a loam does not.

4.2.2 Bulk Density

The dry bulk density of a soil gives an indication of the soil's strength and thus the resistance presented to tillage implements or plant roots as they penetrate the soil. Soil bulk density is defined as the mass per unit volume of dry soil in its undisturbed state. For a soil of a given particle density (typically 2.65 Mg m^{-3}), bulk density is directly related to total porosity, the space available in the soil for gas and water movement and root development. Less directly bulk density is also related to soil strength and permeability. Soils with a high total pore space have a low bulk density and conversely low porosity leads to high bulk density. Bulk densities in excess of 1.6 Mg m^{-3} can restrict root growth and result in very low levels of water movement into and within the soil. Some typical values for different soil textures are given in Table 4.1.

4.2.2.1 Field estimation of bulk density

4.2.2.1.1 Core sampling

This method consists of taking a core sample of soil using a coring cylinder of a known volume which is driven into the soil and then carefully dug out (Fig 4.3). The cylinder, which should be numbered for easy reference, is usually about 0.05 m long with a 0.05 m diameter. If the sample does not completely fill the cylinder (eg. some soil may be lost if it is dry) the void should be measured as accurately as possible, to establish the actual dimensions of the sample. One suggested method of establishing the actual dimensions of the sample would be to fill the voids with fine dry sand, and then empty out the sand and measuring its volume. An alternative, approach if time allows and water content is not being determined, is to thoroughly wet the sampling site prior to the taking of the sample.

Figure 4.3 Soil core sampling for bulk density measurement

Each sample should be taken to the laboratory in a sealed container. After weighing, the samples are oven dried at 105°C for 8 hours and then cooled in a desiccator before re-weighing.

$$\text{Oven dried bulk density } (D_b) = \frac{M}{\pi R^2 L}$$

M = Mass of the dried sample

R = Radius (internal) of cylinder

L = Length of cylindrical sample corrected for any loss of soil as above.

4.2.2.2 Sampling strategy for bulk density measurements

At least four replicate determinations are normally made at each site prior to any tillage work at 0.05 m increments from the soil surface to 0.10 m below the estimated depth of tillage work. Post tillage measurements require more precise determinations to characterise the degree of soil disturbance which will vary with the implement used. For general cultivation implements, such as ploughs and cultivators, it is recommended that at least ten replicate determinations be made per site at 0.05 m increments from the soil surface to 0.10 m below the depth of tillage work. Where tined implements are used for single passes determinations should be made at least three lateral positions, 0, 0.10 and 0.20 m at right angles to the passage of the tine. Figure 4.4 shows how dry bulk density varies with increasing distance from the passage of a tine.

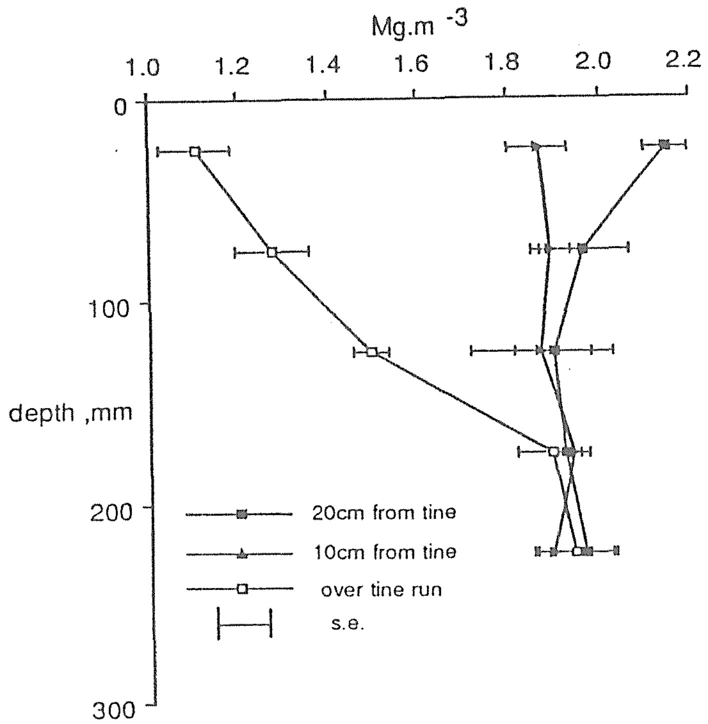


Figure 4.4 Variation in dry bulk density with depth for three positions (0, 0.1 and 0.2 m) at right angles to the passage of a cultivator tine

4.2.2.3 Dry bulk density and porosity

The relationship between dry bulk density and porosity is :

$$\text{Porosity } (V_p\%) = 100 - \left(\frac{\text{dry bulk density}}{\text{particle density (2.65)}} \right) \times 100$$

4.2.3 Moisture Content

Within the soil-water system water occurs in three phases, as a solid (ice), a liquid and a vapour. Under semi-arid conditions, it is the liquid phase that is of particular interest as it reflects the physical properties of the soil in their natural state or as affected by tillage. Soil holds water in two ways: as free moisture in pores and spaces that occur between the solid particles; and as adhesive or swelling moisture, by adsorption on the solid surface of clay and organic particles. Free water is of most interest in tillage studies as soil strength is directly related to soil water content.

4.2.3.1 Measurement method

Methods of determining soil water content can be divided in to two groups, those occurring in the field, and those that necessitate the removal of a sample for laboratory determination by oven drying. The latter technique is the one recommended here, as it is the ultimate reference against which all field techniques are calibrated.

The free moisture content of a soil is determined in the laboratory and is usually presented as a percentage by weight of the oven dry soil. It is recommended that sampling strategy described for the determination of dry bulk densities in section 4.2.2 should be used. Samples should be transferred to a paper sampling bag of known weight (W1) and weighed immediately in the field (W2) and their weight recorded. The laboratory samples are oven dried at 105°C for 8 hours, cooled in a desiccator and then re-weighed (W3). The soil water content is usually presented as a percentage by weight of the oven-dry soil:

$$\text{Soil water content, \% (dry weight basis)} = \frac{W2 - W3}{W3 - W1} \times 100$$

where

W1 = weight of container

W2 = weight of container and wet soil

W3 = weight of container and oven dry soil.

Example: W1 = 5 g, W2 = 105 g and W3 = 85 g after drying at 105°C, then

$$\text{Soil water content, \% (dry weight basis)} = \frac{105 - 85}{85 - 5} \times 100 = 25\%$$

In agricultural practice it is often desirable to know the water content as a percentage by volume of the undisturbed soil. This can be determined either directly, making use of the coring cylinder of a known volume (section 4.2.2.1.1), thus:

$$\text{Soil water content, \% (volume)} = \frac{\text{Soil water content, \% (dry weight basis)}}{\text{volume of sample}}$$

or indirectly by making use of the water percentage by weight and the dry bulk density thus:

$$\text{Soil water content, \% (volume)} = \text{Soil water content, \% (dry weight basis)} \times \text{dry bulk density}$$

4.2.3.2 Estimation by feel method

The chart in Table 4.2 may be used to estimate the moisture content in the field or if other methods are not available.

4.2.4 Mean Clod Diameter

The amount of soil pulverisation is measured by evaluating the mean clod diameter. A sample cube of soil about 0.15 m side is passed though a series of sieves and the weight of soil retained on each sieve is measured. Various sizes of sieves are available but in the example given in Table 4.3, 10, 20, 30, 40, 50 mm mesh sizes are used.

Table 4.2 Feel chart for estimating soil moisture

Percent useful soil water remaining	Coarse textured soil	Moderate coarse textured soil	Medium textured soils	Moderately fine and fine textured soil
	Dry loose, single grained, flows through fingers	Dry loose flows through fingers	Powdery, dry, sometimes slightly crusted but easily breaks down into powdery condition	Hard baked, cracked; sometimes has loose crumbs on surface
50 or less	Still appears to be dry; will not form a ball with pressure	Still appears to be dry; will not form a ball*	Somewhat crumbly, but will hold together from pressure*	Somewhat pliable; will ball under pressure
50 to 75	Same as coarse texture under 50 or less	Tends to ball under pressure but seldom will hold together	Forms a ball somewhat plastic; will sometimes stick slightly with pressure	Forms a ball; will ribbon out between thumb and forefinger
75 to field capacity	Tends to stick together slightly; sometimes forms a very weak ball under pressure	Forms weak ball, breaks easily; will not stick	Forms a ball and very pliable; slicks readily if relatively high in clay	Easily ribbons out between fingers, has a slick feeling
At field capacity	Upon squeezing no free water appears on soil but wet outlines of ball is left on hand	Same as coarse	Same as coarse	Same as coarse
Above field capacity	Free water appears when soil is bounced in hand	Free water will be released with kneading	Can squeeze out free water	Puddles and free water forms on surface

*Ball is formed by squeezing a handful of soil very firmly with fingers.

(Adapted from Texas Agrl. Ext. Stn. Bul. 1941)

Table 4.3 Calculation of mean clod diameter

SIZE OF APERTURE, mm	DIA OF SOIL PASSED THE LEFT SIEVE & RETAINED ON THE NEXT SMALL APERTURE SIEVE, mm	AVERAGE SIZE OF PARTICLES RETAINED ON THE SIEVE, mm	WEIGHT OF SOIL, kg
10	< 10	5	A
20	10 - 20	15	B
30	20 - 30	25	C
40	30 - 40	35	D
50	40 - 50	45	E
	50 >	N	F

Mean soil clod diameter, mm =

$$\frac{1}{W}(5A + 15B + 25C + 35D + 45E + NF)$$

Where $W = A + B + C + D + E + F$

N = Mean of measured dias of soil clods retained on the largest aperture sieve, mm

This calculation applies to one soil sample only, but for small plots it is recommended that 3 samples should be taken and 5 samples for larger plots.

4.2.5 Soil Strength

Soil strength influences the energy required to carry out tillage operations and also determines whether a crop's root system can effectively penetrate the soil to obtain adequate nutrients and water. For these reasons it is frequently necessary in cultural practice/tillage studies to quantify soil strength. Pre-tillage measurements should be taken, but will only be of value if soil water content, soil type and dry bulk density are known.

4.2.5.1 Cone Index

Cone Index is measured using a proprietary made penetrometer conforming to recognised standards Fig 4.5. It is an indication of the soil hardness and is expressed as force per cm² (or kilo Pascals, kPa) of a cone to penetrate the soil. Cone Index under the same soil conditions varies with cone apex angle and area of cone base. The apex angle and base diameter used should be specified. The penetration force is measured at set depths and the results presented gradually as in Fig 4.6.

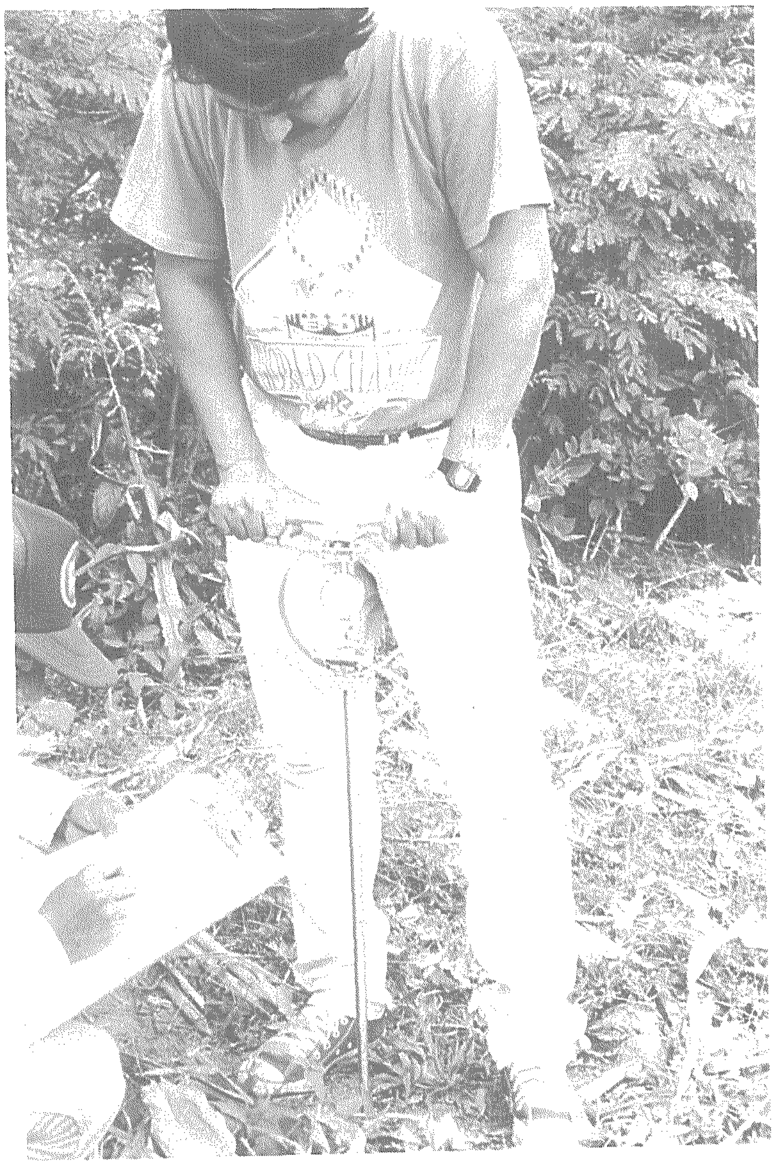


Figure 4.5 Measuring soil resistance with cone penetrometer

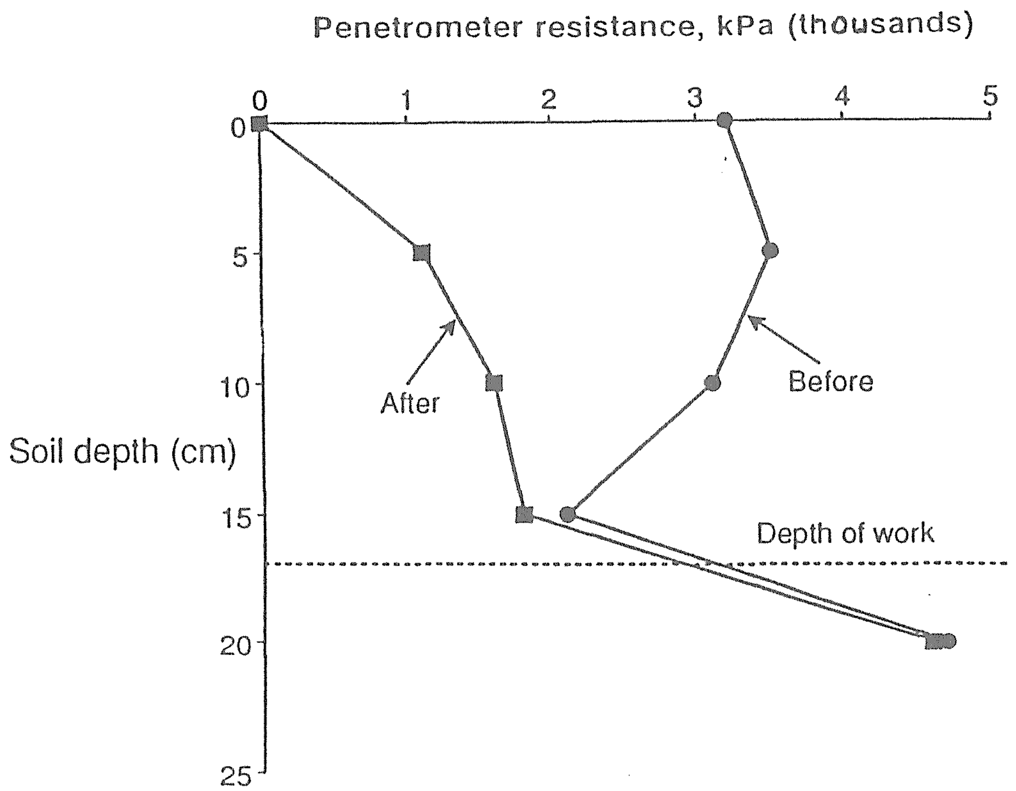


Figure 4.6 Soil resistance to cone penetrometer before and after ploughing

4.2.5.2 Shear Strength

A soil strength measurement is of value in comparing different soils before and after ploughing, more so in clay than in sandy soil. Commercially available soil shear meters are available which are simple to operate, the readings being recorded directly in kPa, kg/cm^2 or similar, see Fig 4.7. Again details of vane diameters and indicators will depend on the precise model selected. Figure 4.8 shows how field measurements can be presented.

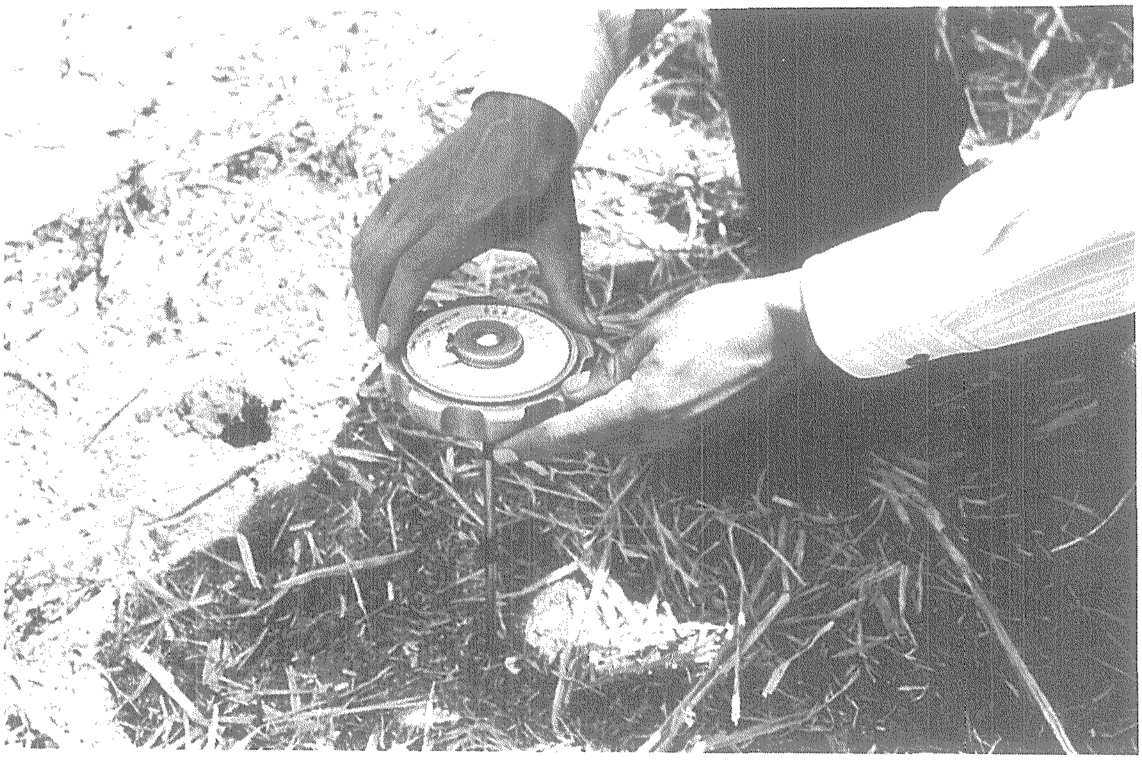


Figure 4.7 Measurement of soil cohesive shear strength

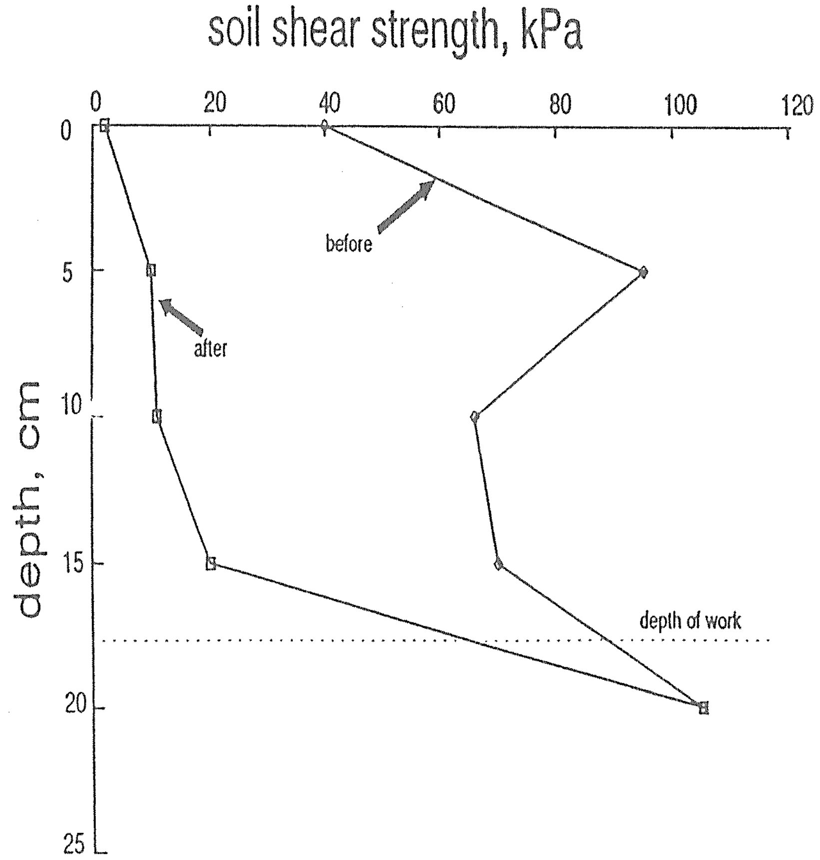


Figure 4.8 Variation in soil shear strength (kPa) before and after ploughing

The vane type shear meter measures only the cohesive component of shear strength. If measurement of both the cohesive and friction components of shear strength are required then a shear box able to be vertically loaded is used (Ashburner and Sims, 1984).

4.3 Measurement of power

All machines need a source of power to enable them to operate. The measurement of power is, therefore a major function of testing and evaluation procedures. It is important in tests of machines whether stationary or in field use to know the power characteristics of the prime mover. It is then possible to establish, for example, whether poor performance in practical operation is due to deficiencies in the power supply.

4.3.1 Rotary power

4.3.1.1 Engine

For tests to determine engine performance, a dynamometer of appropriate size should be used. If this is not available, a machine capable of providing a variable load (generator, water pump) could be used with a torque measuring device fitted into the drive-line (Fig 2.16) with arrangements for the measurement of speed of rotation.

Before any tests are made, the governor, carburetter or fuel pump settings should be checked for correct operation and compliance with manufacturers' recommendations.

A fuel measuring device should be fitted as described in Section 2.2.9 together with arrangements for measuring ambient and fuel temperatures. If the engine is fitted with a variable speed control, all tests should be made with it fully open. Before any readings are taken, the unit should be at working temperature and conditions stabilised.

The shape of the performance curves produced (Section 7, Appendix 7A) will not only provide numerical data on power and fuel consumption, it will show other characteristics of performance. The rise in speed above that equivalent to maximum power and the line of the governor curve will indicate the ability of the governor to maintain speed settings under variations of load. The rise in torque value as speed decreases below maximum power (about 18% in Appendix 7A) will mean that if a sudden overload above maximum power is applied, the engine will not stall.

For official tests where results can be compared with those from other testing stations, fuel consumption is usually presented in mass, for example, kilograms per hour (kg/h) and grams per kilowatt hour (g/kWh). The reasons are that the mass of the fuel injected is one of the important factors determining the power output of the engine and there are variations in the density of fuels. If measurements are by volume, conversion to mass is made by the use of the density of the fuel being used in relation to its temperature.

A torque meter may be fitted into the driveline when the engine is connected to a machine and the power requirement can be measured. If this is not possible, estimations can be made if engine tests are carried out to establish curves showing the relationship between engine power, speed and fuel consumption or exhaust gas temperature or in a petrol engine, the inlet manifold depression (Section 7, Appendix 7B).

4.3.1.2 Power take-off

Fixed dynamometers capable of measuring power developed at tractor power take-offs are large and expensive and are used by large testing organisations and tractor manufacturers. However, less expensive mobile units are available where power is absorbed by a hydraulic pump and valve, usually with water cooling. These units however, are only accurate at particular shaft speeds and are generally not suitable where measurements are required covering the full working range.

This type of unit is ideally suitable when used in conjunction with a pto shaft torque meter (Fig 4.9) for accurate measurements.

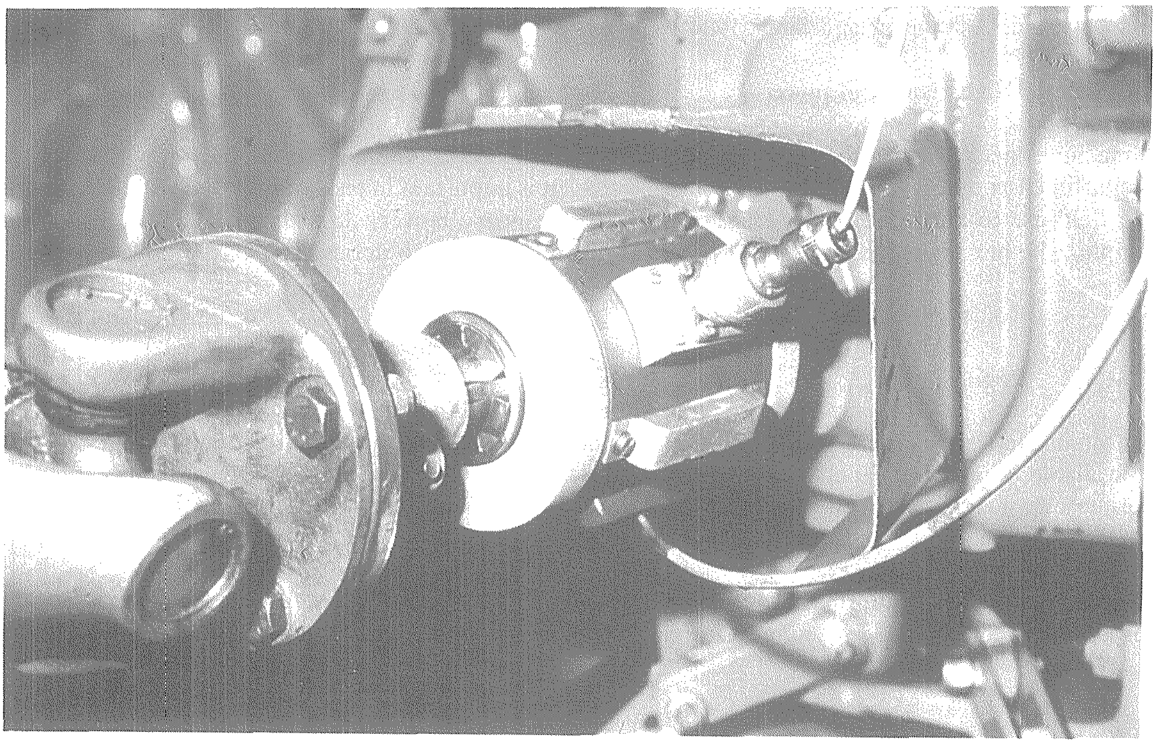


Figure 4.9 Power take-off shaft torque meter and speed counter

The general conditions for carrying out the tests are the same as those used for engines.

The performance curves are also similar to those produced for engines but the torque, power, speed and fuel data is calculated from measurements made during tests at the pto shaft using the engine/pto speed ratio.

When fitting a fuel measuring device into a tractor system, it is important that when measurements are being made, any excess fuel returns are fed back into the feed system **after** the meter (Fig 2.22). The power output at the engine speed equivalent to standard power take-off speeds, 540 and 1000 rev/min is an important factor when tractors are operating powered field machines.

4.3.1.3 Machines

Some methods of establishing the power required to operate machinery has been discussed in Sections 2.2.3 and 4.3.1.1. In some cases, as well as carrying out tests at various machine settings, it is useful to be able to vary the input speed. In this case, an ideal arrangement shown in Fig 4.40 comprises an electric motor coupled to a variable speed gearbox with a torque and speed measuring device fitted into the machine driveline.

4.3.1.4 Electric Motors

The nominal maximum power output and speed of an electric motor are specified by the manufacturer. Methods of measuring the amount of power absorbed by a machine have been discussed in section 2.2.7.

4.3.2 Linear

4.3.2.1 Animal

Animal power is obtained by measuring draft force in relation to forward speed. A force measuring device is fitted between the draft load and the normal yoke or harness towing arrangement. If the line of pull is not horizontal, measurements should be made of the hitch arrangements and angle of pull (Fig 4.10).

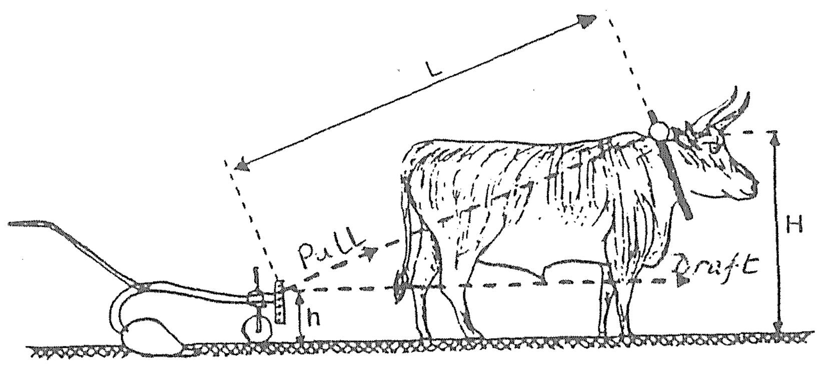


Figure 4.10 Line of pull and horizontal draft. After Zambian Bureau of Standards, 1990(a)

Calculation of the horizontal component (draft) may be made as follows.

1) $$\text{Draft} = \frac{\text{Pull} \times \sqrt{[L^2 - (H - h)^2]}}{L}$$

or

2) Find Θ from: $$\sin \Theta = \frac{H - h}{L}$$

then $\text{Draft} = \text{Pull} \times \cos \Theta$

Power measurements are included in animal performance tests in Section 4.5.

4.3.2.2 Tractor

In order to obtain performance data over the whole range of draft of the tractor, the load applied to the drawbar should be variable and controllable. Testing stations specialising in tractor testing use loading vehicles where power is absorbed either hydraulically or electrically (Fig 4.11). However, a convenient method is to use a second tractor of comparable engine size and weight fitted with an adjustable front towing hitch. With the towed tractor in a similar gear ratio to that of the test tractor, use of the governor control will enable varying loads to be applied (Fig 4.12).

Figure 4.11 Load vehicles for tractor drawbar tests

Figure 4.12 Field measurement of tractor drawbar power

If the line of draft is not horizontal, correction should be made as detailed in 4.3.2.1.

Any draft load exerted to the tractor drawbar will produce slip of the driving wheels. The distance that the tractor moves forward for a given number of revolutions of the drive wheels decreases when the wheels slip.

A simple method of determining the amount of wheel slip is to make a mark on the tractor drive wheel and measure the distance the tractor moves forward, say for 5 wheel revolutions under no-load (A) and then repeat on the same surface and with the same number of revolutions with load (B). The distance A is the mean of several runs made over the same number of wheel revolutions with tractor driven very slowly and when being towed (Fig 4.13).

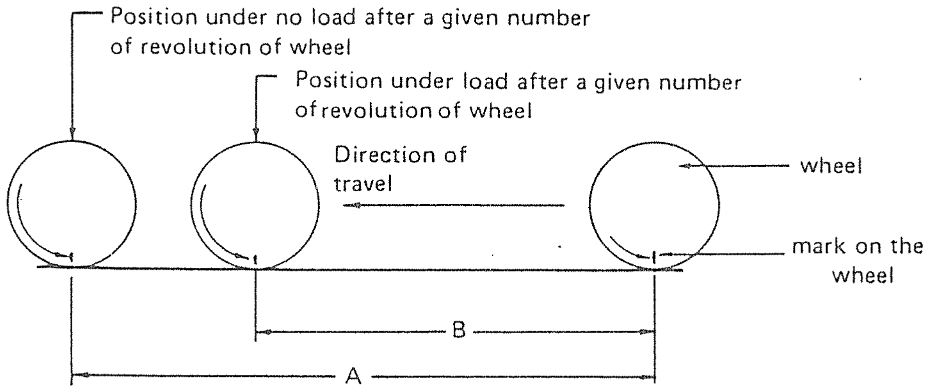


Figure 4.13 Measurement of wheel slip
Source: RNAM, 1983

$$\text{Percentage wheel slip} = \frac{A - B}{A} \times 100$$

The draft force available may be increased by adding ballast to the tractor and wheels. If this is added, it should be in accordance with the tyre manufacturers weight limits.

Means may be provided to measure fuel consumption. If engine or pto tests have already been carried out, comparison of fuel measurements in the field can establish whether maximum drawbar power in the higher gear ratios has been reached.

Tests runs are made in each working gear with maximum governor setting and variable load up to the draft limit to enable performance curves of power and slip to be produced (Section 7, Appendix 7D). In all gears, the power available is limited by wheel slip especially in the lower ratios where the torque available cannot be transmitted to the ground. During official tests to ISO and OECD standards, drawbar tests are made on a hard surface which not only reduces wheelslip but allows results from different testing stations to be compared. These draft forces are much higher than those that can be obtained on surfaces likely to be encountered during normal field work. Taking a coefficient of traction on a hard surface of 1.0 for comparison, typical results from field work show cultivated soils giving 0.5 to 0.7, stubble 0.4 to 0.7 and grassland 0.5 to 0.75. In the higher gears, the pull limit is the torque of the engine and the increase in pull above that at maximum power reflects the shape of the engine curve.

Spaces between the apexes of the power curves are areas of draft and pull (power) which cannot be obtained. If the number of gear ratios is increased, the spaces are closed and greater flexibility is obtained.

4.3.2.3 Machine

The draft power of towed implements and machines during work is calculated from measurements of draft force and forward speed. If the implement is tractor mounted the method of draft measurement described in Section 4.6.1 should be applied.

4.3.3 Hydraulic

4.3.3.1 Oil

With the measuring equipment and circuit set up as described in Section 2.2.9, the pump is engaged and the tractor engine is run with the governor control fully open. When the system has reached working temperature, operation of the throttle valve will allow measurements of flow rate to be made at various system pressures (Fig 4.14).

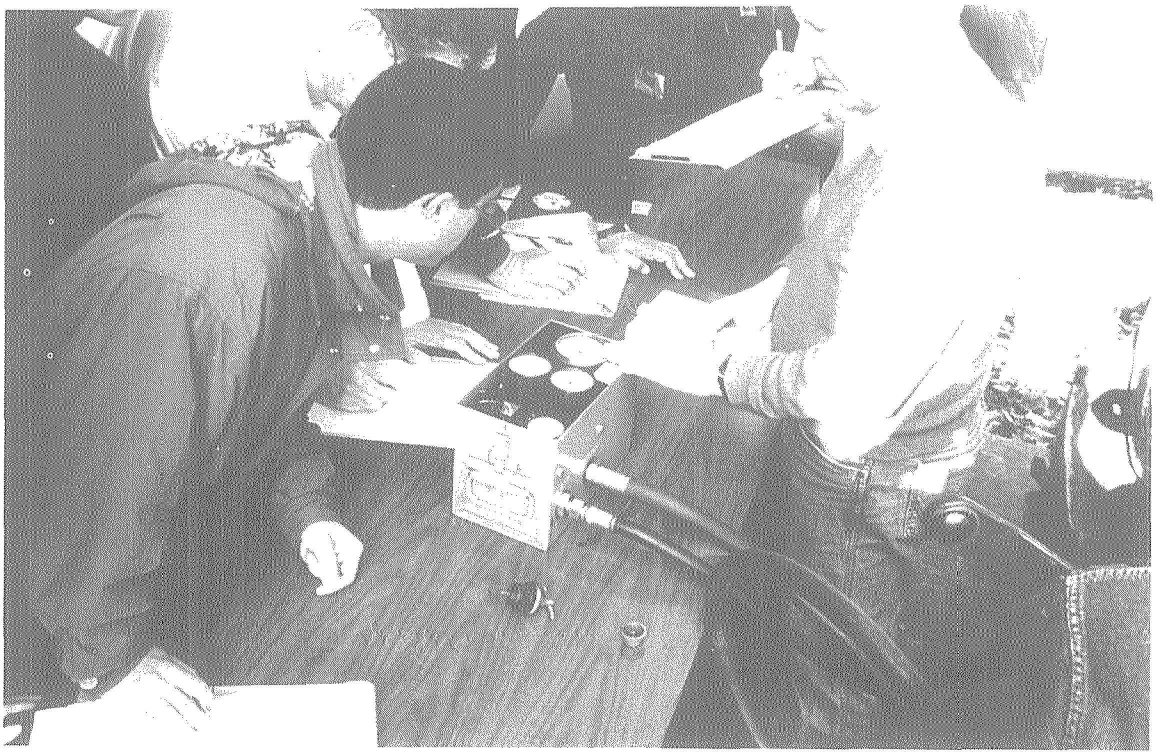


Figure 4.14 Measurement of hydraulic flow and pressure

Pressure is increased until oil flow in the system ceases when all the flow is through the relief valve on the tractor. Hydraulic power is calculated and is then included in performance curves in relation to system flow and pressure (Section 7, Appendix 7C).

Power will increase with pressure at approximately a constant rate to the maximum as flow decreases slightly due to internal leakage. At the maximum power point, the tractor relief valve starts to open. The valve is fully open at the point of maximum pressure.

Circuit pressure will affect the lifting force of the tractor linkage and flow will affect the speed of lifting. Official tractor tests include measurement of lifting force throughout the full range of lift with various linkage arrangements (OECD, 1967).

4.3.3.2 Water

The measurement of input power to a water pump and the outlet power imparted to the liquid will enable the pump efficiency to be calculated. The methods of determining the input power supplied from engines or electric motors has already been described. The flow rate of a water pump will depend on the dynamic head which, at any given speed, will vary with the static suction and delivery heights (heads) and sizes of suction and delivery pipes. In practice, readings from pressure gauges fitted into inlet and discharge pipes (Fig 4.15), the distance they are fitted in relation to the centre line of the pump and the size of the pipes together with the discharge rate will allow the total dynamic head to be calculated. The power imparted to the liquid is then a function of head and discharge rate.

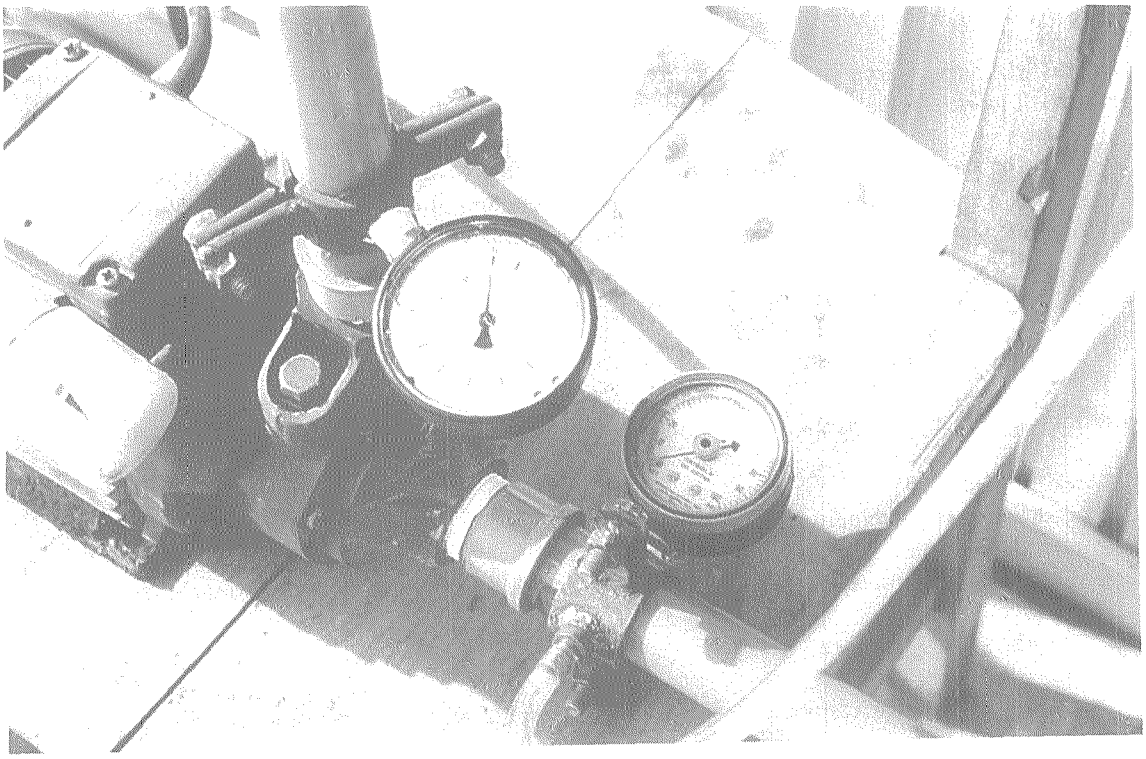


Figure 4.15 Pressure gauges fitted to pump inlet and outlet for determination of head

Operation of valves fitted into inlet and discharge pipes will allow the dynamic head to be changed without alteration of pump location or pipe work. Results for the rate of discharge can then be plotted against variations of head, speed, input power and efficiency.

4.4 Performance of hand tools

4.4.1 Performance tests

Hand tools depend very much for their proper operation on the manipulative skills of the user. The complicated movements involved make it virtually impossible to measure directly the mechanical work or power transferred from the operator to the machine although it is possible to measure the rate of bodily energy consumption by the test subject.

The two main techniques for assessing human power consumption, by measuring oxygen consumption or heart rate are reviewed in Section 5. In general the respirometry technique is intrinsically more accurate but less suited to work, such as field work, involving mobility and movement. In such cases heart rate measurements will usually give an acceptably accurate indication of power consumption.

When measuring performance, it should be considered that:

a) Work rate depends upon the power which the operator is willing and able to supply, not upon any inherent demand by the machine.

b) The power which the operator is able to supply depends upon the length of time for which it is supplied.

Operators will wish to give of their best in testing different tools and machines. If a test is conducted over a short time period (less than one hour) they will usually work at rates which cannot be sustained over a full working day. Tests should be made continuously by the same operator for at least four hours in each of several soil or crop conditions.

The total work output (area covered, quantity of soil or seed sown, etc) is then measured and the average hourly rate of work calculated. This method enables a realistically sustainable work rate to be determined.

Information on the work rate as found by testing should be supplemented by the operators' subjective judgements as a guide to a reasonable work regime, including an estimate of necessary rest periods. The quality of work should also be assessed, preferably on a comparative basis.

An example of a test procedure for a hand hoe is given in Section 11.

4.4.2 Ergonomic assessments

In addition to performance tests, assessments should be made on ergonomic design and control including:

a) Working posture.
b) Size, shape and movement of drive handles/pedals, controls and adjusting devices.
c) Controllability.
d) Arrangements for materials handling (feed to, and delivery from, processing machines).

4.5 Animal performance

Draft animal performance cannot be expressed in the same terms as tractors and will vary according to weight, condition, fatigue and length and severity of work.

There are two aspects of animal performance considered in the test procedure. Firstly, machine designers and manufacturers and to some extent harness makers may be interested in maximum instantaneous force. This is the force, relative to speed and animal weight, exerted if an implement is stopped by some obstruction in the soil. It is known empirically that the maximum instantaneous force of an animal (or animals) is approximately equal to body weight in the case of bovines, and may rise to twice body weight for equines. So that an ox team weighing 800 kg would be capable of producing a maximum instantaneous force of about 800 x 9.81 = 7,848 N.

The maximum instantaneous force is influenced not only by the animals' body weight, but it is also proportional to the square of forward speed. Figure 4.16 shows the maximum forces achieved by an ox team weighing 600 kg over a range of forward speeds. It can be seen that the force achieved (3 kN) at 0.7 m/s, is half that obtained at 1.3 m/s (6 kN). Figure 4.17 shows a practical arrangement for determining the maximum forces.

Secondly, the information of more interest to farmers is the maximum force, speed and duration that animals can sustain throughout the working day. Tests are designed to determine the maximum in each case without animals suffering excessive fatigue and may be carried out on a track (Fig 4.18) or in the field, and means must be provided to apply a variable draft load. If a purpose built vehicle is not available, an adjustable plough or tool carrier that allows soil acting elements to be added to removed could be suitable for this purpose. The shorter tests proposed in the procedures will only give an indication of the animals' potential the longer tests should be made wherever possible and will yield more reliable information.

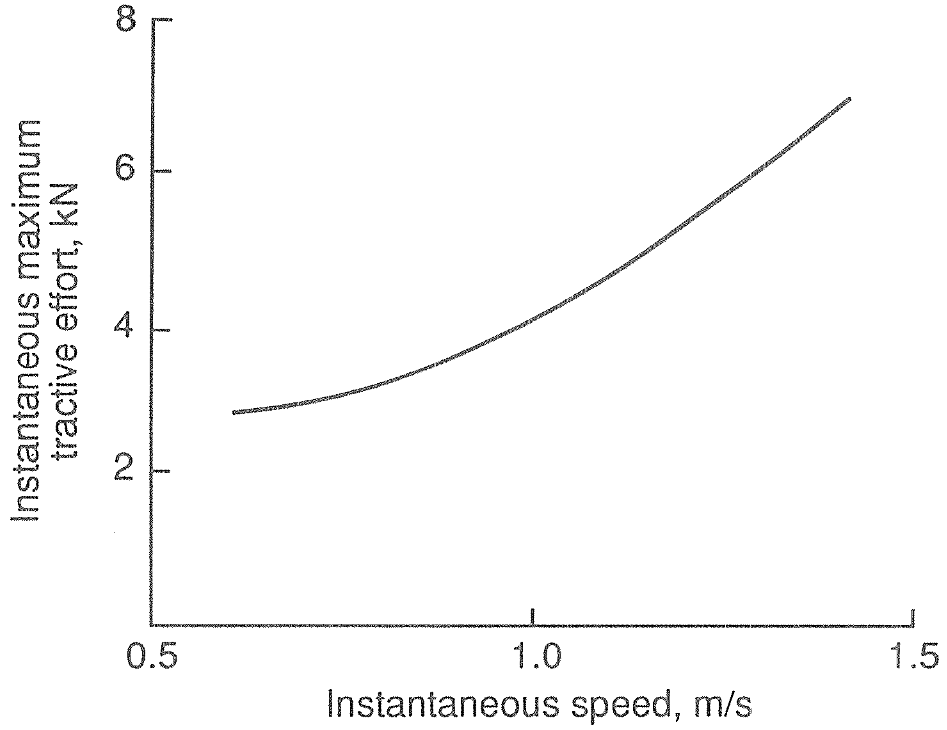


Figure 4.16 Instantaneous maximum forces of a 600 kg ox team over a range of forward speeds. After Viebig, 1982

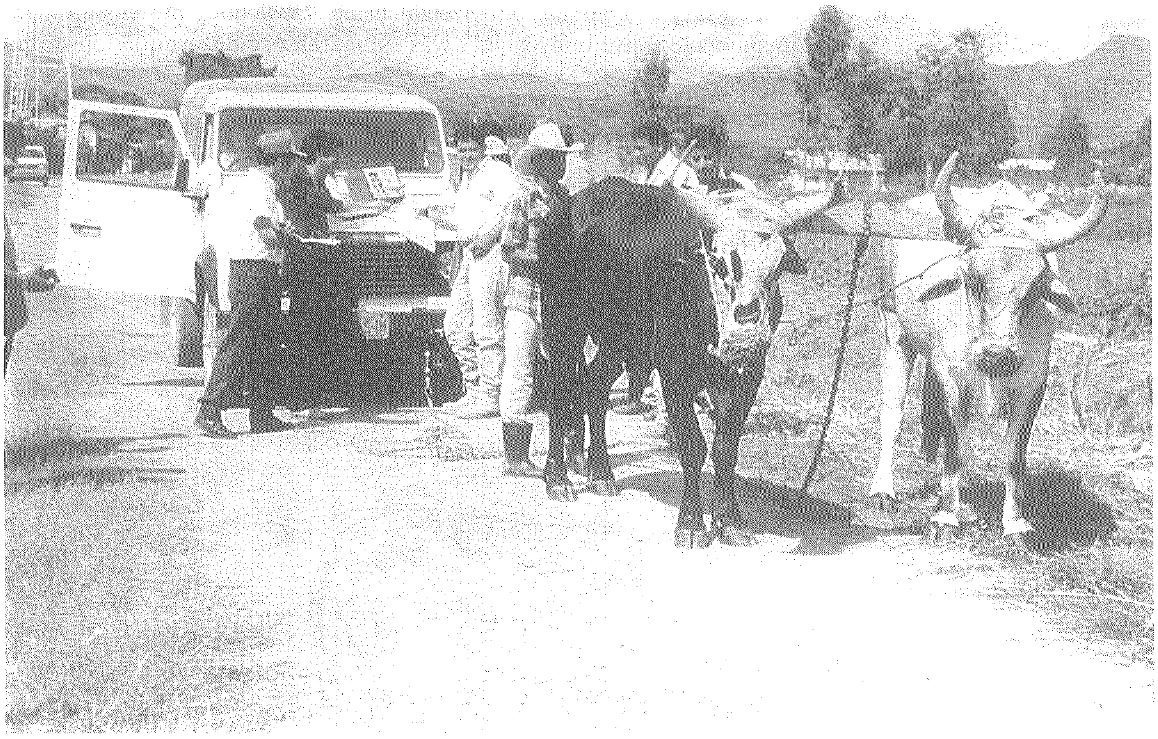


Figure 4.17 Measurement of instantaneous maximum force of oxen using a vehicle as an anchor

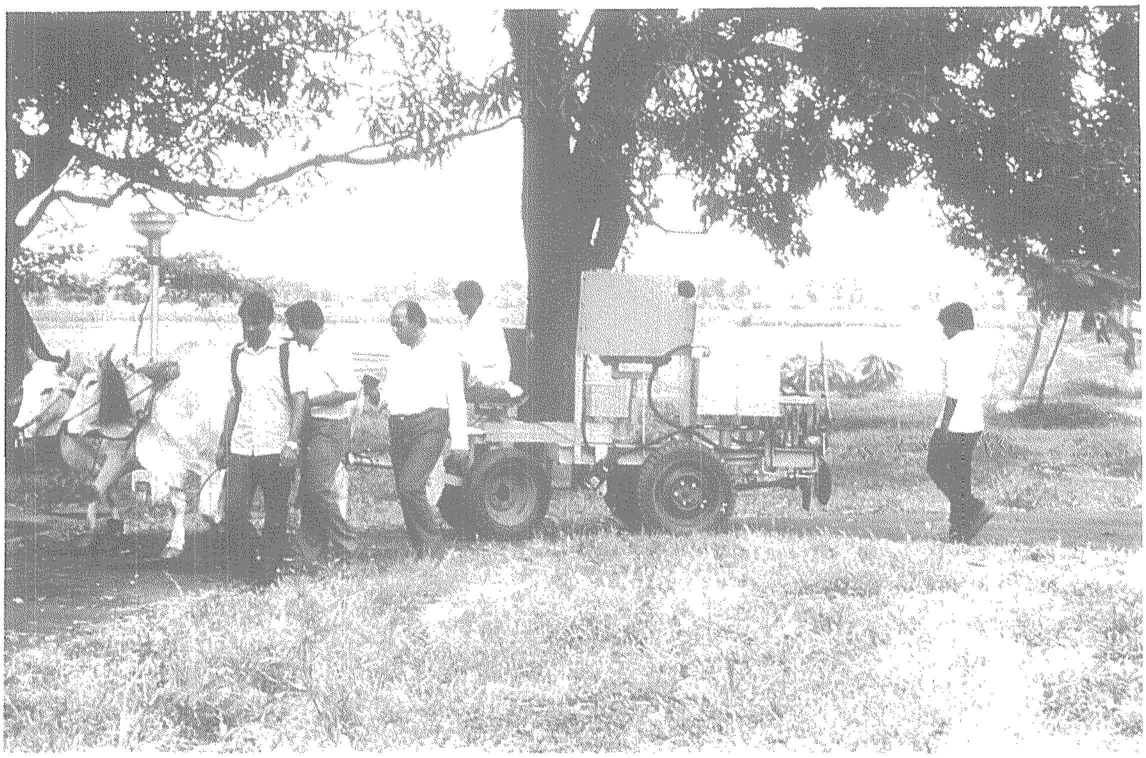


Figure 4.18 Hydraulic load car for draft animal performance measurement

A draft animal's weight is of crucial importance in determining its draft capabilities. If it is not possible to weigh the animals directly it will be necessary to estimate bodyweight using lineal body dimensions. In a study of bovines in Mexico (Sims y Jácome 1985) live body weight was estimated using the equation (Figure 4.19):

$$\text{Weight (kg)} = G^2 \times L \times 92.46$$

Where:

G = The heart girth in metres
L = Body length from front shoulder to the base of the tail in metres

Ideally each species and breed of animal ought to be weighed and the relationship between weight, heart girth and body length estimated empirically.

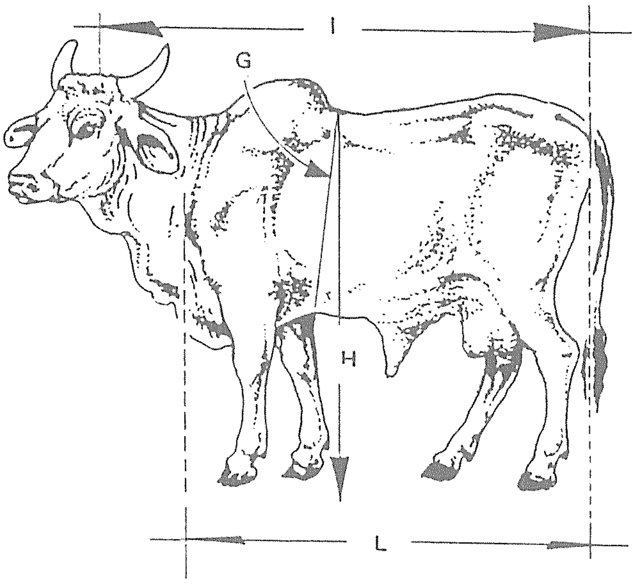


Figure 4.19 Estimation of bovine weight
Source: Sims et Jácome, 1987

4.6 Machine performance

4.6.1 Cultivators (primary and secondary)

4.6.1.1 General

It is important to specify the details of design and construction and range of settings of an implement on which tests are to be carried out. Before any field work is attempted, the implement should be examined, the specification provided by the manufacturer checked and operators should familiarise themselves with settings and operating details.

If part of the investigation is to study wear of soil engaging parts, these should be measured and weighed so that further measurements can be made after periods of work.

The test conditions must also be clearly specified. The tractors and animals selected should be compatible with the use of the implement under test and should be driven by experienced operators.

Field sites chosen for a particular soil type should reflect the objectives of the test and may include a range of typical farm conditions.

Plots and distances for speed measurement should be marked out with an area of similar soil conditions for preliminary trials and for no-slip distance measurements. From experience, a convenient size for the plots is 0.16 hectare (40 m square in strips of 10 m wide) for animals and 1 hectare for tractors. In order that time taken for turning is not unreasonably high, the rectangular plots should have a side ratio of not less than 2:1.

Soil strength should be measured and samples for soil conditions and type analysis should be taken at random sites on the marked plots.

4.6.1.2 Draft measurement

Draft force measurements can be made during the test on a towed implement by fitting a dynamometer into the towing arrangement (Fig 4.20).

Figure 4.20 Measurement of implement draft

If the implement is tractor mounted, the following method should be used on the trial plot prior to the main test (Fig 4.21). A dynamometer should be attached to the front of the tractor on which the implement is mounted. Another tractor should be available to pull the implement-mounted tractor through the dynamometer. The auxiliary tractor pulls the implement-mounted tractor in neutral gear but with the implement in the operating position. Read or record the draft in the measured distance (20 m) as well as the time taken to traverse it. On the same field, lift the implement out of the ground and read or record the draft. The difference gives the draft of the implement.

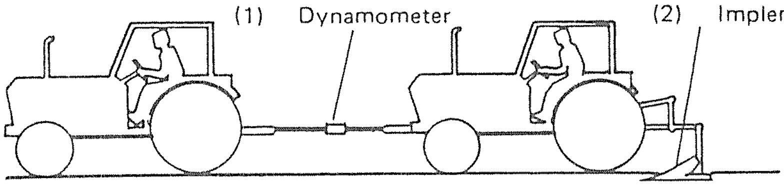


Figure 4.21 Measurement of draft of a tractor mounted implement
Source: RNAM, 1983

4.6.1.3 Machine capacity and field efficiency

When the implement has been satisfactorily set, each test plot should be completed without stopping unless this is necessary due to adjustments, breakdowns or animal rest periods. Measurements are made of draft, forward speed and wheelslip (Fig 4.22). Where applicable, width and depth of work and total work area and time should be recorded.

The time lost in the field due to turning and other factors including failure to use the full width of the implement will affect field efficiency. This is calculated as follows:

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$$

where:

$$\text{Effective field capacity (ha/h)} = \frac{\text{Total area cultivated (ha)}}{\text{Total work time (h)}}$$

and

$$\text{Theoretical field capacity (ha/h)} = \frac{\text{Mean working width (cm) x Mean speed (m/s) x 36}}{10\ 000}$$

4.6.1.4 Soil Inversion

Besides observation, soil inversion is quantitatively expressed as ratio of numbers of weeds or stubbles of last crop left on soil surface after operation to that before it:

$$F = \frac{W_P - W_E}{W_P} \times 100$$

where

F = Indicator for soil inversion; ratio of weed and crop stubble being covered.

W_p = No of weeds or crop stubble before operation per unit area.

W_E = No of weeds or stubble exposed on the surface after operation.

Figure 4.22 Field measurement of forward speed, wheelslip and turning time

This can be done most conveniently by using a light frame of wood and angle iron to a square of 1m side, inside dimension. It is also helpful if wires are welded across this square to give four smaller squares of 0.5 metre side (Fig 4.23). The frame is dropped on the uncultivated land and the number of weed and stubble roots in the 1 metre square counted and recorded. In a plot 40 x 10m, only 3 readings are necessary, one in the middle and one 3 metres approximately from each end.

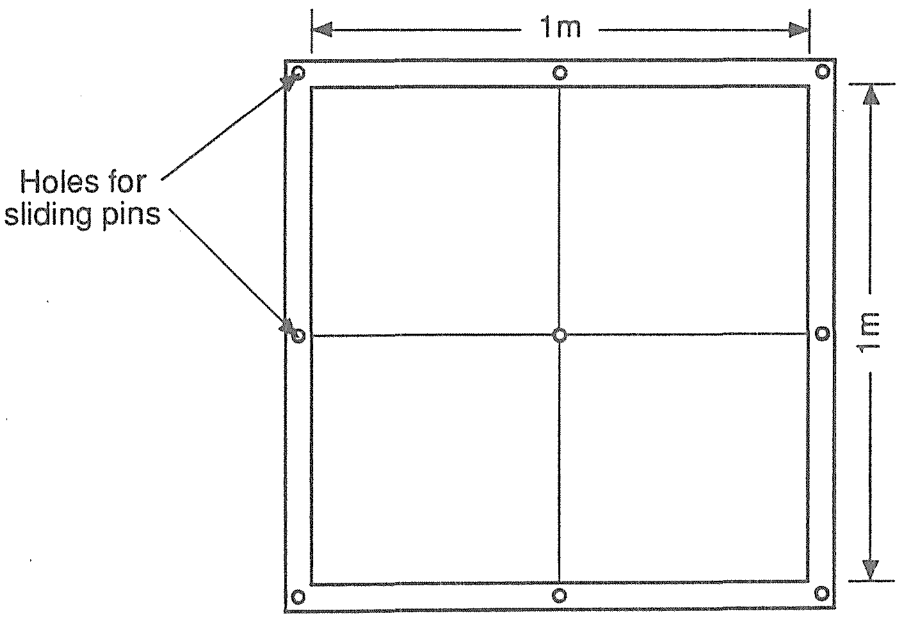


Figure 4.23 Frame for assessment of soil inversion and surface evenness

After cultivation, the same count is taken usually to record the number of uncovered roots of weed or stubble in the 1m square frame. This is not a strictly accurate measurement because weeds only lightly covered may continue to grow, but it has to be accepted in many cases where it is not feasible to go back to the plot later for a more accurate count.

4.6.1.5 Surface evenness

This measurement is taken to give some value to the levelling effect of the secondary cultivation implement. A suitable tool is an adaptation of the frame used for the weed and stubble count. At each corner, at the mid-way point of each side, and at the centre of the frame, pieces of tube are fixed in the frame. In each of these 9 holes in turn, a sliding pin is placed so that the graduations on it indicate the depth of the soil below the plane represented by the frame itself.

In operation, the frame is dropped on the ground in a random manner and the depth of the soil surface below each of the nine holes is recorded.

Surface evenness is the average of all 9 readings. Three replications should be made in a small plot, five in a large one.

4.6.2 Seeders and planters

4.6.2.1 General

The effectiveness of a seeder or planter will depend not only on its mechanical design but on type and condition of seed, the condition of the soil and field topography which should all be adequately described.

4.6.2.2 Laboratory tests

Laboratory tests are made with differing seed types and sizes to examine the performance of the metering mechanism and provide data for settings and field tests.

With the machine jacked clear of the ground delivery rates are measured with hoppers full, half full and a quarter full. The seeds used should not contain any damaged grains to enable any damage caused by the machine to be established. The seed distribution pattern may be measured on a specially designed test rig where the ground wheels are driven at speeds recommended for field operation. Seeds are distributed on to a belt moving at the same linear speed and covered with a sticky substance such as grease or heavy oil.

If a rig is not available, the machine may be run over a level track of at least 10 metres at the recommended speed. A surface to prevent to seed from bouncing such as clean sand, coconut matting, thick felt or coated card is laid beneath the seed outlet (Fig 4.24). Runs are made using each outlet with a variety of seeds and rate settings. Measurements are made over about 2 metres, of the spacing between individual seeds or seed hills and calculations are made of average seed spacing, seed spacing standard deviation and evenness.

These calculations are also used for field measurements of seed placement. In this case, modifications are made to the machine to enable the furrow to remain open and not covered. The measurements may be made on plots used for output tests.

4.6.2.3 Field tests

Tests are made on selected plots to measure total output (kg/ha) in differing soil and field conditions. Measurements are made of total area covered, operating time, speed, draft (Fig 4.25) and wheelskid. The effects of vibration and work on slopes may also be investigated. During the tests, observations may be made on ease of operation and adjustment and any maintenance or safety features.

Figure 4.24 Sand track for seed distribution assessment

Figure 4.25 Measurement of seeder draft

4.6.3 Fertiliser distributors

Fertiliser distributors fall mainly into three categories, full width machines which include pneumatic spreaders, broadcasters and distributors attached to and operating with seeders and planters. All machines are designed to distribute quantities of fertiliser at pre-determined rates as uniformly as possible or to place fertiliser accurately alongside seeds. Machines may be trailed by animals or tractors and driven by land wheels or tractor mounted or semi-mounted and driven by the tractor power take-off.

Test procedures are designed to cover all types of machine with tests in the laboratory and in the field. The type and condition of the fertiliser may affect the results and should be checked and specified in the report, only types recommended for the machine under tests should be used.

Measurements to examine the performance of the metering mechanisms may be made in the laboratory. The methods for determining transverse distribution patterns differs depending on the type of machine under test.

Where machines place the fertiliser in rows the delivery from each spout will be recorded. For other machines, the spread material will be divided in longitudinal strips equal to the number of outlets and the amounts weighed. The results of weighings will be presented as a histogram, (Fig 4.26) and the percentage variation from the average of the highest and lowest outputs will be recorded.

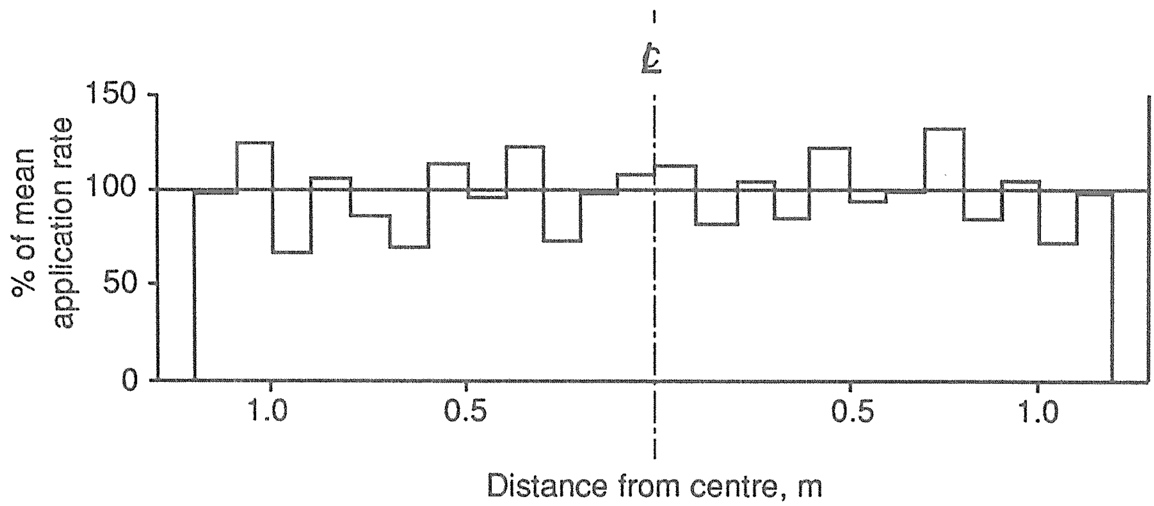


Figure 4.26 Lateral distribution of fertilizer with a full width distributor

For broadcasters, the machine is operated over a level floor area at normal speed and feed rate settings. During the run, fertiliser is collected in a series of trays placed at right angles to the line of travel (Fig 4.27). Following each run, the contents of each tray is weighed and histograms of the distribution pattern are drawn. If trays are not available, an alternative method is to spread the fertiliser on to a clean floor area and to sweep up equal strips parallel to the direction of travel and to weigh the amounts collected.

Using the results of the transverse distribution tests, histograms of the total spreading rate at various points of overlap across the bout can be drawn (Fig 4.28). From these results, the optimum bout width can be established.

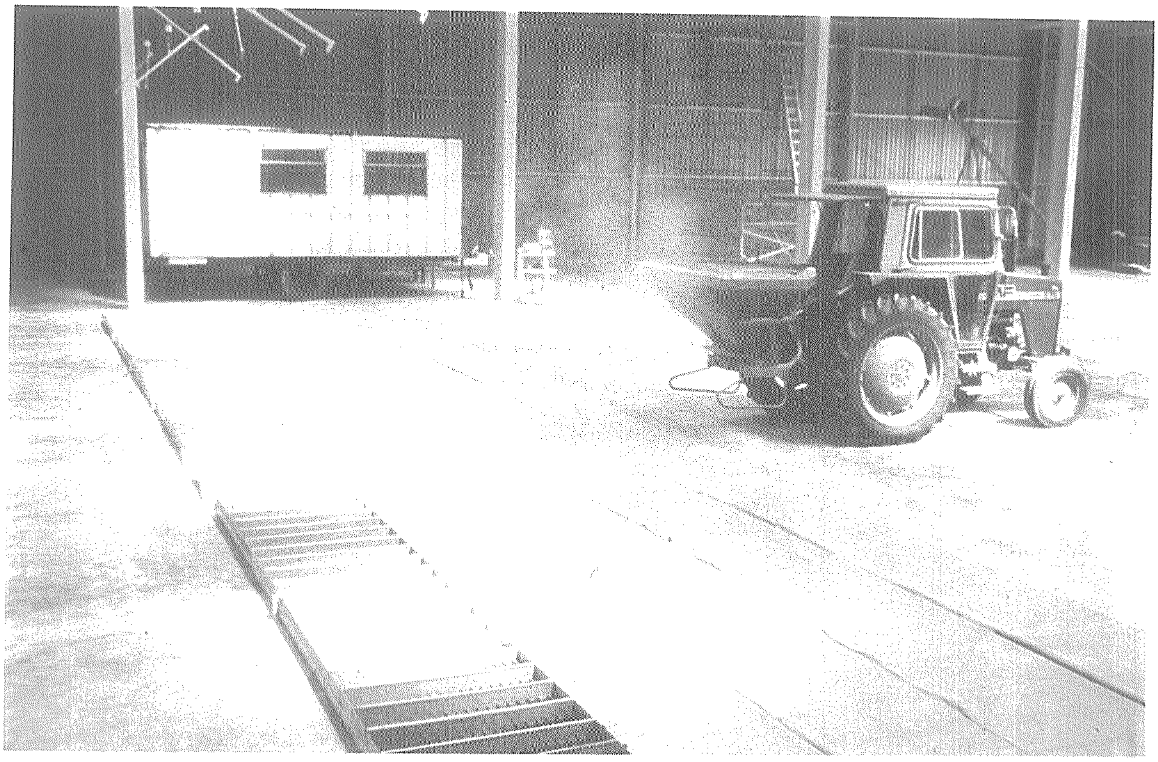


Figure 4.27 Measurement of lateral distribution of a broadcast fertilizer distributor

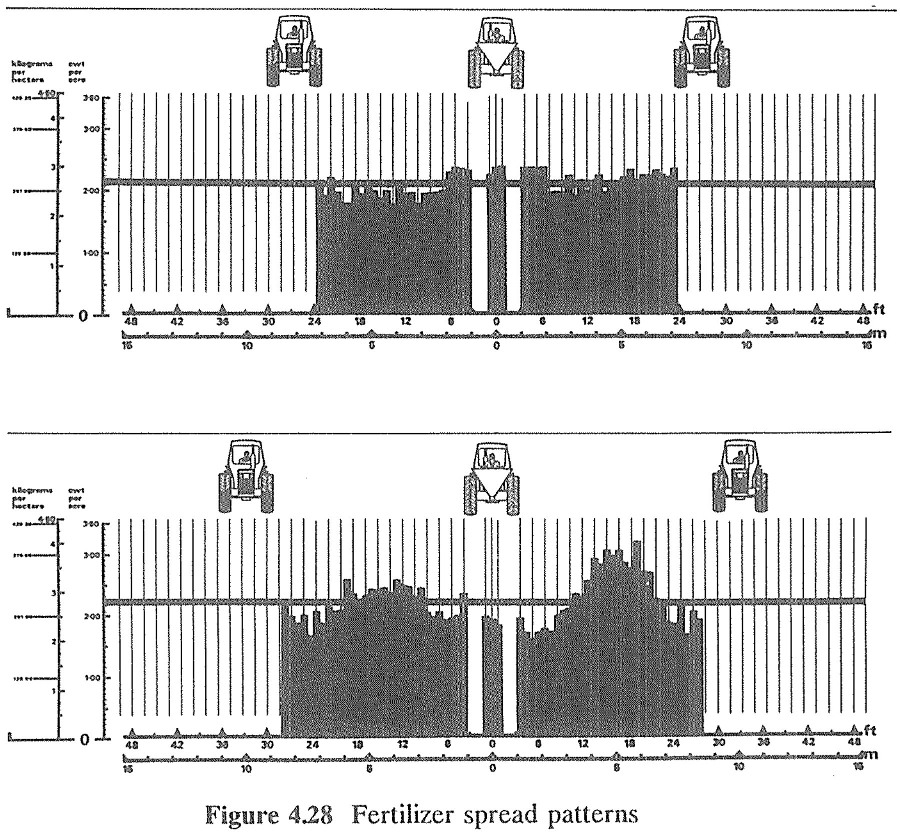


Figure 4.28 Fertilizer spread patterns
Source: Culpin, 1982

Histogram indicates total spreading rate at various points across the bout, after overlap. Upper histogram shows a good performance, within acceptable limits. Lower histogram indicates (a) bout width is too narrow, causing peaks in both left and right overlap areas; (b) the bad peak on the right side was due to the fertilizer being spread further on the left side than on the right.

4.6.4 Knapsack Sprayers

Knapsack sprayers and blowers are carried by the operator. Sprayers are hand operated and comprise a tank with a pump and cylinder to allow pressure to be maintained. Blowers have a small engine driving a fan directing air through a tube, pesticide is injected from a tank through a variable nozzle into the air stream.

For sprayers requiring continuous operation, the efficiency of the pumping arrangement is important for spraying accuracy and ergonomic considerations. A test is carried out to determine the ratio of the volume of fluid discharged to that of the piston or plunger displacement. Where sprayers have external pressure tanks, these should be tested for safety.

Nozzle output is determined by measuring the total volume of spray for a given time. Tests are made with various nozzles and output pressures, a pressure gauge being fitted as near to the nozzle as possible (Fig 4.29).

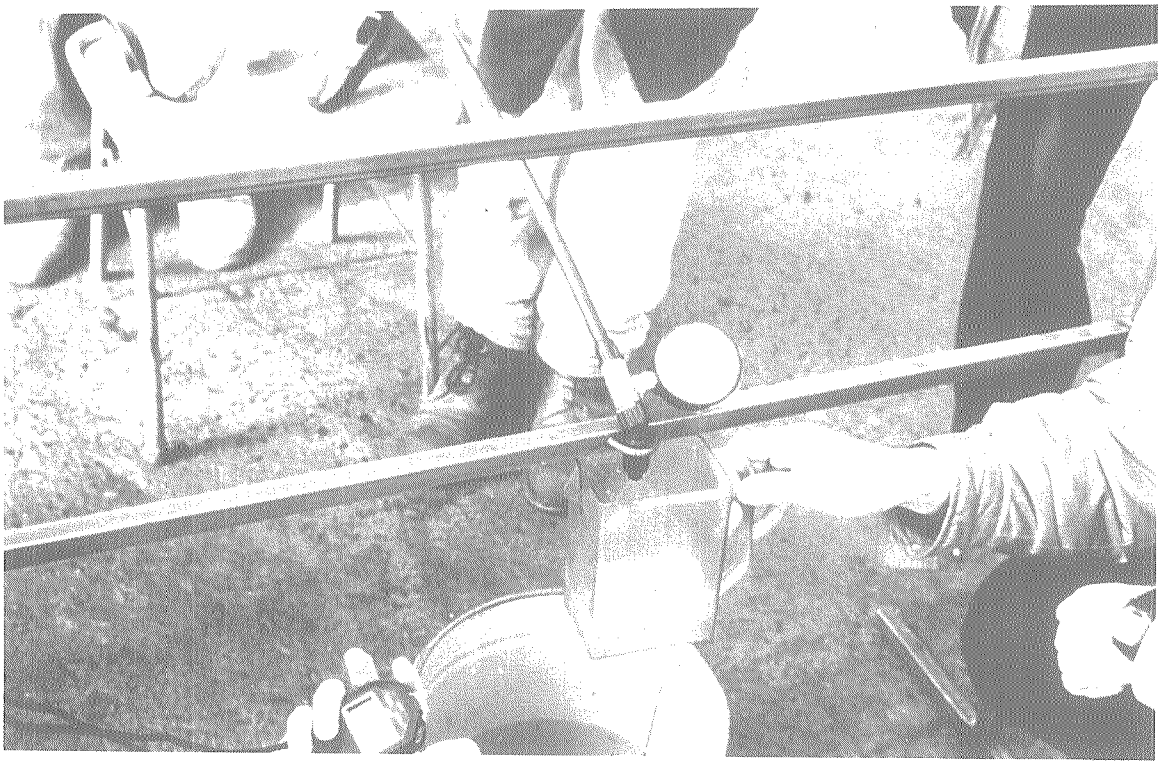


Figure 4.29 Measurement of spray nozzle pressure and delivery

The pattern of nozzle spray distribution is established using a "Patternator" measuring device (Fig 4.30), consisting of channels for collecting the liquid and graduated cylinders for measuring the amount collected in each channel. Observing the liquid level in the cylinders will show a "pattern" of distribution (Fig 4.31). Measurements are made of the volume of liquid in each cylinder.

Tests at various pressures and nozzle heights above the channels are made and histograms of distribution are plotted as shown in Fig 4.32.

The rate of output of motorised blowers is established by placing a known volume in the spray tank and with the engine running at the recommended speed, measuring the time taken to emit the whole amount. Repeat tests may be made with various nozzles and settings.

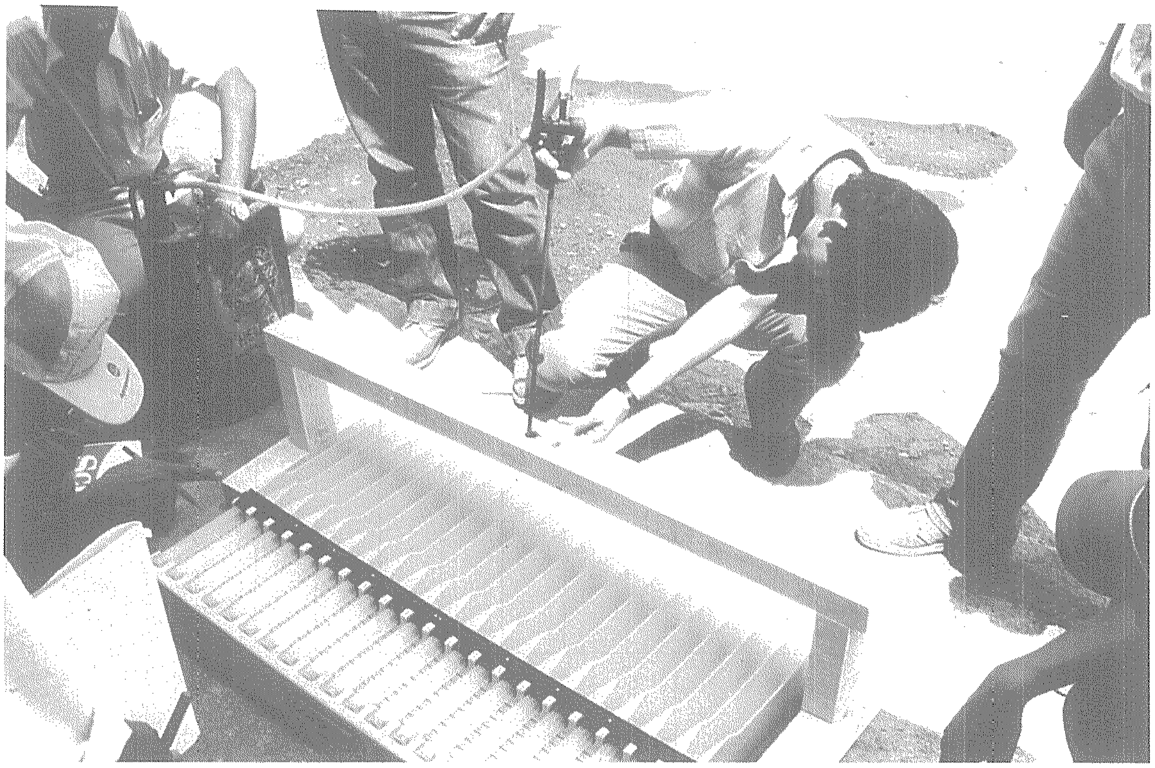


Figure 4.30 Use of "Patternator" spray distribution rig

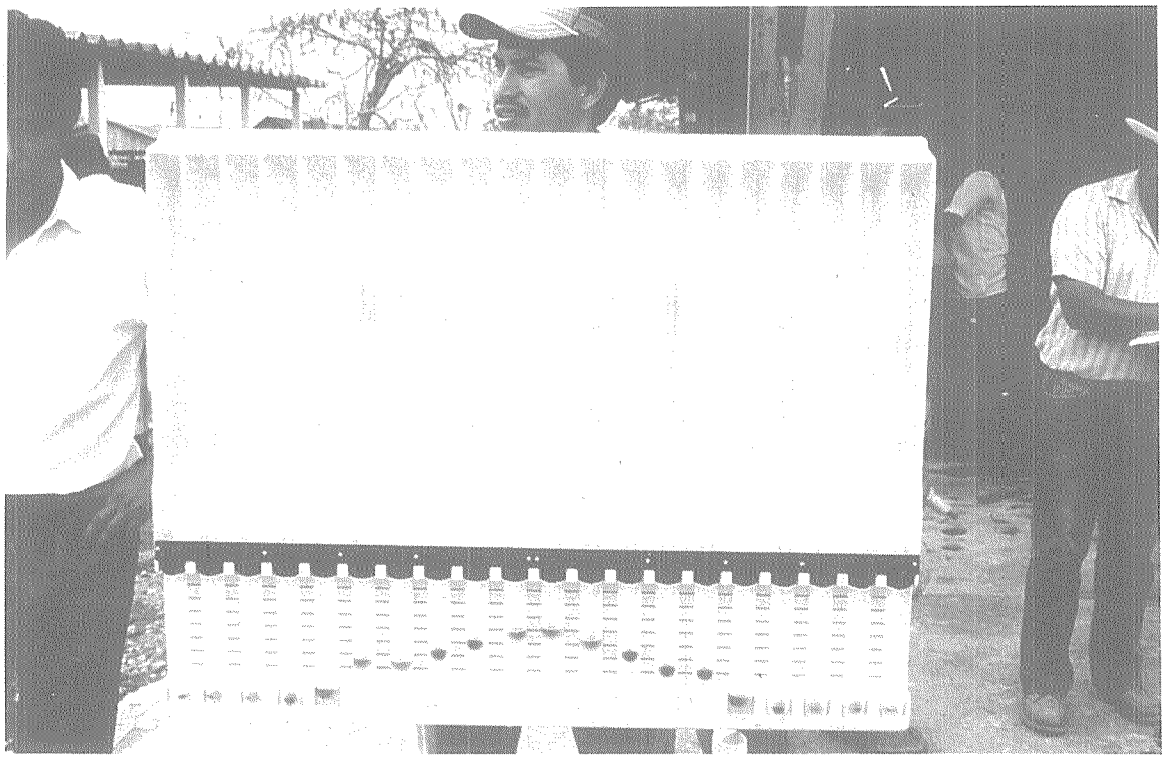


Figure 4.31 Spray nozzle distribution pattern

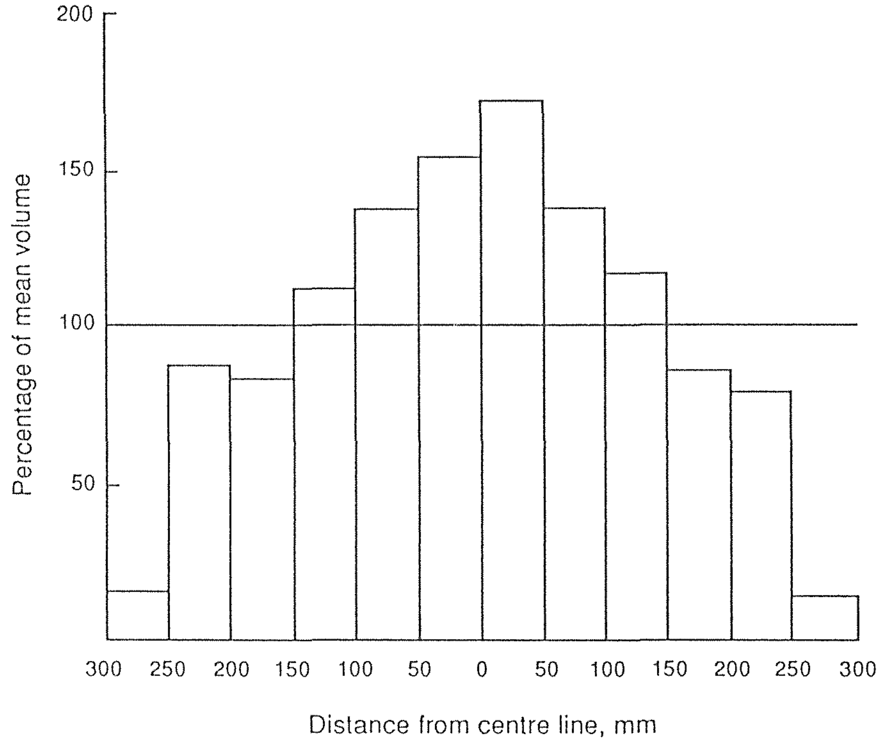


Figure 4.32 Histogram of spray distribution

The horizontal throw and distribution of spray is measured by setting up target cards as shown in Fig 4.33. A dyed liquid is sprayed for 5 seconds and the cards are then examined. Tests should be made in a wind free environment with various nozzle settings. A simple alternative method is to spray clean liquid over a dry concrete floor which will allow spread distances to be measured. The vertical throw is measured by setting targets to a rope which can be raised as sown in Fig 4.34, the nozzle is set at an angle and measurements are made as for horizontal throw.

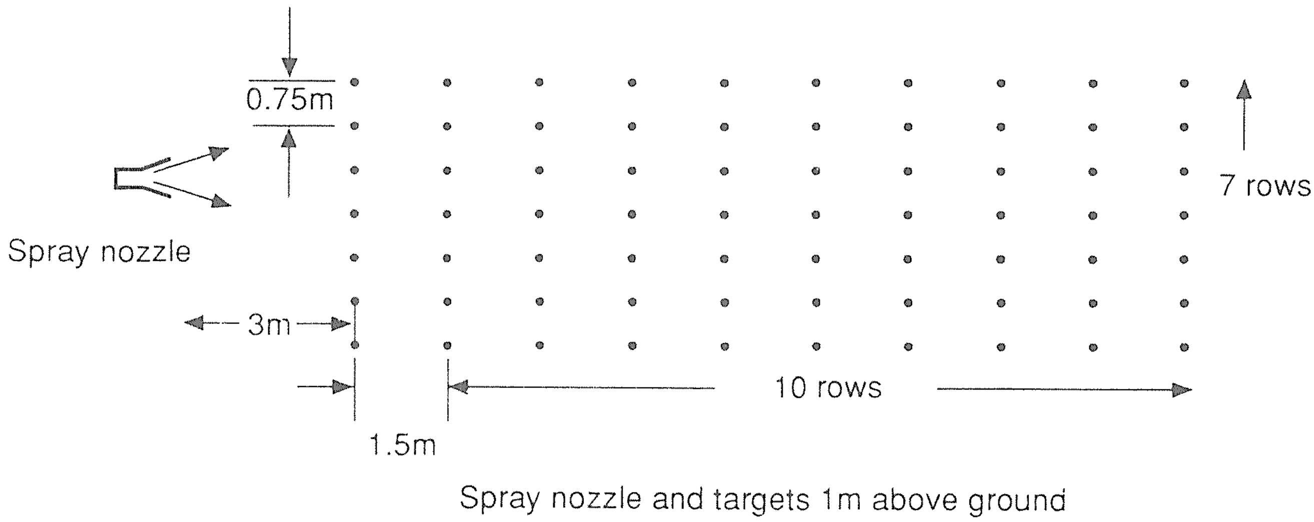


Figure 4.33 Arrangement of targets for horizontal throw tests

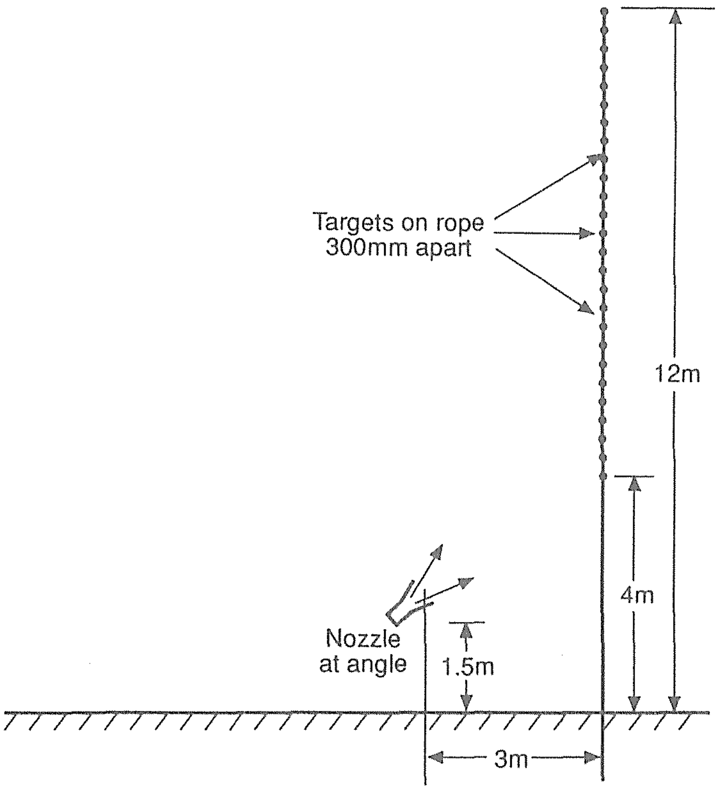


Figure 4.34 Arrangement for targets for vertical throw tests

Engine fuel consumption is established by measuring the time for the engine to use a known quantity of fuel. The engine throttle is maintained fully open and the sprayer is adjusted to maximum feed rate. With the engine running as for the fuel consumption test, the maximum noise level is measured at the operators ear position (Fig 4.35).

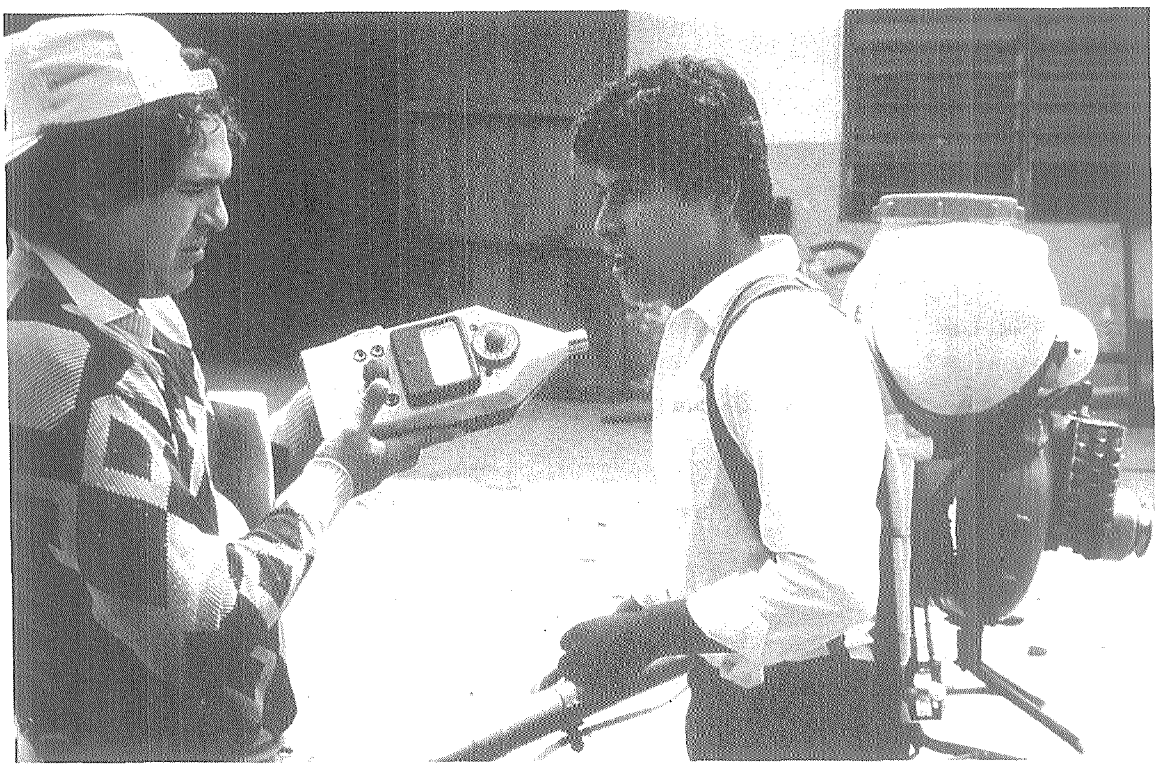


Figure 4.35 Noise level test

4.6.5 Field Sprayers

Field sprayers may be tractor mounted or trailed and consist basically of a tank and power driven pump supplying liquid through a control valve to a boom carrying a number of nozzles. They are designed to apply a required rate of chemicals on various types of field crops.

Liquid supply to the nozzles will depend on the speed of the main pump, the pump efficiency and the system pressure. With the pump running at the recommended speed and the main tank half full, measurements are made of discharge at various system pressures. Calibrated containers may be used for this purpose.

Discharge and distribution patterns of individual nozzles at various heights may be made using the method described for Knapsack Sprayers. Total discharge for the whole boom is measured using calibrated containers under each nozzle (Fig 4.36). The bout width is the number of nozzles multiplied by the nozzle spacing in metres.

The distribution pattern for the whole boom is determined. For this test, a "Patternator" is used and if this is not wide enough to cover the whole boom measurements may be made in sections. All nozzles must be working when measurements are made (Fig 4.37).

Figure 4.36 Spray boom discharge measurement

Figure 4.37 Measurement of whole boom distribution

4.6.6 Manual pumps

Manually operated pumps are available in many designs incorporating vertical, horizontal and semi-rotary pumping actions. Operation may be by hand-lever, foot-pedal(s) or a combination of both.

The height of the pump above the water source and the height of the water outlet will affect the pump performance, as will the rate of operation. The pumping rate will be a function of an operator's ability to operate consistently over a reasonable period. The tests are designed therefore, to include these variables and ascertain their effect on pump performance. For the tests, the pump is mounted in such a way that height changes may be made while allowing normal operation (Fig 4.38) and discharge to be measured by a calibrated container. Typical performance curves show discharge plotted against total head (Fig 4.39) and against pumping rate.

Figure 4.38 Manual pump test

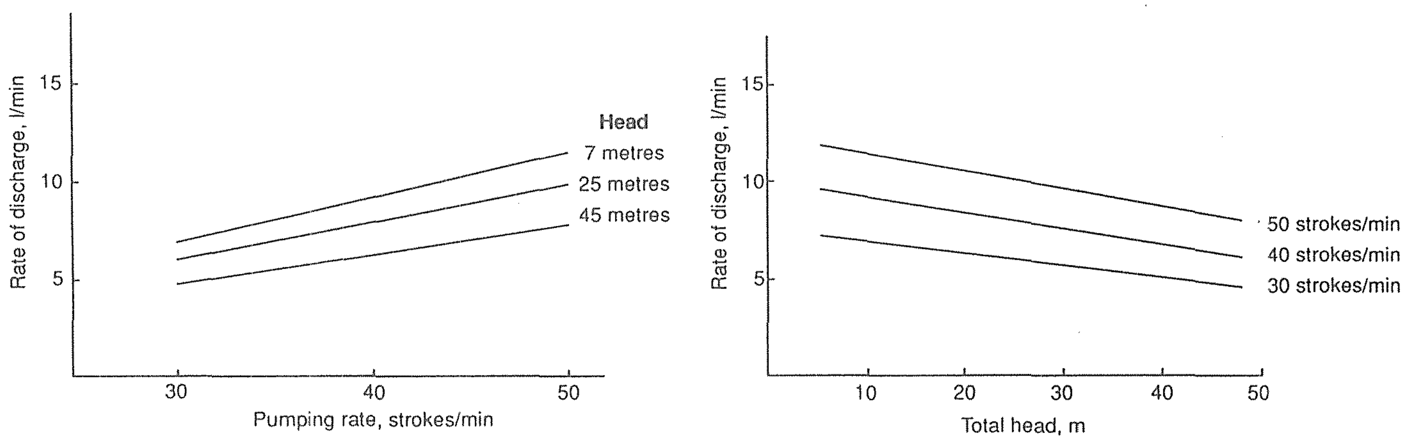


Figure 4.39 Typical curves of discharge of manual pump at varied head and pumping rates
Source: World Bank, 1982

The pump performance tests are not designed to measure the human power required for operation. However, practical tests under variable conditions will allow operators to work the pump for longer periods (not less than one hour), and will enable practical and some ergonomic assessments to be made.

4.6.7 Power operated pumps

The object of the tests of power driven pumps is to establish their efficiency by measuring the outlet power calculated from the rate of discharge and total head and then comparing this with the inlet power. The methods for establishing inlet power from the prime mover is discussed in Section 4.3. Pump output power measurement is discussed in Section 4.3.3.2.

4.6.8 Grain Threshers and Shellers

Threshers and shellers may be operated manually or driven by engines or electric motors. They are designed to separate grains from harvested material. The machines comprise feed arrangements for the crop, threshing or shelling drums and discs and components for separating the straw, cobs and trash from the grains.

The feeding arrangements of threshers may be of the "hold-on" type where the heads of the cut crop are fed into the threshing drum with the lower part of the straw being manually or mechanically held. The 'throw-in' type is where the cut crops are fed into the machine in full. Whole cobs are fed singly or by hopper into shelling machines.

The power requirement for the machine is measured as described in Section 4.3 (Fig 4.40), and the assessment of human power is discussed in Section 5.

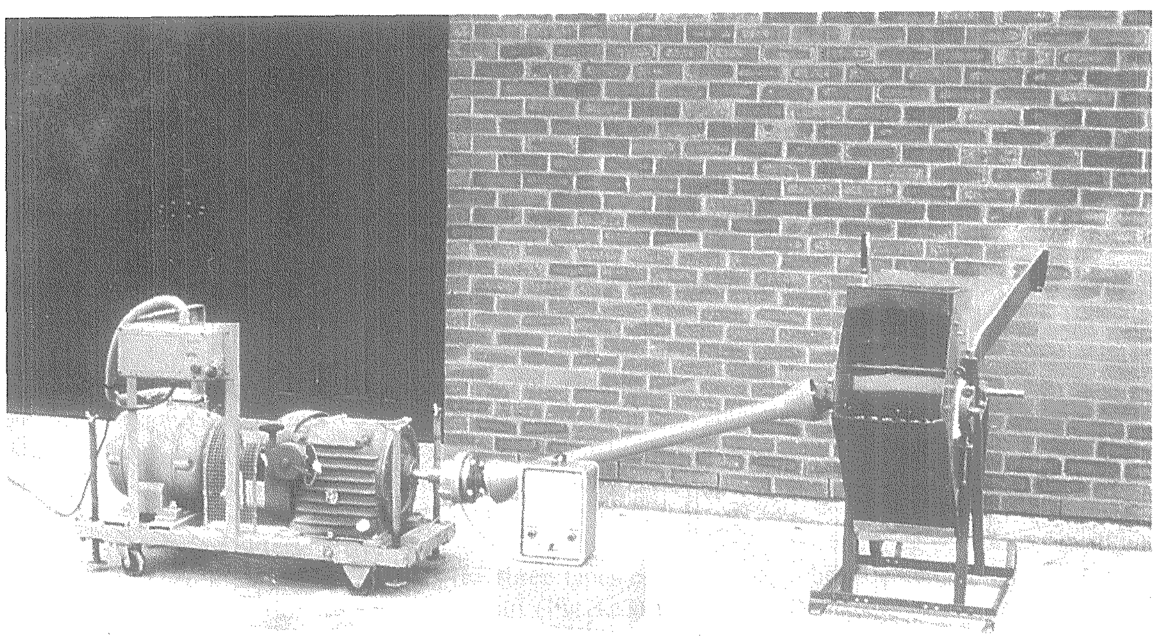


Figure 4.40 Geared electric motor with torque meter to measure the input power requirement of a small thresher

The machine should be operated for longer periods of at least 5 hours when operators can make observations on ease of feeding and operation, and of outlet arrangements. Comments should also be made on aspects of repairs and adjustments and ease of material flow through the machine.

4.6.9 Combine harvesters

The combine harvester is a self propelled or trailed machine, designed to cut material from a standing crop passing it through the machine, separating the grain from the straw and chaff. The performance of a combine harvester is greatly influenced by the type and condition of the crop and the field condition and topography.

One of the most important criteria applied to tests of harvesters is the output in relation to the area harvested. This is limited by the grain losses through the machine which rise as the throughput increases, and are defined as follows:

- Grain losses
  - Cutter bar losses
  - Total threshing losses
    - Drum losses (grain remaining in the ears after passing over shaker or top sieve)
    - Loose grain
      - Straw shaker losses
      - Sieve losses

Test procedures are designed to measure these factors and to assess the effectiveness of the machine with various crops and travel speeds giving changes in levels of throughput.

Bulk samples are taken from the output stream during the test runs and divided to obtain 500g samples (Fig 4.41) for determination of moisture content, damage and rubbish content.

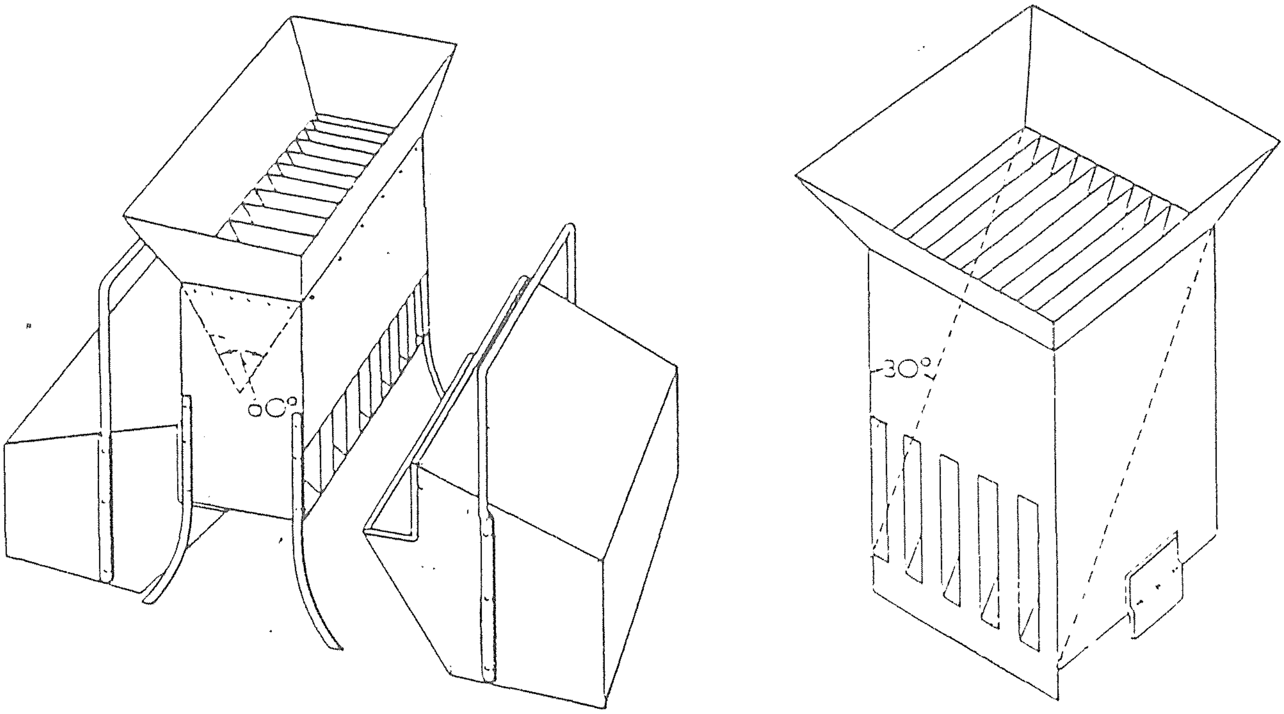


Figure 4.41 Examples of sample dividers
Source: British Standards Institution, 1952

"Cutter bar losses" are obtained by comparing the weight of grain left on the ground for a given area after cutting, (Fig 4.42) with the average of samples taken throughout the uncut test area.

Figure 4.42 Measurement of combine cutter-bar losses

Threshing losses are assessed by separating and collecting the output from the straw shakers and the sieves throughout the test run (Fig 4.43).

The straw is weighed and any loose grains are collected as "straw shaker losses". The loose grain present in the sieve output is also collected as "sieve losses". Any grain remaining in the ears after passing over the shakers or sieves is threshed out (Fig 4.44) and designated the 'drum loss'. The losses are expressed as a percentage of the machines grain output and as weight per unit area (kg/ha).

Where a large number of tests are to be made, some form of continuous re-threshing equipment is required. Fig 4.45 shows such a unit which enables the three types of grain loss to be assessed simultaneously. The sheets used for the collection of straw and chaff (Fig 4.43) are fed into the front of the machine enabling the loose grains to be collected, the residue being re-threshed for measurement of drum losses.

If tests are made at various forward speeds and throughput, the curves shown in Fig 4.46 can be drawn. This information will allow the harvester to be 'rated' and compared with other machines under similar crop and field conditions.

Figure 4.43 Collection of combine straw shaker and sieve outputs during a test run

Figure 4.44 Rethreshing material for measurement of combine drum loss

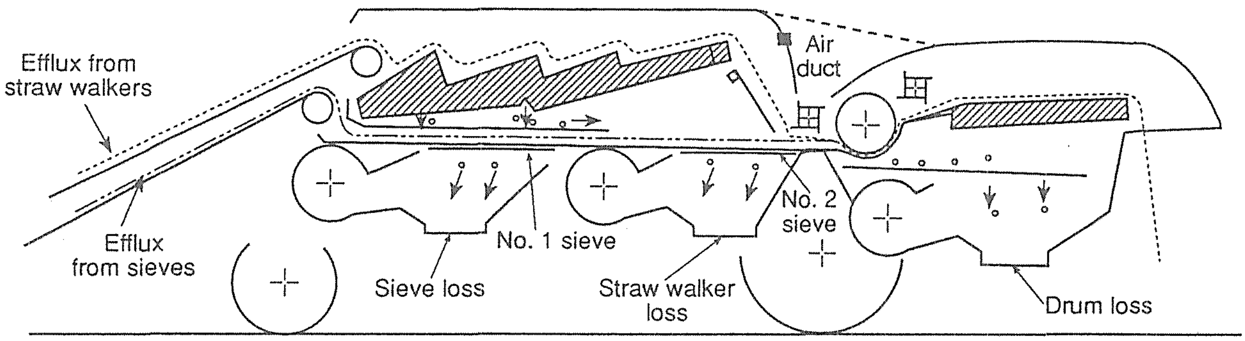


Figure 4.45 Re-thresher for measurement of grain losses during combine testing

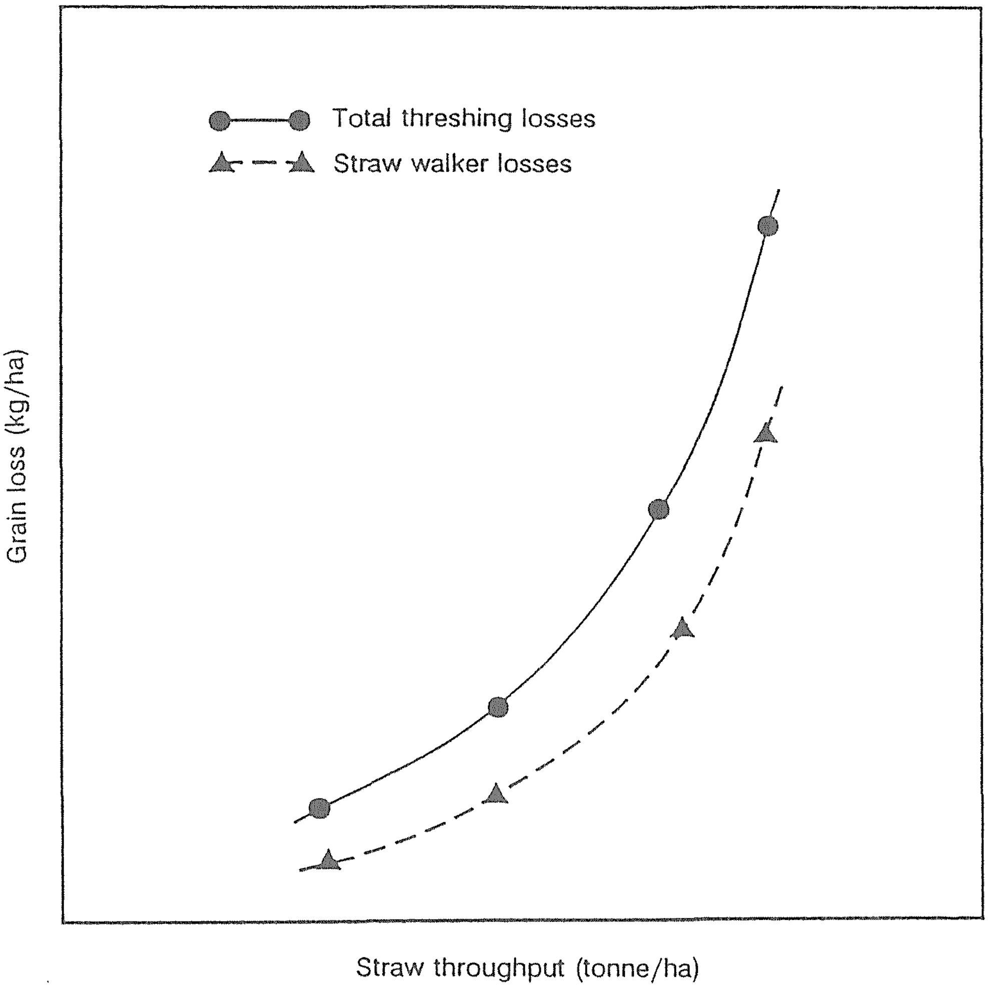


Figure 4.46 Relationship between straw throughput and threshing losses

4.6.10 Animal carts

Cart tests are designed to measure the maximum loading limit in relation to the haulage capacity of the animal(s), the shape and strength of cart construction and the wheel and axle loadings. Impact tests which are designed to apply shock loading to the cart and longer haulage trials are made with the cart loaded to its capacity limit in the track tests. Further controlled haulage trials for longer periods and trials on farms will allow general observations to be made of failures, repairs and adjustments, stability, comfort of the operators and animals, containment of load and safety.

As explained in the Procedure for Evaluation of Animal Carts (Section 21) measurement of the horizontal draft force can be complicated by the fact that the animal's resultant pull force does not necessarily pass through the draw pole. A towing dolly (Fig 4.47) can be used to measure the draft. It consists of a rigid frame connected to a rear freely pivoting link via a dynamometer. The hitch points of the drawpole and dynamometer are adjustable vertically to accommodate different designs. The rig is mounted on wheels to be towed by a tractor.

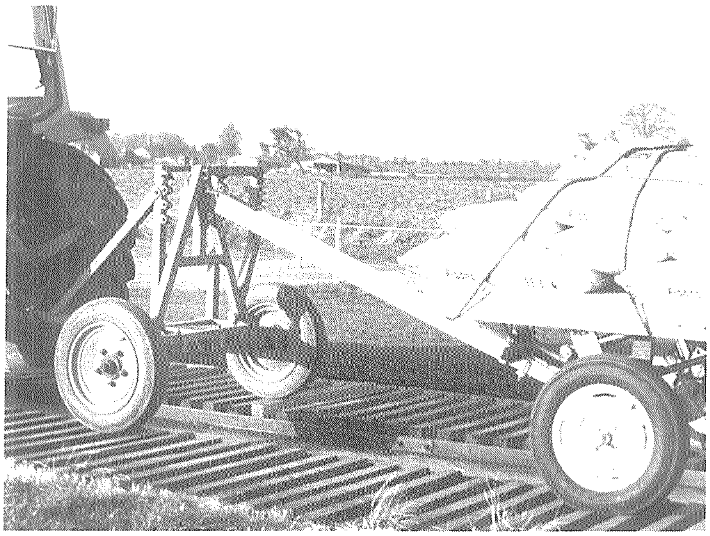


Figure 4.47 A towing dolly for measuring the horizontal component (draft) of the pulling force of a cart

5 ERGONOMICS APPRAISAL OF AGRICULTURAL EQUIPMENT

5.1 Introduction

Ergonomics is the science of work. This general statement is made more meaningful if ergonomics is understood to be

- the application of scientific information about human beings, to
- the design of objects, systems and environments intended for human use (after Pheasant, 1991).

Thus ergonomics involves the application of anatomical, physiological and psychological knowledge and methodology to evaluate and optimise work performance and human health, safety and comfort.

Although ergonomics is a multi-disciplinary science, basic ergonomics is often regarded to be merely "commonsense". However, whereas commonsense is an individual's subjective opinion, based largely on his or her own personal experiences, ergonomics involves the application of objective data concerning the range of people expected to use a certain piece of equipment (user population or user group). An ergonomics approach also encourages evaluation of designs and avoids the pitfall of "commonsense solutions" being seen as the only solutions, with their suitability remaining untested. It is also essential to remember that one's own experiences as a human-being are not necessarily representative of those of the population at large and therefore reference to scientific fact and professional advice, rather than intuition, are always advisable.

The purpose of this Section is to provide these fundamental scientific facts together with basic principles to enable a technician to undertake elementary but valid appraisals of simple equipment. Once the ergonomics approach has been adopted within design and testing philosophies, the expected user group will be able to use the resulting equipment more productively and safely.

5.2 Human characteristics

Human beings act as power sources and controllers. The equipment they operate must be compatible with the size, shape, strength and senses (eg vision, hearing, etc) of the user population. All these characteristics change during life and may depart significantly from the norms for a given age, as a result of disease or malnutrition. It is important to remember that a user population is not necessarily the same as the associated general population (eg women might not drive tractors).

5.2.1 Body size

The science of the dimensions of the human body is called anthropometry. The human body requires many dimensions to describe it even only approximately. Fig 5.1 gives examples of the key major dimensions and Table 5.1 provides the associated measurements for German adult males and females. The sizes of different limbs may also be important: hand size, for example, should be considered in the design and evaluation of tools, controls or machine guards. The key dimensions of the hand are illustrated in Fig 5.2 and associated measurements given in Table 5.2, also for German adults.

In addition to body sizes, the distances that can be reached by the hands or feet may be important in the operation of equipment, particularly larger units, from the standing or sitting position. These distances are called reach envelopes and depend on both body dimensions and ranges of movement of the relevant limbs.

Checking the size compatibility between a tool or piece of equipment and the user or users is an obvious first step in any ergonomics appraisal. Before the appraisal can be made properly, relevant anthropometric data of the user population must be available. As detailed anthropometric data on developing country populations are rarely available, reference could be made, in the first instance, to the data given by Pheasant (1986) for various nationalities around the world. Anthropometric measurements can be taken locally: Fig 5.3 shows stature being measured in Zimbabwe.

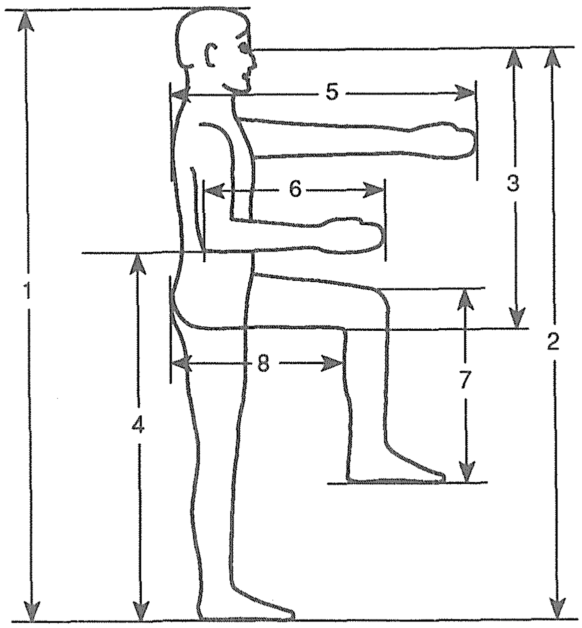


Figure 5.1 Indication of measurements (in cm) listed in Table 5.1 (after Kroemer, 1964 cited by Granjean, 1980)

Table 5.1 Measurements indicated in Figure 5.1

Measurement No.	Part of body measured	Men		Women	
		Mean	90% confidence interval	Mean	90% confidence interval
1	Standing height	172	160-184	161	150-172
2	Eye level, standing	161	150-172	150	138-162
3	Eye level, above seat	79	73-85	74	68-80
4	Elbow height, standing	106	98-114	97	89-105
5	Forward reach	82	75-87	70	63-77
6	Elbow to fingertip	47	43-51	42	38-46
7	Sole of foot to knee	55	51-59	50	46-54
8	Back to hollow of knee	50	46-54	46	43-50

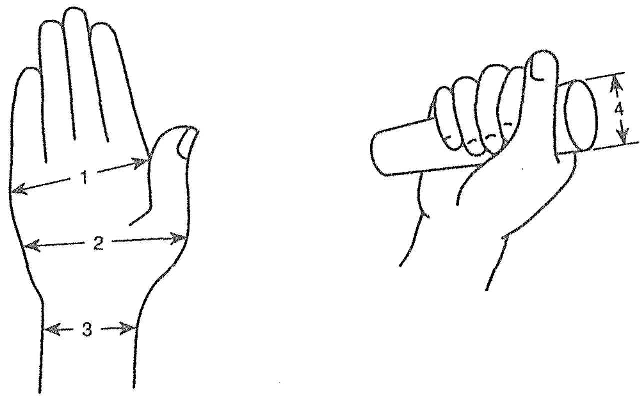


Figure 5.2 Indication of measurements listed in Table 5.2 (after Jurgens, 1973, cited by Grandjean, 1980)

Table 5.2 Measurements indicated in Figure 5.2

Measurement No.	Part of hand measured	Men		Women	
		Mean	90% confidence interval	Mean	90% confidence interval
1	Circumference of hand	21.1	19.3-23.0	18.7	17.5-20.1
2	Breadth of hand	10.6	9.8-11.3	-	-
3	Circumference of wrist	17.1	15.5-18.8	16.1	14.3-17.9
4	Maximum grasp (circumference)	13.4	12.0-15.3	-	-

Equipment must be suitable for a range of people, not just people with average dimensions. Anthropometric data are, therefore, usually presented as means with standard deviations or percentile values. In general, since it is reasonable to assume that body dimensions vary according to the Normal Distribution, it is straightforward to calculate a dimension for a given proportion of the population. It is customary for a design to attempt to cater for 90 or 95% of the target population: the critical dimensions are then the 5th percentile and 95th percentile values or the 2.5th and 97.5th percentile values respectively. Appraisals should consider these aspects.

5.2.2 Body strength

Body strength represents the potential of the body's ability to perform mechanical work. Mechanical work may be performed in two ways. Firstly, by relative movement between body limbs which can be effected only by a muscle developing tension and shortening around a joint (eg elbow, knee) and bringing the two adjacent limbs, or segments, closer together. Secondly, if posture and the task permit, body weight can be exploited to overcome external forces.

The amount of tension that can be developed in muscles depends on three factors - the cross-sectional area of the muscle, the degree to which the muscle has already contracted and the rate at which the individual muscle fibres can be refuelled. Furthermore, since motivation plays a significant role in activating muscle fibres, this should not be overlooked.

Figure 5.3 Measurement of stature

Thus, the apparent strength of the body depends on the circumstances and is a function of the body's posture and musculature. Because of this complexity, tables of strength data are not so widely available as tables of body size data. However very approximate indications of arm strength for various postures are given in Figs 5.4 and 5.5. Note that in Fig 5.5, strength is expressed in terms of body weight.

For manual handling activities, maximum load data have been published (eg see ILO, 1990). These may be interpreted, with caution, as being equivalent to strength data.

Although it might appear not to be scientifically objective, in many instances the most effective means of evaluating the demands on human strength associated with a task or tool is through the careful collection of subjective data. By methodically observing users performing tasks and collecting their opinions, this valuable and maybe crucial insight is added to the evaluation. It must be remembered that if a tool or piece of equipment requires effort which is regarded as excessive by the user, it will not be used.

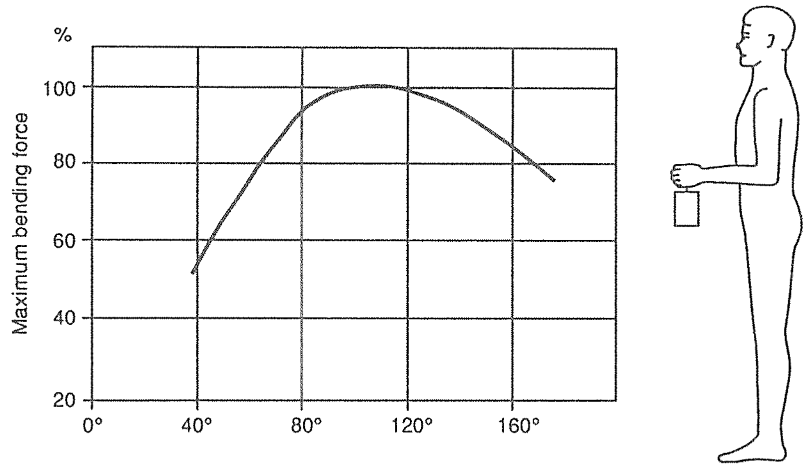


Figure 5.4 Maximum bending strength in the elbow joint in relation to the angle at the elbow (after Clarke et al, 1950 and Wakim et al, 1950 cited by Grandjean, 1980)
Note that 100% force = 25 kgf = 254 N

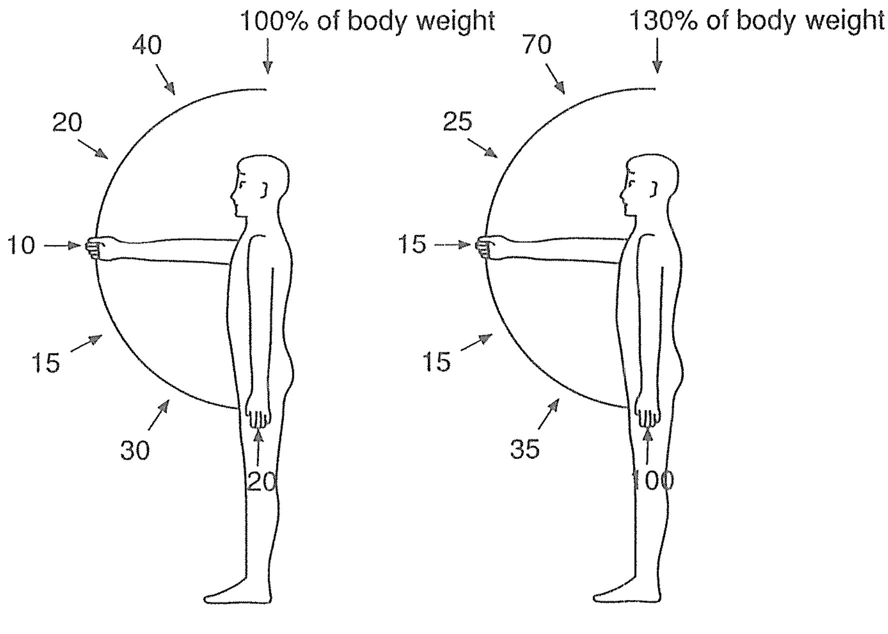


Figure 5.5 Maximum power of pulling (left) and pushing (right) for a man
Feet 30 cm apart. The values at various angles are given as a percentage of the body weight. (Simplified, after Rohmert, 1966, cited by Grandjean, 1980)

5.3 Energy demands

In equipment evaluation, the energy demands on the users exert a very strong influence on the acceptability of the equipment. Human beings derive the energy they use for work and internal processes from the food they eat. If there is an imbalance, fat and body tissues will be augmented or depleted, thus nutrition and energy demand are closely linked.

As mentioned above, work is done by muscular contractions: working muscles need to be refuelled and waste products removed. Although the process is very complex, the amount of work (static or dynamic), in terms of metabolic demand, can be determined reasonably accurately from measuring the body's oxygen consumption. Although oxygen is not the fuel, 1 litre of oxygen can be considered equivalent to 20.7 kJ of metabolic energy. A less direct, but simpler way of assessing workload is to measure heart rate. When metabolic energy is converted to external ("mechanical") work (ie force x distance) through the muscles, the majority of the energy is released as heat: at least 3 units of heat to 1 unit of work.

5.3.1 Static workload

A static workload generally involves the maintenance of a fixed posture and would usually include the support of some (static) external load. Thus, although no work is being done in the conventional mechanical sense (ie a force is not being moved through a distance), a physiological stress is, nevertheless, imposed. This could be observed or measured through elevations in oxygen uptake or heart rate.

Many workloads involve both static and dynamic components and it is often helpful to examine each component separately. A typical example would be the operation of a knapsack sprayer when the lance should be held in a fixed position. Thus one arm experiences a static workload, whilst the other arm (pumping) and the legs (walking) experience dynamic workloads. Also, the maintenance of any awkward or difficult posture represents a static workload.

Supporting a static load, as diagrammatically shown in Fig 5.6, is stressful mainly because the muscle's opportunity to refuel (see 5.2.2 above) is inhibited. Dynamically working muscles are not so seriously affected in this way because their movements assist the circulation of nutrients and removal of waste products.

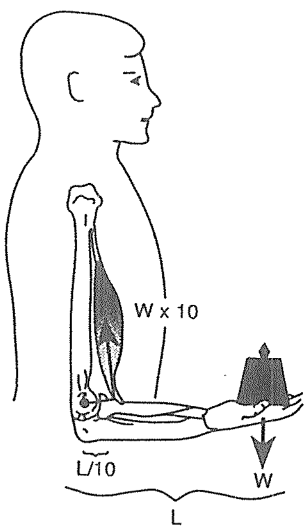


Figure 5.6 Static load holding a weight. The tension in the biceps muscle counteracts the weight in the hand according to the Principle of Moments.

The measurement of oxygen consumption is beyond the scope of simple ergonomics appraisals. It involves the collection of expired gases through a mask followed by monitoring the oxygen concentration and volume flow rate of the expired air. More information on the measurement of oxygen uptake can be found in Wilson and Corlett (1990) or Rodahl (1989).

Heart rate is more easily monitored as an indication of workload and can be measured in a number of ways. When the body is effectively motionless, direct palpation would be the simplest and cheapest method. The only equipment required would be a watch or, preferably, a stop-watch. When a suitable blood vessel has been located, the number of pulses are counted over a fixed period (at least 20 s recommended) and the result expressed as a rate per minute. A relatively inexpensive alternative method would be to use a stethoscope.

It would generally be preferable to use equipment that not only sensed but also recorded heart rate. This is more convenient, but also more expensive. A wide range of proprietary equipment to record human heart rate is now marketed but it is not possible to state here what would be locally available.

Such equipment usually operates using sensors based on one of two principles: The changing infra-red absorption of a small part of the body (eg finger, ear lobe) as a pulse occurs or the electrical activity generated by the heart. The recording equipment is likely to be dedicated to the sensor and may or may not need a computer to interpret the recorded data. Fig 5.7 shows a worker wearing a device which monitors heart rate by detecting the electrical activity of the heart. The device is simple to use but requires a computer to interpret the data.

Figure 5.7 Heart rate measurement

The most sophisticated equipment for monitoring the electrical activity of the heart, the electrocardiogram (ecg), would not generally be appropriate to ergonomics appraisals.

5.3.2 Dynamic workload

Dynamic workload is the term used to describe varying or rhythmic efforts, in contrast to the stationary effort discussed above. A dynamic workload is the combined effect of the magnitude of the effort involved, the rate at which it is applied and its duration. All three factors must be considered in appraising a workload. A dynamic workload can be determined in the conventional mechanical sense by measuring the force applied and the distance through which it moves. The energy demand is the product of these two and the rate at which the energy is expended gives the power demand.

$$\text{Power} = \text{Energy/time} = (\text{Force x distance})/\text{time}$$

The human mechanical power output over a working day has been generally accepted as about 70 W. However this value probably relates more to reasonably fit and healthy populations in developed countries than to agricultural workers in developing countries. Recent evidence suggests that 40 W would be a more realistic value for developing countries (Dibbits, 1993).

The level of dynamic workload which is acceptable is influenced by the duration of the task. Over short periods mechanical power output can be much higher, for example, very approximately 3 kW instantaneously, 1 kW for a minute or 400 W for an hour (Patrick, 1993).

For an ergonomics appraisal the energy and power demands can be approached in two ways - direct mechanical measurement, as outlined above, and the effects that these demands have on the human body.

Physical work induces a wide range of physiological stresses such as changes in breathing rate, oxygen uptake, heart rate, body temperature, the concentrations of metabolites in the blood etc. For simple ergonomics appraisals, heart rate would be the most appropriate of these variables to monitor.

The benefits of measuring heart rate are well illustrated by a simple time history of the heart rate changes associated with muscular work (see Fig 5.8). If the person has not been physically active for some time before the start of work, the heart rate will be around the resting level for that person. After work starts the heart rate will rise and should reach a steady level as work continues. If this steady state is not reached, the implication is that the workload is too high for the person to sustain. After the end of work the heart rate decreases until it eventually returns to the resting level: this is called the recovery period.

In assessing the physical workload there are several other aspects of the heart rate that can be helpful, in addition to determining whether working heart rate has reached a steady level. Working heart rate, if it can be measured (palpation and stethoscopes are generally impracticable) can be related to resting heart rate or maximal heart rate (eg see Astrand and Rodahl, 1970). The determination of maximal heart rate is not straightforward, so for simple appraisals working heart rate can be compared to resting heart rate. As a very approximate guide, working heart rate over a sustained period should not exceed twice a person's resting heart rate. For an individual, working heart rate is closely correlated with oxygen uptake and hence metabolic energy expenditure, but the variation between individuals and the influence of other factors, such as heat, precludes the establishment of a firm relationship between heart rate and energy expenditure.

As with the determination of strength requirements associated with particular tasks or tools, subjective assessment can also prove useful in the evaluation of the energy demands. Determining the validity of such assessments and interpreting their meanings are generally beyond the scope of simple appraisals. However, one method of subjectively assessing workload, and relating it to objective measures, that has gained wide acceptance and is regarded as reliable is Christensen's Ratings of Perceived Exertion (RPE). The approximate relationships between the subjective rating, heart rate and other physiological variables are given in Table 5.3.

Work causes fatigue, in the working muscles particularly and in the body generally. The period during which the physiological variables adjust from working levels back to base levels is called the recovery period (eg see Fig 5.8). The length of the period is influenced by the power output attained and the total energy expended: the latter probably exerts the greater influence over the length of the recovery period. The

Table 5.3 Metabolism, respiration, temperature and heart rate as indication of work load (After Grandjean, 1980)

Assessment of work load	Heart rate Pulses/min	Oxygen consumption Litres/min	Lung ventilation Litres/min	Rectal temperature °C
"Very low"	60-70	0.25-0.3	6-7	37.5
"Low"	75-100	0.5-1	11-20	37.5
"Moderate"	100-125	1-1.5	20-31	37.5-38
"High"	125-150	1.5-2	31-43	38-38.5
"Very high"	150-175	2-2.5	43-56	38.5-39
"Extremely high"	over 175	2.5-4	60-100	over 39

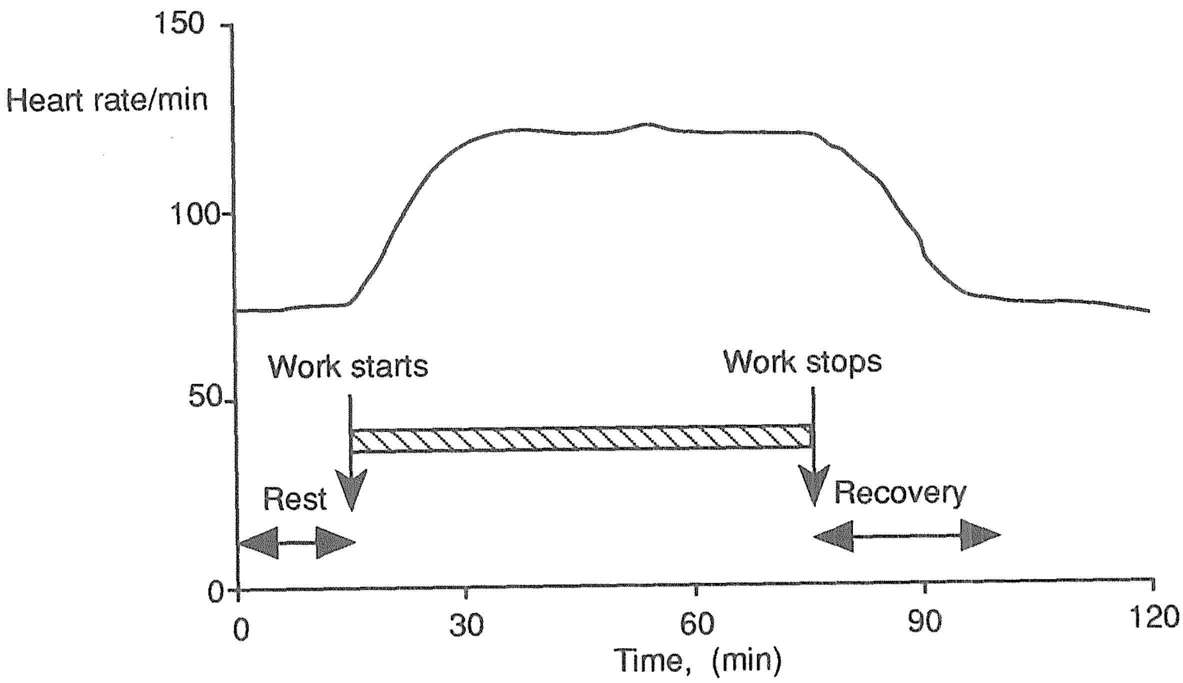


Figure 5.8 Typical variations in heart rate before, during and after work

manner in which heart rate decreases after work and approaches the resting level offers some insight into how arduous the work has been, or how well the individual has coped with the workload. Monitoring heart rate after the end of work, which can be done simply by palpation or by using a stethoscope, can provide a useful indication of the overall work demands.

If heart rate is measured as soon as work ceases, even during a break in work, it must be emphasised that this will not be the working heart rate. Heart rate starts to decrease immediately activity stops and the result will be a changing heart rate, which is difficult to interpret.

5.4 Environmental factors

Environmental factors include thermal variables (such as temperature, humidity), air quality, noise and vibration. The environment can influence the physical performance of a task either directly or indirectly. For example, heat or humidity may reduce work capacity directly and air pollution may affect physical performance by initiating an allergenic reaction which inhibits breathing. Heat could also affect work capacity indirectly through dehydration.

The factors considered in this section are thermal stress, air quality, noise and vibration. Thermal stress and air quality are of greater relevance in the evaluation of simple agricultural equipment. With more complicated, engine-powered equipment noise and vibration must also be considered.

5.4.1 Thermal stress

Human beings are homothermous and their internal organs can tolerate only small changes of temperature -the generally accepted range being between 36 and 39°C (although the comfort range is considerably less than this). As mentioned above one unit of mechanical work involves the generation of at least three units of metabolic heat energy. To avoid heat stress this heat must be lost, usually to the environment. The main methods of heat loss are through convection and evaporation (of sweat) which become less effective with increases in air temperature and relative humidity respectively.

Body temperature is usually measured in one of three locations - the rectal passage, the ear canal or under the tongue - the last of these being generally the most convenient.

Increases in body temperature are counteracted by an increase in blood flow to the peripheral parts of the body, thereby promoting heat loss by convection, and activation of the sweat glands. The increased heat flow to the skin imposes an extra burden on the heart and reduces the blood supply to working muscles. Both these reactions may reduce effective working capacity and this reduction becomes more pronounced at higher temperatures.

In humid environments sweat can not evaporate so easily and the cooling effect, caused by the body providing the latent heat required for evaporation, is diminished. This is potentially more serious than the diminished convective loss and the body can quickly overheat to the point of heat stroke (collapse, loss of consciousness) In less severe conditions, the limited capacity of the sweat glands may be the dominant factor and, in the longer term, dehydration can develop.

In appraising human work performance, particularly when energy demands are of major interest, the thermal environment should also be monitored. This will help avoid confusion between work stress and thermal stress, especially for comparative tests of equipment when thermal conditions may vary. The most important variables to measure are air temperature and relative humidity. Because air movement enhances both convective and evaporative heat losses, air speed close to the testing area should also be measured.

Other factors which affect human heat exchanges are mean (infra-red) radiation levels, especially solar radiation, and clothing insulation (which may be particularly important in the case of protective clothing). If these vary during the course of comparative tests, some attempt should be made to quantify them. Further information can be found in McIntyre (1980) or Kerslake (1972).

Cold stress is rarely a problem with physically active people, even in cold environments.

5.4.2 Air quality

Aerial pollutants may be particulate matter (organic or inorganic) or gaseous. In the outdoor agricultural environment gaseous pollutants are unlikely to be cause for concern, except for emissions from internal combustion engines.

Particulate matter is generally undesirable because of its harmful effects on the respiratory system. There may be an immediate effect on work capacity through restriction to breathing rate or a longer-term effect through lung damage. In both cases work capacity is affected by reducing the body's access to oxygen.

Environmental dust and gas measurement and analysis are beyond the scope of simple environmental appraisals but it is important to appreciate that equipment which causes a deterioration in air quality would be unsatisfactory from an ergonomics point of view.

Further information can be found in Rodahl (1989) and Matthews and Knight (1971).

5.4.3 Noise

The source of noise in agriculture is associated mainly with the use of engine power and with static power driven machines.

Research has established that exposure to an average noise level exceeding 80 dBA over an 8-hour working day can damage hearing. It is difficult to establish the average levels when there is a variation in noise during the exposure period. It is recommended therefore, that all equipment should be designed to have noise levels below 80 dBA at all times.

If the noise level cannot be reduced at source, some type of protection should be provided for the operator and various types of ear protectors are available.

5.4.4 Vibration

Sources of vibration are also mainly associated with power driven implements and machines. There is a distinction between whole-body vibration and that affecting limbs such as hands and arms.

Whole-body vibration can be experienced when driving tractors or riding on machines being towed whilst hand-arm vibration is associated with hand-held motorised equipment. Shocks and jolts will magnify the effects of background vibration.

The effects of exposure to vibration vary according to the frequency (Hz), acceleration (m/s^2) and exposure duration. They vary from nausea at low frequencies to joint and bone disorders produced by long exposure to high frequencies. Prevention is achieved at the design stage, through reducing the transmission to the operator through the use of damping materials, or by reducing exposure time.

5.5 Safety and comfort

All equipment should be designed to be safe and comfortable for the intended users. Otherwise productivity and health may suffer.

Safety, however, is not only a matter of design, it depends on how the equipment is used. Even for simple equipment this may involve some training for the users. Some equipment, knives for example, can not be made intrinsically safe but the design should discourage abuse and misuse and users should be shown the recommended method(s) of operation. Powered equipment, in particular, can be dangerous and the design should be appraised for the possibility of misuse by both the intended and unintended user. The observation of a small sample of workers using an item of equipment in the work environment (or a simulated work environment) is a useful means of appraisal. These "user trials" allow the observer to determine whether the equipment is actually used as it was intended and expected to be used. As a result, design faults or training deficiencies may be identified and rectified. Powered equipment that has exposed moving parts should be accompanied with safety guards (provided by the supplier) and the effectiveness of any safety device should also be appraised. There may be local legislation regarding this.

Safety and comfort can be related to all the issues discussed above as equipment that is not well matched to the characteristics and abilities of users can be both dangerous and uncomfortable. The environmental factors mentioned above are also implicated as they can all cause discomfort or physiological damage. The visual environment should also be mentioned from the safety point of view. Adequate levels of light are essential for tasks to be undertaken productively and safely. Furthermore the use of colour can be an extremely useful method of coding, providing visual contrast or highlighting (eg red for danger). Further information is available from Grandjean (1980) or Matthews and Knight (1971).

Problems of postural discomfort can be reasonably well assessed on a subjective basis by use of a "body map" - see Fig 5.9. The human body, or parts of it, is divided into sections and the users of the equipment under test are asked to indicate which segments are sources of pain or discomfort. This can be elaborated by introducing a rating scale (eg 0 to 5 for no discomfort to severe discomfort) or a ranking scale and collecting assessments over periods of time. Further information can be found in Wilson and Corlett (1990) or Corlett and Bishop (1976). Fig 5.10 shows the use of a body map.

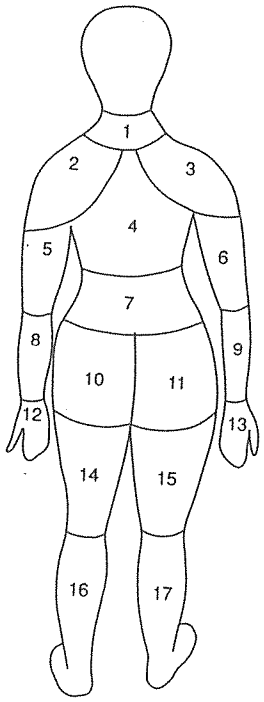


Figure 5.9 Body map used for evaluating Body Part Discomfort with women agricultural workers in Zimbabwe

A person's approach to safety and comfort is influenced by his or her current attitude and physical state. A person who is fatigued or tired is more likely to make errors of judgement; a person in a hurry is likely to take greater risks; some people believe that accidents only happen to <u>other</u> people.

The imposition of rest breaks is well accepted in industrial/factory situations as a method of avoiding excessive fatigue, either physical or mental, and thereby increasing the levels of safety and comfort with which work is accomplished. For the very demanding items of equipment the introduction of rest breaks to allow brief periods of recovery, may improve user acceptability. However, in the agricultural situation, the dispersed nature of the labour force and the occasional need to meet externally imposed deadlines (eg by the weather) might make the enforcement of rest breaks difficult or impractical.

Figure 5.10 Use of body map

6 ECONOMICS[1]

The acceptance of a machine by a farmer will be influenced not only by its technical characteristics but also by its cost and the benefits that it will produce. Economic appraisal of a machine's performance is a most important aspect of the evaluation process but it is unfortunately frequently neglected.

The summary of simple concepts of economic analysis which are discussed in this Section are based on notes prepared by Gwyn Williams for an introductory course on agricultural economics (Williams and Sims, 1993).

6.1 Calculation of costs and benefits

A producer who invests in farm machinery is confronted by three basic costs:

- The cost of capital associated with the purchase.
- The costs of operation and maintenance of the equipment.
- The cost of replacing the equipment at the end of its useful life.

Costs can be divided into two groups: fixed and variable. By way of illustration the example can be taken of the purchase of an animal drawn disc harrow which will be used for 100 hours per year over a period of eight years before it will need to be replaced. An analysis of the costs is given in Table 6.1.

Table 6.1. Calculation of annual fixed and variable costs of farm machinery. Equipment: animal drawn disc harrow.

1. New value: $1000	3. Useful life: 8 years
2. Residual value: $250	4. Annual use: 100 hours
	5. Annual interest rate: 14%
5. Annual fixed costs:	**US$**
Depreciation (VN-VR)/UL	93.75
Interest (VN+VR)/2 x i	87.50
	Sub total: 181.25
6. Annual variable costs:	
Replace 1 disc @ $20	20.00
Replace 1 bearing each 2 years @ $15	7.50
Labour, welding material etc.	15.00
	Sub total: 42.50
Hourly fixed and variable costs:	
Fixed costs/h (181.50/100h)	1.81
Variable costs/h (42.50/100h)	0.42
Total FC and VC per hour:	**2.23**

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[1] *All costs are expressed in US$ as of November 1994*

Fixed costs

In general the fixed costs are independent of the amount of work that a machine does per year. The most important components are: depreciation and interest paid for the use of the invested capital.

Depreciation is calculated by dividing the purchase or new value of the machine (VN) by the estimated number of years of useful life (UL). If it is expected that the machine will be sold at the end of its period of use, a residual value (VR) is estimated. In this case the depreciation is calculated by dividing the average value by the useful life: (VN-VR)/UL. In high inflation situations it is advisable to review the value each year and use a realistic market value of VN.

For interest calculations it is assumed that the farmer uses money lent by a bank and the interest rate (i) is the current market rate. If the farmer uses his own money, an opportunity cost is applied. This will be the interest rate which could be achieved in the best alternative use of the invested capital. As a minimum opportunity cost, the current market rate is applied.

Once the interest rate has been determined, the annual interest cost is calculated a follows: (VN+VR)/2 x i. The new and residual values are summed as together they represent capital that cannot be invested in other ways. The total investment is divided by 2 to calculate the annual interest charge over the useful life.

Variable costs

Variable costs vary with the amount of use that the machine receives. They comprise the costs of: fuel; lubricants; replacement parts; maintenance and repair and operators' time.

The best way to estimate these costs is to maintain a register of those previously incurred in the use of similar equipment. If, as is often the case, such information does not exist, the costs can be estimated using manufacturers recommendations or published guidelines. For example, Table 6.2 gives suggested values for repair and maintenance for tillage equipment and tractors. Care should be taken when using these sources as the conditions for which they are valid may not be relevant in a given case.

Table 6.2 Costs of repair and maintenance as a percentage of new price (Source: Hunt, 1973)

Machine	Average cost as %VN/100h
Tillage	
Cultivator	6.0
Disc harrow	6.5
Disc plough	4.5
Mouldboard plough	7.0
Spike tooth harrow	4.0
Spring tine harrow	6.0
Tractors	
Wheeled	1.2
Tracked	0.8

From Table 6.2, the annual repair and maintenance cost of a wheeled tractor with a new value of $15 500 and an annual use of 500 hours would be: (15 500 x 0.012) x 500 ÷ 100 = $930 per year.

Economic performance of machinery

In order to use information on machinery costs for budget analysis, it is necessary to express them in terms of work done. This requires output to be calculated (in, for example, ha/h; kg/h, etc).

The test procedures included in this manual detail methods which enable machinery output to be calculated by means of controlled tests under realistic conditions. These will give the times required to complete units of work and also the technical capacity of the equipment (depth and width of work, forward speed , etcetera). This information allows effective and theoretical output to be calculated and thus the machine's efficiency.

The effective output of a machine is expressed in terms of work completed during a specified time period. The theoretical estimate is calculated from the parameters measured in the field for example, for tillage machinery, theoretical field capacity (TFC) is expressed as follows:

$$TFC = \frac{W \times V \times 36}{10\,000}$$

Where:

W = width of work, cm

V = mean forward speed, $m.s^{-1}$

Field efficiency is calculated by dividing the theoretical field capacity by the effective capacity measured under realistic farming conditions:

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$$

As an illustration, the performance of an animal draft tillage operation can be analyzed. Suppose that the system comprises the mouldboard plough and an eight disc harrow whose performance characteristics are shown in Table 6.3.

Table 6.3 Calculation of output and cost of tillage with an animal drawn mouldboard plough and disc harrow

Cost of labour: $6/day
Working day: 6 hours
Total labour and equipment cost (fixed and variable): $4.98 x 6 = $29.88/day[1]
Total animal cost = $2.28/day

Operation	Width, cm	speed, m/s	Field efficiency, %	Output, ha/h	Output, days/ha	Total cost,$/ha
Plough	23	0.80	75	0.05	3.33	42.55
Disc (x 2)	113	0.71	65	0.19	1.75	68.52
					Total	**111.07**

[1] *See Appendix 6A*

6.2 Partial Budgets

Although the calculation of machinery operation costs is made possible through field evaluation, the effect on a farming system of small changes, such as the adoption of alternative mechanization technologies, requires budget analysis.

Whole farm budgets quantify the profitability of the farming system and its components and are needed when large scale system changes are contemplated. Smaller changes (such as changes of crop variety, area sown or machinery employed) can be assessed by the use of the simpler partial budget.

Partial budgets only include those variables which vary with the proposed change. For example a change in tillage practice would not (necessarily) imply a change in type or volume of fertiliser applied and so the cost of fertiliser would not be included in the budget. The simplest and most useful form of partial budget is that which analyses the net benefit of a proposed change and is the budget considered here.

The first step in partial budget formulation is to describe in detail the proposed change and to note the date of budget preparation. The budget comprises four elements as follows:

	Costs		Benefits
i)	Additional costs	ii)	Costs avoided
iii)	Income foregone	iv)	Additional income

The impact of the proposed change on net benefit is calculated by subtracting the total new costs from the total new benefits. If the benefits are greater than the costs then the change is advantageous; if not then it would not be recommended.

It may be that some of the factors that may influence the decision on whether to change or not may not be easy to quantify and include in the budget. In this case a list of the non-monetary factors is included as a footnote. Examples include: the degree of risk associated with the proposed change; changes in family labour requirements; need for credit, etcetera.

As an example, consider a farmer who grows 10 ha of basic grains including 5 ha of rice. Hitherto he has hired a tractor and equipment from a local contractor for tillage and rice seeding. Now that the cost of hiring has risen he suspects that it may be more profitable to do his tillage with draft animals equipped with tillage machinery and to sow by hand. He realizes that he will have to hire additional labour and that his rice yields may suffer as a result of the tillage change, nevertheless he considers that the change may be advantageous.

Table 6.4 shows the partial budget for the proposed change. It defines the proposal and then details the costs and benefits generated and the net benefit expected. Non-monetary considerations are also noted.

As the farmer sows 10 ha of basic grains only 50% of the new costs will be charged to the rice enterprise. In the case of the oxen, the capital costs are not included as they are subsequently sold at the same or a higher price than their cost. On the other hand, the equipment costs are distributed over their projected useful life (six years for the plough and eight years for the disc harrow) giving a total annual depreciation of $160.42 (Appendix 6A).

Table 6.4 Partial budget for the change of tillage and seeding technology for rice

Proposed change: Replace hired tractor, tillage equipment and seeder with a draft animal powered and manual system in 5 ha rice.

COSTS, $		BENEFITS, $	
Annual additional costs		Annual costs avoided	
Plough depreciation	33.33	Tractor hire	
Harrow depreciation	46.87	Ploughing @ $366.14/ha	1830.70
Interest @ 14%	115.21	Seeding @ $182.90/ha	914.50
Operation and maintenance			
Plough	28.33		
Harrow	41.25		
Oxen	123.84		
	Sub total: 378.83		Sub total: 2754.20
Manual labour @ $6/day			
Ploughing @ 3.33 day/ha	212.75		
Harrowing @ 2.50 day/ha	342.60		
Seeding @ 1.00 day/ha	60.00		
	Sub total: 615.35		
Seed 75 kg/ha at $1/kg	75.00	Seed 65 kg/ha	65.00
Annual income foregone		Additional income	
5000 kg rice @ $4.00 kg	20,000.00	4850 kg rice	19,400.00
TOTAL COST	21,129.18	TOTAL BENEFIT	22,210.20
Net benefit = Total benefit - total costs = 1081.00			
Net benefit/ha = 216.20			

Other considerations:

The proposed change will require: i) an increase of 25 days to complete the tillage operations; ii) grazing land for the animals.

The interest rate applied supposes that the farmer borrows money at an annual rate of 14 per cent in order to buy the animals and their equipment. If the farmer uses his own capital the charge is still made as he would forego the interest that would have been earned had it been invested. In this case the item would appear as "income foregone".

6.3 Net Present Values and Future Cash Flows

If $100 is deposited in a bank account which pays 10 per cent per year, after one year the deposit will be worth $100 x 1.10 = $110. After two years it will be worth $110 x 1.10 = $121 and so on. After five years it will be worth $161.

Seen in reverse, if the same bank promises to pay $161 in five years time, supposing an interest rate of ten per cent, its value if paid today would be $100. As an example, if we want to know how much $1000 paid in five years time would be worth today at an interest rate of ten per cent, we would have to divide the figure by 1.10 each year as shown in Table 6.5.

Table 6.5 Present value of $1000 paid five years hence

Year	Amount promised at year end, $	Discount factor %	Value at year's beginning, $
1998	1000	1.10	909
1997	909	1.10	826
1996	826	1.10	751
1995	751	1.10	683
1994	683	1.10	621
1993	621	1.10	564

It can be seen that $1000 in five years is worth $621 today at a 10% discount rate. The calculation is known as a discounted cash flow and is used to calculate the present value or cost of future cash flows. Published compounding and discounting tables (eg: IBRD, 1973) are employed to facilitate the calculation of present values.

The net present value (NPV) of future income will always be less than the sum of future income streams with positive rates of interest, but the determination of the appropriate interest rate can sometimes be difficult. An alternative method of analysis is to calculate the discount rate of future income to reduce the NPV to zero, this discount rate is called the internal rate of return (IRR). The IRR can be used to compare the value of alternative projected changes, any project is considered profitable if the IRR is greater than the interest charged on borrowed capital.

An example of the use of Net Present Values (or Costs) is to compare the cost of purchasing and operating a new animal drawn disc harrow using either "own" or "borrowed" capital. Table 6.6 demonstrates the possible costs associated with these two alternatives.

Table 6.6 Calculation of Net Present Cost of Capital and Operating Costs of Farm Machinery. Equipment: Animal drawn disc harrow

(i) Purchase using own capital

Year	0	1	2	3	4	5	6	7	8
Capital cost	1000								
Residual value									-250
Interest lost @ 7.5%	0	75	75	75	75	75	75	75	75
Operating costs									
Replace disc			20	20	20	20	20	20	20
Replace bearing			15		15		15		15
Labour		15	15	15	15	15	15	15	15
Annual costs	1000	90	125	110	125	110	125	110	-125

Net Present Cost **1419.50**
Discount Factor 15.0%

ii) Purchase using borrowed capital

Year	0	1	2	3	4	5	6	7	8
Capital cost	0	125	125	125	125	125	125	125	125
Residual value									-500
Interest on loan @ 25%	0	250	219	188	157	125	94	63	32
Operating costs									
Replace disc	0	20	20	20	20	20	20	20	20
Replace bearing	0		15		15		15		15
Labour	15		40	40	40	40	40	40	40
Annual costs	0	410	394	348	332	285	269	223	43

Net Present Cost **1885.30**
Discount Factor 15.0%

From this example and these assumptions in Table 6.6 it can be concluded that it will cost less for the farmer to purchase the harrow using his own capital ($1885.30 - $1419.50 = $465.50). However should interest rates change the situation may be reversed.

6.4 Variability, risk and sensitivity analysis

Farmers generally seek to improve the net benefits while trying to avoid the risk of enterprise failures. Researchers should bear this in mind whilst making farmer recommendations, average high returns are not attractive if there may be total failure in some years. Risk comes from two principal sources, yield and price variability.

The effects of different possible yield and price situations can be quantified by means of sensitivity analysis. As an example the case of tractor power being replaced by animal and human power for tillage and seeding (Section 6.2) can be analyzed. In addition to examining the effects on net benefit of reduced field prices and yield for rice, Table 6.7 analyses the impact of higher labour costs.

Table 6.7 Sensitivity analysis for the change of tillage and seeding technology for rice

	Power source					
	Animal	Tractor	Animal	Tractor	Animal	Tractor
	Yield reduced by 25%		Daily wage rate increased by 50%		Rice price reduced by 33%	
Gross benefit	14550	15000	19400	20000	12998	13400
Variable costs	994	2810	994	2810	994	2810
Labour	615		922		615	
Net benefit	12941	12190	17534	17190	11389	10590
Marginal net benefit	751		344		799	

The sensitivity to changes in yield and price is not very great due to the high cost of tractor hire. On the other hand it is very sensitive to increases in labour costs.

6.5 Equilibrium point partial budget

The partial budget analysis presented in Section 6.2 predicts the outcome of proposed changes, however as the future is uncertain, many of the assumptions are also risky. The equilibrium point partial budget calculates the value of selected parameters which will result in equal costs and benefits. The value thus calculated is known as the equilibrium point value, if it is much higher or lower than the projected value then the future profitability (positive or negative) can be predicted with greater confidence.

Again the example used will be the replacement of technology for rice establishment, however as the area is to be increased to 15 ha the purchase of a second hand tractor and equipment is proposed. This will allow timely tillage and seeding and permit custom work for neighbours. The decision on whether to purchase the equipment depends on the number of hours of custom work expected and this is assigned the letter "h" in Table 6.8.

Table 6.8 Point of equilibrium partial budget

Proposed change: Replace hired tractor with purchased second hand tractor and equipment. To be used on 15 ha rice and custom work for neighbours for "h" hours per year.

Date: November 1993

COSTS		BENEFITS	
Additional costs	**$**	**Costs avoided**	**$**
Tractor and equipment depreciation (VN-VR/UL	7633	Tractor hire 75 h @ $96/h	7200
Interest (VN+VR)/2 x 14%	10 640		
Operation and maintenance (75+h) hours @ $20.80/h	1,560+20.8 h		
Income foregone	**$**	**Additional income**	**$**
		Rent tractor h hours@ $96/h	96 h
Total cost:	**19 833 + 20.8 h**	**Total benefit:**	**7200 + 96 h**

The additional income generated is the difference between benefits and costs:

Additional income, \$ = 7200 + 96 h - 19 833 - 20.8 h = 75.2 h - 12 633

The equilibrium point value of "h" is where costs equal benefits, ie additional income is zero:

75.2 h - 12 633 = 0
h = 168 hours

APPENDIX 6A

COSTS AND OUTPUT OF FARM MACHINERY

i) **Animal draft mouldboard plough**

New value: $400	Useful life: 6 years
Residual value: $0	Annual use: 200 hours
Annual fixed costs:	**$**
Depreciation (VN-VR)/UL	66.67
Interest (VN+VR)/2 x i at 14%	28.00
	Sub total: 94.67
Annual variable costs:	
1 share @ $30	30.00
1 mouldboard @ $70/UL	11.67
Labour, welding material, etc @ $15/year	15.00
	Sub total: 56.67
Hourly fixed costs	0.47
Hourly variable costs	0.28
Operator @ $1.00/hour	1.00
Total hourly costs	**1.75**
Output (ha/hour) = (W x V x C x FE)/H[1]	0.05

1. W = width of work, 23 cm
V = mean forward speed, 0.8 m/s
C = conversion factor, 36
FE = Field efficiency, 75%
H = 1 hectare = 10 000 m^2
Thus output = (23 x 0.8 x 36 x 0.75)/10 000 = 0.05 ha/hour

ii) **Animal draft disc harrow**

New value: $1000	Useful life: 8 years
Residual value: $250	Annual use: 100 hours
Annual fixed costs	**US$**
Depreciation (VN-VR)/UL	93.75
Interest (VN+VR)/2 x i @ 14%	87.50
	Sub total: 181.25
Annual variable costs	
Replace 8 discs/UL @ $20/disc	20.00
Replace 4 bearings/UL @ $15/bearing	7.5
Labour and materials	15.00
	Sub total: 42.50
Hourly fixed costs	1.81
Hourly variable costs	0.42
Operator @ $1/hour	1.00
Total hourly costs	**3.23**
Output (ha/h) = (W x V x C x FE)/H[1]	0.19

1. W = width of work, 113 cm
V = mean forward speed, 0.71 m/s
C = conversion factor, 36
FE = Field efficiency, 65%
H = 1 hectare = 10 000 m^2
Thus output = (113 x 0.71 x 36 x 0.65)/10 000 = 0.19 ha/hour

iii) 50 kW tractor

New value: $24000	Useful life: 6 years
Residual value: $4000	Annual use: 500 hours
Interest rate: 14%	Price of diesel fuel: $1.78/liter
Annual fixed costs:	USS
Depreciation (VN-VR)UL	3333
Interest (VN+VR)/2 x i	1960
	Sub total: 5293
Annual variable costs:	US$
Operation and maintenance @ 0.85 VN/UL	3400
Fuel 4000 l	7120
	Sub total: 10520
Hourly fixed costs	10.58
Hourly variable costs	21.00
Total hourly costs	**31.58**

iv) **Tractor mounted 4 disc plough**

New value: $4500	Useful life: 15 years
Residual value: $300	Annual use: 175 hours
Interest rate: 14%	Price/ disc: $20
Annual fixed costs	**US$**
Depreciation (VN-VR)/UL	280
Interest (VN+VR)/2 x i	336
	Sub total: 616
Annual variable costs	
Operation and maintenance @ 0.05 VN/75 hours	225.75
Hourly costs	
Hourly fixed costs	3.52
Hourly variable costs	1.29
Total hourly costs	**4.81**
Output (ha/h) = (W x V x C x FE)/H[1]	0.34

1. W = width of work, 91 cm
V = mean forward speed, 1.3 m/s
C = conversion factor, 36
FE = Field efficiency, 80%
H = 1 hectare = 10 000 m^2
Thus output = (91 x 1.3 x 36 x 0.80)/10 000 = 0.19 ha/hour

v) **Tractor mounted 24 disc harrow**

New value: $6000	Useful life: 15 years
Residual value: $400	Annual use: 150 hours
Interest rate: 14%	
Annual fixed costs	**US$**
Depreciation (VN-VR)/UL	374
Interest (VN+VR)/2 x i	448
	Sub total: 822
Annual variable costs	
Operation and maintenance @ 0.07 VN/150 hours	420
Hourly costs	
Hourly fixed costs	5.48
Hourly variable costs	2.80
Total hourly costs	**8.28**
Output (ha/h) = (W x V x C x FE)/H[1]	0.97

1. W = width of work, 240 cm
V = mean forward speed, 1.4 m/s
C = conversion factor, 36
FE = Field efficiency, 80%
H = 1 hectare = 10 000 m^2
Thus output = (240 x 1.4 x 36 x 0.80)/10 000 = 0.97 ha/hour

vi) **Pair of draft oxen**

New value: $1000	Useful life: 5 years
Residual value: $1000	Annual use: 850 hours
Interest rate: 14%	Price of fodder: $0.6/kg
Cost/man hour: $1.00	Yoke: $20
Annual fixed costs	**$**
Depreciation (VN-VR)/UL	000
Interest (VN)/2 x i	70
	Sub total: 70
Annual variable costs	
Supplementary feed @ 100 kg/ox	120.00
Yoke: 1/3 years	6.67
Straps and ropes @ 0.01 VN/year	10.00
Veterinary costs @ 0.02 VN/year	20.00
Care @ $1.75 hours/week	91.00
	Sub total: 247.67
Total annual costs	**317.67**
Total hourly costs	**0.38**

SECTION B: TEST PROCEDURES

7 POWER MEASUREMENT

CONTENTS

7.1 Scope 97

7.2 Diesel and Petrol Engines 97

7.2.1 Laboratory tests 97
7.2.1.1 Definitions 97
7.2.1.2 Test Procedure 98
7.2.1.3 Report 98
7.2.2 Field Tests 99
7.2.2.1 Output shaft power 99
7.2.2.2 Power estimation 99

7.3 Tractors 100

7.3.1 Definitions 100
7.3.1.1 Power Take-off Power 100
7.3.1.2 Hydraulic Power 100
7.3.1.3 Drawbar power 100
7.3.2 Power-Take-Off Power 100
7.3.2.1 Laboratory Tests 100
7.3.2.2 Field Tests 102
7.3.3 Hydraulic Power 102
7.3.3.1 Test Equipment and Arrangement 102
7.3.3.2 Test Method 102
7.3.3.3 Results 102
7.3.3.4 Report 102
7.3.4 Drawbar Power 103
7.3.4.1 Definitions 103
7.3.4.2 Test Conditions and Equipment 103
7.3.4.3 Test Method 104
7.3.4.4 Results 104
7.3.4.5 Test Report 104

7.4 Electric Motors 106

7.4.1 Output Shaft Power 106
7.4.2 Motor Input Power 107
7.4.3 Report 107
7.4.3.1 Specification 107
7.4.3.2 Results 107
7.4.3.3 Repairs or adjustments 107

APPENDIX 7A Engine Performance Curves 108

APPENDIX 7B Crankshaft Power/Manifold Depression 108

APPENDIX 7C Hydraulic Pump Performance 109

APPENDIX 7D Tractor Drawbar Performance 109

7 POWER MEASUREMENT

7.1 Scope

These procedures cover the measurement of power output of diesel and petrol engines, tractors and electric motors.

The procedures give explanations of definitions, terms and relevant testing methods and prescribes measurements to be made and reported.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance of the power unit.

7.2 Diesel and Petrol Engines

These engines are generally used to provide power to drive tractors and machines such as mills, grinders, shellers, water pumps, planters. tillers, harvesters and sprayers.

7.2.1 Laboratory tests

The purpose of these tests is to establish the maximum performance of the engine over the full range of engine speed.

7.2.1.1 Definitions

7.2.1.1.1 Engine power

The power measured at the flywheel or crankshaft.

7.2.1.1.2 Rated speed

The engine speed specified by the manufacturer for continuous operation at full load.

7.2.1.1.3 Specific fuel consumption

The amount of fuel consumed per unit of work. When consumption is measured by volume, the mass of fuel per unit of work shall be calculated using the density corresponding to the fuel temperature at which the measurement was made.

7.2.1.1.4 Manifold depression

The pressure measured in the inlet manifold of a spark ignition engine at a point downstream of the carburetter.

7.2.1.1.5 Brake

A means of applying a controllable load to the output shaft of the engine.

7.2.1.1.6 Dynamometer

An instrument for measuring the force exerted by the brake on the output shaft of the engine.

7.2.1.2 Test Procedure

7.2.1.2.1 Test equipment

The engine shall be coupled to a suitable brake incorporating a torque measuring device or with a torque meter fitted into the drive line. Means shall be provided for measuring engine speed, fuel consumption, inlet manifold pressure (where applicable) and engine and ambient temperatures.

7.2.1.2.2 Preliminary adjustments

If the engine is new it should be run-in in accordance with the manufacturer's instructions. The fuel pump or carburetter and governor should be set to comply with the manufacturer's recommendations for the particular application.

7.2.1.2.3 Test method

Where a governor control is supplied it shall be set to the fully open position as recommended in 7.2.1.2.2.

After an initial warm-up period to enable conditions to become stabilised, the maximum power and the corresponding engine speed and fuel consumption shall be established.

With full load applied, measurements are made at varying engine speeds to a speed lower than that at which maximum torque occurs.

The governor curve is established by taking measurements at varying loads between maximum power and no-load speed.

At each of the points taken as indicated above, the engine speed, torque and fuel consumption shall be measured only when conditions have become stabilised.

Engine, fuel and ambient temperatures shall also be recorded. The tests shall be carried out continuously.

7.2.1.2.4 Results

The recorded results will enable performance curves to be plotted of torque, power and fuel consumption in relation to engine speed (see Appendix 7A) and tabulated (see 7.2.1.3.3).

7.2.1.3 Report

7.2.1.3.1 Photograph

A photograph showing the principal details of the engine shall be provided.

7.2.1.3.2 Specification

Make:	
Model:	
Serial No:	
Manufacturers name and address:	
Number of cylinders:	
Capacity:	cm^3
Cooling system:	
Rated engine speed:	rev/min
No-load engine speed:	rev/min
Manufacturers setting of fuel pump or carburetter:	
Manufacturers rated power:	kW

7.2.1.3.3 Summary of test results and conditions

Power, KW	Engine Speed, rev/min	Fuel Consumption			Temperatures			Ambient Conditions	
		Hourly		Specific g/kWh	Coolant °C	Fuel °C	Inlet Air °C	Temp °C	Pressure mm Hg
		l/h	kg/h						
Maximum Power									
Rated Engine Speed									
Maximum Torque									
Unloaded									

7.2.1.3.4 Performance curves
(See Appendix 7A)

7.2.1.3.5 Repairs and adjustments
Comments

7.2.2 Field Tests

During field work it is often required to measure the power that an engine is developing. There are several methods of doing this.

7.2.2.1 Output shaft power

A torque meter is fitted between the engine output shaft and the input shaft of the machine. With the machine operating normally, measurements are made of torque, speed and fuel consumption as described in 7.2.1.

Calculations of engine power and fuel consumption requirements may be made at varied machine settings.

7.2.2.2 Power estimation

If it is not mechanically possible to fit a measuring device into the drive line, one of the following methods may be used to estimate the power requirement.

7.2.2.2.1 Inlet manifold depression (Petrol engines only).

The relationship between power and manifold depression must first be obtained by means of a standard dynamometer test (7.2.1).

First the full power/speed curve is plotted and manifold depression is measured by attaching a manometer to a suitable tapping. The test is repeated at a series of throttle settings until the envisaged working range of the engine is covered. Appendix 7B illustrates a calibration over six throttle settings and curves of equal manifold depression (mm of water) are drawn to give the approximately horizontal lines. Measurement of manifold depression and engine speed in the field will then allow power to be estimated by reference to the calibration curves.

7.2.2.2.2 Exhaust gas temperature

In a method very similar to that described in 7.2.2.2.1. the exhaust gas temperature of an engine can be calibrated against power produced. A suitable thermo-couple (eg. iron-constanta or chromel-alumel) inserted in the exhaust manifold can be used for temperature measurement. Exhaust gas temperature is plotted on the power/speed curves as in the case of manifold depression.

A family of curves is produced at a series of throttle or governor settings.

Approximate power produced in the field can then be obtained by measuring exhaust gas temperature and engine speed and referring to the calibration curve.

7.2.2.2.3 Fuel consumption

If the engine fuel consumption is plotted on the power/speed curves as was the case for manifold depression (7.2.2.2.1) and exhaust gas temperature (7.2.2.2.2) and the calibration is repeated for a series of throttle or governor settings then power produced in the field can be estimated by measuring fuel consumption and engine speed and referring to the calibration chart.

A fuel flow meter must be fitted in the fuel line and connected so that the injector leak back on a diesel engine is not included in the fuel consumption measurement.

7.3 Tractors

The agricultural tractor is designed to carry or propel tools or machines and where necessary to operate them when stationery or in motion. The most commonly used power outlets are the power take-off, the hydraulic system and the drawbar.

7.3.1 Definitions

7.3.1.1 Power Take-off Power

The power measurement at any shaft designed by the manufacturer to be used as a power take-off.

7.3.1.2 Hydraulic Power

The power available from the tractor's hydraulic system, at a convenient tapping supplied by the manufacturer, to drive external motors or cylinders.

7.3.1.3 Drawbar power

The power available at the drawbar sustainable over a distance of at least 20 metres.

7.3.2 Power-Take-Off Power

7.3.2.1 Laboratory Tests

7.3.2.1.1 Test Method

The tractor is coupled to a suitable brake, incorporating a torque measuring device, by drive shaft or with a torque meter fitted into the drive line.

All the requirements for test equipment, adjustments and methods given for engines (7.2.1.2). shall also apply.

The recorded results will enable performance curves to be plotted as in Appendix A except that the torque will be the equivalent crankshaft torque. This is calculated from the torque measured at the power take-off shaft and the ratio of the engine to power take-off shaft speed. The results are then tabulated (see 7.3.2.1.3.3).

7.3.2.1.3 Report

7.3.2.1.3.1 Photograph

A photograph showing the principal details of the tractor shall be provided.

7.3.2.1.3.2 Specification

Make:
Model:
Serial No:
Manufacturers name and address:
Engine
Type:
Number of cylinders:
Cooling system:
Rated speed: rev/min
No-load speed: rev/min
Manufacturers setting of fuel pump or carburetter:
Manufacturers rated power: kW
Power take-off
Size of shaft: mm dia
Number of splines:
Speed at rated engine speed: rev/min

7.3.2.1.3.3 Summary of test results and conditions

Power kW	Speed, rev/min		Fuel Consumption			Temperatures			Ambient Conditions	
	Engine	PTO	Hourly		Specific g/kWh	Coolant °C	Fuel °C	Inlet Air °C	Temp °C	Pressure mm Hg
			l/h	kg/h						
Maximum Power										
Rated Engine Speed										
Maximum Torque										
Unloaded										

7.3.2.1.3.4 Performance curves (see 7.3.2.1.2 and Appendix 7A).

7.3.2.1.3.5 Repairs and adjustments
Comments

7.3.2.2 Field Tests

Tractors are used to drive stationary machines and soil engaging implements through power take-off shafts. The power required to operate these machines may be measured or estimated using the methods given for engines (see 7.2.1 and 7.2.2).

7.3.3 Hydraulic Power

7.3.3.1 Test Equipment and Arrangement

Oil is taken from an external tapping on the tractor by pipe which is as large as possible through a throttle valve to a suitable flow meter and then returned to the tractor oil reservoir. A pressure gauge should be fitted into the line as near as possible to the outlet from the tractor. Means shall be supplied to measure the oil temperature in the tractor oil reservoir.

It should be noted that some tractor models are fitted with a closed centre hydraulic system. In this case, the flow meter will be required to withstand the boost pump pressure as the oil return will be solidly connected.

7.3.3.2 Test Method

The tractor engine is run with the governor control fully open and the hydraulic pump engaged. Pressure is applied to the system by the valve to warm up the oil in the reservoir to 60°C-70°C.

Measurements will then be made of oil flow at varying pressures from the lowest to the maximum sustained by the open relief valve.

7.3.3.3 Results

The recorded results will enable hydraulic power to be calculated and curves of oil flow and power in relation to system pressure to be plotted. Examples are given in Appendix 7C and summarised in the report.

7.3.3.4 Report

7.3.3.4.1 Photograph

See 7.3.2.1.3.1

7.3.3.4.2 Specification

As 7.3.2.1.3.2 with the following additions:-

Hydraulic System

Type:
Relief valve pressure setting: bar
Type, number and location of tapping points:

7.3.3.4.3 Summary of results

Maximum hydraulic power:	kW
Corresponding pressure:	bar
Corresponding oil flow:	l/min
Flow at minimum pressure:	l/min
Maximum sustained relief valve pressure:	bar

7.3.3.4.4 Performance curves
(see Appendix 7C)

7.3.3.4.5 Repairs and adjustments:
Comments

7.3.4 Drawbar Power

7.3.4.1 Definitions

7.3.4.1.1 Draft

The force exerted on the tractor drawbar by a load being towed by the tractor. The force is measured by installing a dynamometer between the tractor drawbar and the load.

The line of draft should be horizontal but if this is not possible, the angle of pull should be measured and the horizontal pull calculated by the following formula.

Horizontal pull = measured pull x cos of the angle.

7.3.4.1.2 Speed

If the time is recorded for the tractor to move forwards under load for the distance measured when establishing the wheelslip, the true forward speed can be calculated.

7.3.4.1.3 Stall

There are two reasons for a tractor coming to rest under increasing drawbar load. In the slower gears it is usually by excessive wheelslip and in the higher gears by the engine speed falling below that of the maximum torque. (See diagram Appendix 7D).

7.3.4.2 Test Conditions and Equipment

7.3.4.2.1 Surface conditions

Drawbar tests may be carried out on a variety of surfaces consistent with the use of the tractor, such as grassland, stubble or cultivated land.

The site chosen for the tests should be level with even surface cover. A description of the land should be given in the report together with measurements of shear strength and type of surface cover.

7.3.4.2.2 Wheel equipment and ballasting

Tyres and wheels fitted should be selected from the range specified by the tractor manufacturer.

The tyres should be in new condition.

Ballast weights may be added to the tractor only if they are commercially available and water may be added to the tyres. Ballasting and tyre pressures should be consistent with the tyre manufacturers recommendations.

7.3.4.2.3 Drawbar

The height of the drawbar may be adjusted within its range but must remain fixed throughout the test. The height shall be chosen in such a way that direction of the tractor can always be controlled and P x H shall never exceed 0.8 x W x Z. This ensures that at least 20%W is maintained on the front wheels.

Where:
P = maximum drawbar pull
H = static height of line of draft
W = static weight of front wheels on the ground
Z = wheel base

7.3.4.2.4 Drawbar load

For test purposes, the load applied to the drawbar should be controllable and cover the whole draft range of the test tractor.

A convenient method is to use a further tractor of comparable engine size and weight fitted with an adjustable front towing hitch. With the towed tractor in a similar gear ratio to that of the test tractor, use of the governor control will enable varying loads to be applied.

7.3.4.2.5 Fuel consumption and temperature

Means may be provided to measure fuel consumption as in the power test on engines. The amount of fuel used over the timed duration of test run is measured. Temperatures of the fuel, engine and ambient air shall be measured.

7.3.4.3 Test Method

With the fully equipped tractor, measurements shall be made to establish the weight on the axles and the wheelbase and drawbar settings.

After warming up the tractor and with the governor control set to the maximum position, checks shall be made to ensure that the maximum no-load engine speed is in accordance with the manufacturers recommendations.

Test runs are made in each working gear at maximum governor setting and varying drawbar load to enable the performance curves to be drawn. (See example Appendix 7D).

For each point on the curve, when the drawbar load is established, the time and distance shall be recorded for 5 revolutions of the driving wheel. The power and wheel slip will then be calculated.

Measurements of fuel consumption in the higher gear ratios will help to establish whether maximum power has been achieved.

7.3.4.4 Results

Together with the performance curves, the results are summarised in tabular form in the report, together with any repairs and adjustments and remarks.

7.3.4.5 Test Report

7.3.4.5.1 Photograph

A photograph showing the principal details of the tractor shall be provided.

7.3.4.5.2 Specification

Make:
Model:
Type:
Serial No:
Manufacturers name and address:

Engine

Type:
Number of cylinders:
Capacity: cm^3
Cooling system:
Rated speed: rev/min
Manufacturers setting of the fuel pump or carburetter:
Manufacturers rated power: kW

Transmission

Type:
Number of gears:
Forward:
Reverse:

Gear ratios and travelling speeds

Gear No.	Group or Range	Number of engine revolutions for one revolution of the driving wheels	Nominal travelling speed* at rated engine speed of.... rev/min, km/h

* Calculated with a tyre dynamic radius index of mm. (ISO 4251/1 - 1984)

Drawbar

Height above ground - maximum: mm
- minimum: mm

Distance to rear of rear wheel centre: mm

7.3.4.5.3 Test conditions

Tractor

Wheels

Front - size of tyre:
tyre pressure: bar

Rear - size of tyre:
tyre pressure: bar

Weight

Front axle: kg
Rear axle: kg
Total: kg

Ballast if fitted

Front: kg
Rear: kg
Wheel base: mm
Height of drawbar above ground: mm

Field

Location:
Soil description:
Previous cultivation:
Crop residue:
Shear strength mean reading:

7.3.4.5.4 Summary of test results

Maximum power

Gear	Power, kW	Corresponding			Wheel Slip %	Fuel Consumption		Temperature, ° C			Atmospheric Pressure mm Hg
		Pull N	Speed km/h	Engine speed rev/min		kg/h	g/kWh	Fuel	Coolant	Ambient	

7.3.4.5.5 Performance curves (see Appendix 7D)

7.3.4.5.6 Repairs and adjustments:
Comments

7.4 Electric Motors

Single and three phase electric motors are used to drive machinery such as mills, grinders, shellers and water pumps.

They are essentially constant speed machines and their maximum output is normally rated and specified by the manufacturer. However it may be necessary to establish the power required to drive a particular machine.

7.4.1 Output Shaft Power

A torque meter is fitted between the motor output shaft and the input shaft of the machine. With the machine operating normally, measurements are made of torque and speed and power calculated.

7.4.2 Motor Input Power

If it is not mechanically possible to fit a measuring device into the drive line, it is possible to measure the electrical power required by the motor.

A proprietary watt meter should be installed between the power supply and the motor. Electrical connections should be made as prescribed by the meter manufacturer in his instruction book.

With the machine operating normally, measurements of power are made.

7.4.3 Report

7.4.3.1 Specification

Make:
Type:
Manufacturers name and address:
Voltage:
Single or 3 phase:
Rated speed: rev/min
Rated power: kW

7.4.3.2 Results

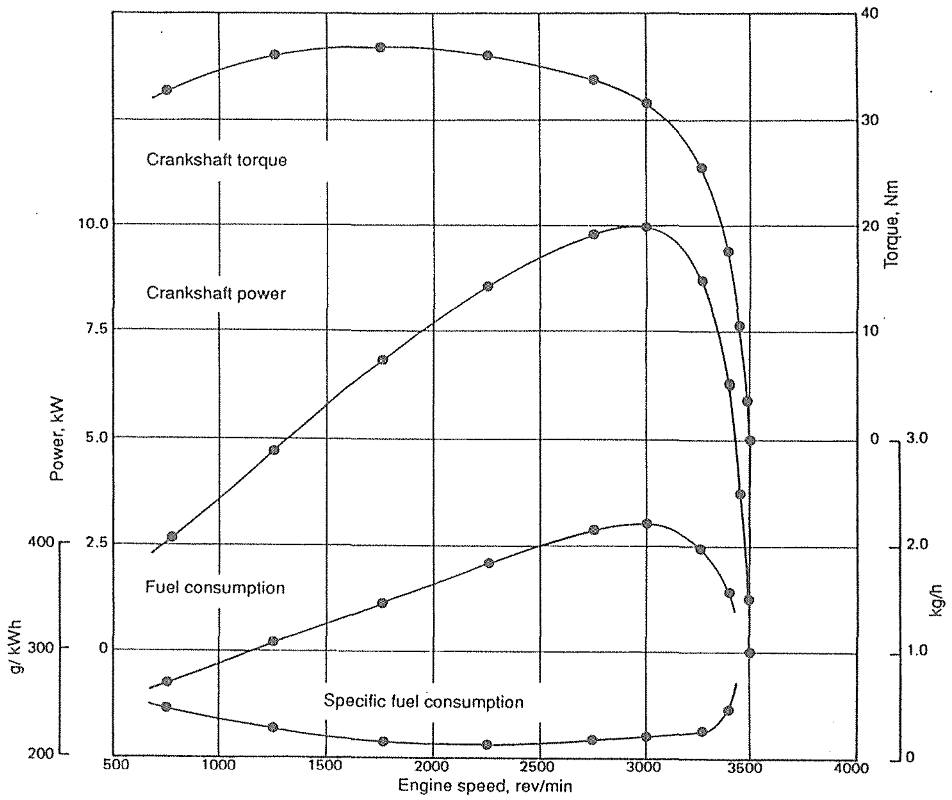
Machine setting	Shaft speed, rev/min	Output/input, Kw

7.4.3.3 Repairs or adjustments

Remarks

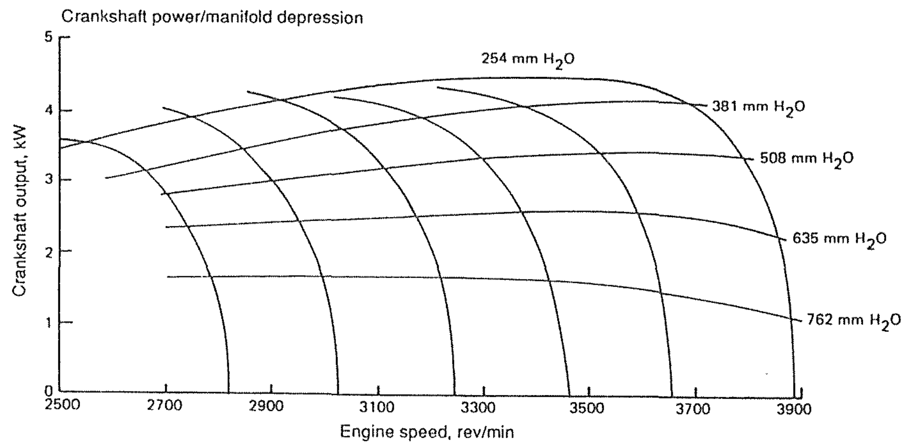
APPENDIX 7A

ENGINE PERFORMANCE CURVES



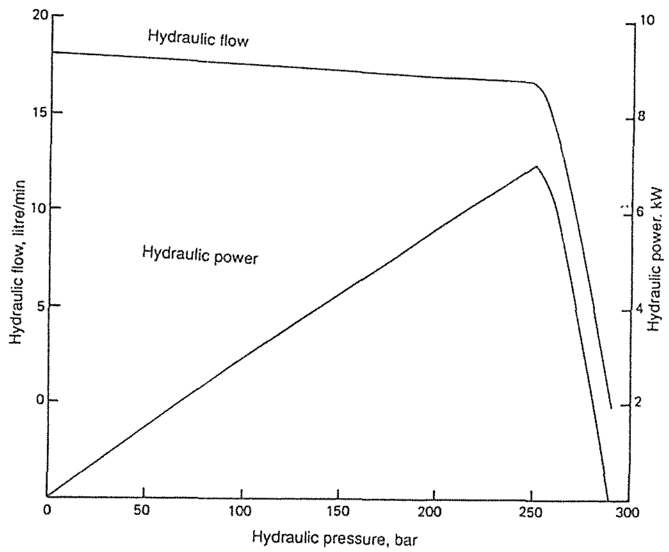
APPENDIX 7B

CRANKSHAFT POWER/MANIFOLD DEPRESSION



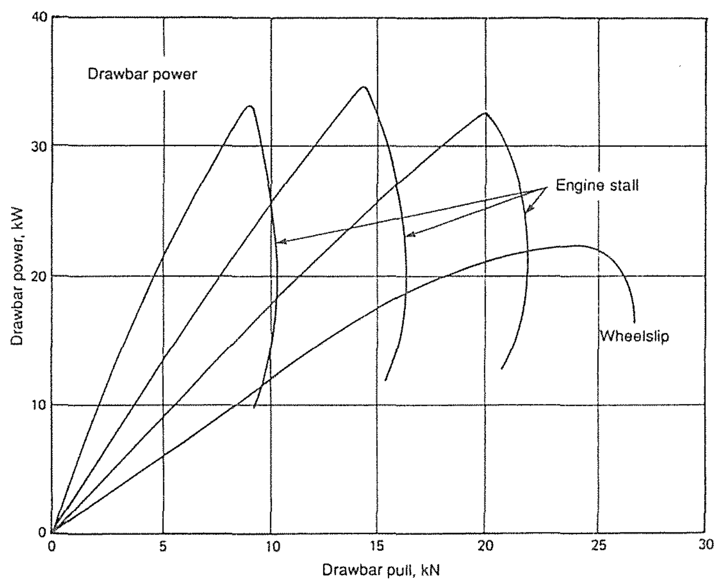
APPENDIX 7C

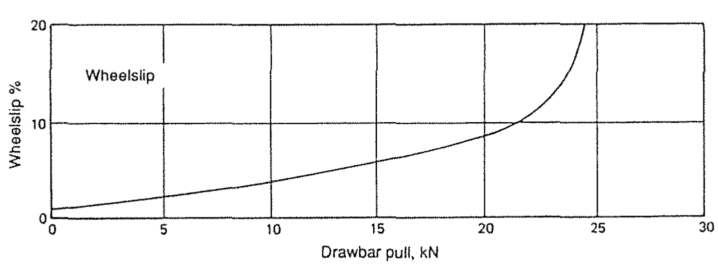
HYDRAULIC PUMP PERFORMANCE



APPENDIX 7D

TRACTOR DRAWBAR PERFORMANCE





8 PROCEDURE FOR EVALUATING DRAFT ANIMAL PERFORMANCE

CONTENTS

8.1 Introduction 111

8.2 Description of the Animals 111

8.2.1 Selection of test animals 111
8.2.2 Physical condition 111
8.2.3 Weight 111

8.3 Description Yokes and Harnesses 111

8.3.1 Yokes 112
8.3.2 Harnesses 112

8.4 Test Procedure 113

8.4.1 Instantaneous maximum force 113
8.4.2 Power tests 113
8.4.2.1 Maximum force sustainable over the working day 113
8.4.2.2 Short test of maximum sustainable force 114
8.4.2.3 Maximum speed sustainable throughout the working day 114
8.4.2.4 Short test of maximum sustainable speed 114
8.4.3 Effect of length of work day 114

8.5 Test Report 115

8.5.1 Description of the animals 115
8.5.2 Description of the yoke or harness 116
8.5.3 Maximum instantaneous draft force 116
8.5.4 Maximum force sustainable over the working day 116
8.5.5 Short test of maximum sustainable force 117
8.5.6 Maximum speed sustainable throughout the working day 117
8.5.7 Short test of maximum sustainable speed 117
8.5.8 Effect of length of working day 117

APPENDIX 8A Fatigue Scoring for Work Oxen 118

APPENDIX 8B Field Data Sheets 119

8 PROCEDURE FOR EVALUATING DRAFT ANIMAL PERFORMANCE

8.1 Introduction

Measurement of draft animal performance is complicated by the variability between animals and with the same animals according to their physical and mental state. Because of this the work capacity of an animal cannot be expressed in the same terms as tractors (see Section 7), and it's performance will vary according to the length and severity of previous work.

The procedure explains the definitions and terms employed and describes the methods for measuring power developed over relatively short periods; and output over periods of longer duration.

8.2 Description of the Animals

The breed of animal, it's age, physical state; nutrition, body weight etc., have a profound effect on work animal performance, and such information must be recorded.

8.2.1 Selection of test animals

For each breed to be tested selected animals will be well fed, healthy and of typical size. Results of tests with these animals will be taken as the breed norm.

Subsequently tests will be carried out on a range of animals of the same breed which are representative of the population of the animals used in agricultural work in the region.

8.2.2 Physical condition

Although methods exist for describing the physical condition of animals, these usually require a profound knowledge of animal physiology. For example Pullan (1978) suggests six categories for bovines according to the degree of emaciation. For the present test procedure, three categories are recommended:

1: Emaciated animals with an absence of sub-cutaneous fat, ribs visible through the skin and vertebrae sharp to the touch.

2: Animals in the normal condition <u>for the season</u>. The "normal" condition will vary according to the season, for example: at the end of the dry season it is probable that the normal condition is slightly emaciated; whilst at the end of the rains the animals will probably be fat.

3: Fat animals. The vertebrae cannot be felt even under considerable hand pressure, and the animals have "full" bodies.

Any presence of disease or other unusual condition that is detected will also be noted.

8.2.3 Weight

The draft animals should be weighed. If it is not possible to weigh them directly it will be necessary to estimate bodyweight (see Section 4.5)

8.3 Description Yokes and Harnesses

The yoke or harness used by a draft animal can have an effect on it's output as it is the means by which power is transmitted from the animal to the point of work.

8.3.1 Yokes

The type of yoke (horn, withers or other) used will be described giving the materials from which it is made and the principal dimensions (Figure 8.1).

- total length (a)
- distance between animal centres (b)
- dimensions of the yoke section (c and d)

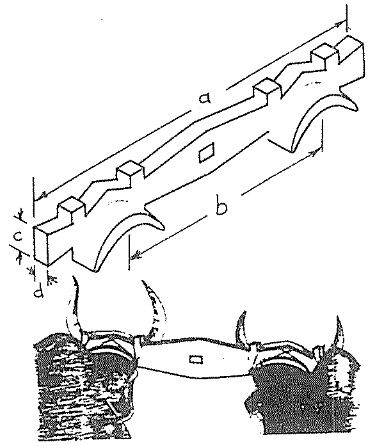


Figure 8.1 Traditional horn yoke
Source: Sims, 1987

8.3.2 Harnesses

The type of harness will be described including components, materials and principal dimensions (Figure 8.2).

A) Breastband harness
B) Breeching strap
C) Bridle and bit
D) Full collar harness
E) Back strap and belly strap

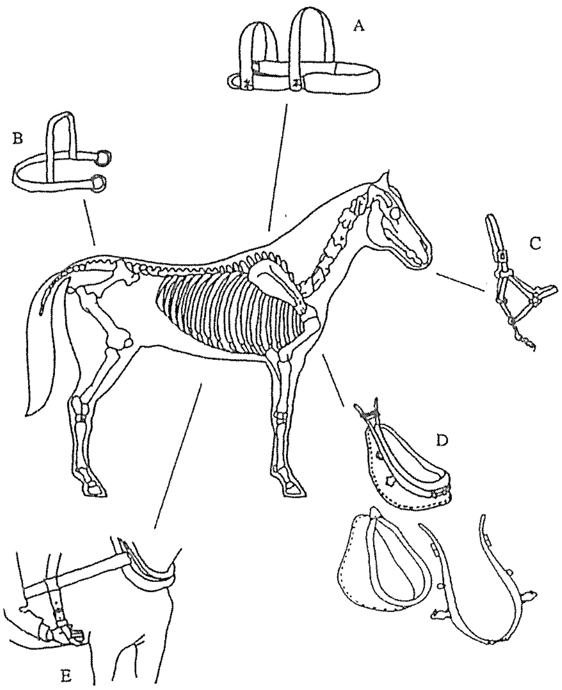


Figure 8.2 Some horse harnessing options
Source: Starkey, 1989

8.4 Test Procedure

8.4.1 Instantaneous maximum force

The maximum instantaneous force is that which the animal (or animals) can produce as a result of the inertia of the body if the animal is suddenly stopped by an obstacle (for example a large stone or root) in the soil.

The animal (or animals) are connected to the base of a tree (or other immovable object) by a cable 25-30 m in length. A force transducer (preferably one that records peak values) is connected to the cable between the tree and the animal, close to the base of the tree. The animal is made to walk forward and the maximum force produced when it is stopped by the cable is recorded. The forward speed is measured over the last 10 m with the aid of a stopwatch and two stakes spaced at 10 m.

The test is repeated at least five times over a range of forward speeds similar to those that would be achieved in normal agricultural tasks.

8.4.2 Power tests

The power developed by draft animals is a measure of the work (force x distance) done per unit time. It therefore depends on the draft force developed (N), and the forward speed (m/s).

In practice farmers know that, as the draft force is increased over the range normally experienced during field work, forward speed reduces. The animals' steps become irregular and the animals tire quickly requiring, as a result, longer rest periods to recuperate. By contrast for light draft work the animals are able to work at higher forward speeds without forfeiting their output over extended work periods. Nevertheless it seems that each species and breed of animals, and even individuals, have a range of forward speed which is preferred and comfortable (usually in the range of 0.6-1.5 m/s for bovines).

The farmer is interested in the maximum force and speed that his animals can sustain. Data on maximum power achievable over short periods are not of much practical use to him. For this reason the procedures for power measurement are designed to give information on the sustainable upper limits of the two parameters (force and speed).

8.4.2.1 Maximum force sustainable over the working day

In order to vary the load that the animal has to pull, an implement is needed that can be adjusted to change it's resistance in small and regular increments. An adjustable plough or a tool carrier that allows soil acting elements to be added and/or removed could be suitable for this purpose.

The rested draft animals are hitched to the adjustable implement with a force transducer in the line of pull to measure the draft force exerted. The draft force is measured each two or three furrows (or equivalent) to ensure that it remains approximately constant throughout the working day.

The test is started with a load equivalent to approximately 0.1 of the weight of the animals. The length of the working day will be the same as the norm for the region. For the first day the animals will be allowed to work normally as they wish, that is without provoking excessive fatigue, to provide the base line for comparison with subsequent stages of the test.

After each working day the animals are allowed to rest for a day to recuperate. Every other day is considered as a working day and the load is increased by increments of 10% each day until the animals display symptoms of excessive fatigue[1]. The maximum sustainable load is that which the animals are able to exert for the entire working day without suffering excessive fatigue.

---

[1] It is difficult to quantify the degree of fatigue of a work animal. Appendix 8A describes a system developed in India , nevertheless if the test personnel do not have the necessary experience they are advised to seek veterinary advice from personnel with experience of local working animals; and/or the opinion of the farmers themselves.

8.4.2.2 Short test of maximum sustainable force

It is possible that under some circumstances the procedure described in Section 8.4.2.1 may be too lengthy. In this case a shorter procedure can be followed to gain some idea of the maximum sustainable force.

Using the same methods and materials described in Section 8.4.2.1, the loads are applied for periods of 30 minutes with a rest period of a further 30 minutes between each test. The maximum load is that which the animals can sustain without producing symptoms of excessive fatigue.

8.4.2.3 Maximum speed sustainable throughout the working day

As has been explained work animals cannot usually increase their speed of work for prolonged periods whilst exerting high draft forces. Consequently during the test to measure the maximum forward speed, a light draft implement is coupled to the animals (for example: seeder; mower; light rake).

During the first day of the test the animals are allowed to work at their preferred speed. On subsequent work days the speed is increased until the maximum sustainable speed is determined. During the tests the speed is measured by taking the time required for the animals to walk a marked distance of 20 m (see Section 2.2.5).

As in the procedure for maximum sustainable load, the animals are allowed to rest for a day between each test run.

8.4.2.4 Short test of maximum sustainable speed

As in the case of the test for the maximum sustainable load, it is possible that the day-long tests described in Section 8.4.2.3 may be impractically lengthy, and that a shorter test would yield sufficient information.

Both in the case of maximum sustainable force and maximum speed, the short tests are only used to gain an idea of the order of size of the data. They cannot give the same confidence that could be placed in the results of the extended tests.

Using the same materials and methods described in Section 8.4.2.3, the forward speed is increased and maintained at each level for 30 minute periods of work followed by 30 minutes of rest. The maximum sustainable speed is that which does not produce symptoms of excessive fatigue.

8.4.3 Effect of length of work day

The duration of the working day has a marked effect on the maximum draft force that the animals can exert and sustain. Reducing the day to two or three hours would allow greater loads to be applied; on the other hand animals can only work for long periods - up to eight hours - with light draft loads.

A length of working day of five or six hours is typical for bovines in the tropics; horses and mules often work for longer - up to seven or eight hours per working day.

To compare the relative resistance of different breeds it is necessary to make them work with the maximum sustainable load determined in test 8.4.2.1. The first day the animals work the normal working day length in the region and, alternating work days and rest days, the working day is increased in increments of 30 minutes each time.

For this test it is necessary to weigh the animals at the beginning and before each working day. A reduction in weight, whilst maintaining a strictly normal diet for the region, would indicate an excessive expenditure of energy and, therefore, an excessively long working day.

8.5 Test Report

8.5.1 Description of the animals

Species:

Breed:

Sex:

Age: ......years

Weight ....kg

Body measurements:

Length: ....m
(Between the horns and the base of the tail - "l" in Figure 4.19)

Length: ....m
(From the front of the front shoulder to the base of the tail - "L" in Figure 4.19)

Height: ....m
(From ground level to withers - "H" in Figure 4.19)

Width of haunches: ....m

Heart girth ....m
("G" in Figure 4.19)

Physical condition: poor/normal/good

8.5.2 Description of the yoke or harness

Type:

Sketch:

Fabrication material(s):

Total length (yokes) ......m

Length between animal centres (yokes) ......m

Section dimensions (yokes) cm x cm

8.5.3 Maximum instantaneous draft force

Summary of the test results.

The results will be presented in tabular and graph (Figure 4.16) form. The data sheet for field work is given in Appendix 8B.

Forward Speed (m/s)	**Average Instantaneous Maximum Draft Force (N)**

8.5.4 Maximum force sustainable over the working day

The maximum force sustainable without provoking symptoms of excessive fatigue: ......N

See Appendix 8B for the field work data sheet.

8.5.5 Short test of maximum sustainable force

The maximum force sustainable for a period of 30 minutes without provoking symptoms of excessive fatigue:

......N

See Appendix 8B for the field work data sheet.

8.5.6 Maximum speed sustainable throughout the working day

Maximum speed sustainable throughout the working day without provoking excessive fatigue: ......m/s

See Appendix 8B for the field work data sheet.

8.5.7 Short test of maximum sustainable speed

Speed sustainable for a 30 minute period without provoking excessive fatigue: ......m/s

See Appendix 8B for the field work data sheet.

8.5.8 Effect of length of working day

Length of working day with maximum draft load: ......hours

See Appendix 8B for the field work data sheets.

APPENDIX 8A

FATIGUE SCORING FOR WORK OXEN

Source: Upadhyay and Madan, 1985.

	SCORE				
	1	2	3	4	5
Respiration rate/min	*R_o+15	R_o+30	R_o+45	R_o+60	R_o+75
Heart rate/min	*H_o+10	H_o+20	H_o+30	H_o+40	H_o+50
Rectal temp (°C)	*T_o+0.5	T_o+1.0	T_o+1.5	T_o+2.0	T_o+2.5
Frothing	First signs	Starts to dribble	Continuous dribbling	Froth on upper lips	Full mouth frothing
Leg coordination	Stride uneven	Occasional dragging of feet	Leg movement not coordinated frequent foot dragging	Complete loss of coordination in all legs	Unable to move
Excitement	Composed	Disturbed	Nostrils dilated, bad temper	Prominent eye ball movement	Furious and trying to stop
Inhibition of forward movement	Brisk	Free movement	Slow walking	Very slow	Stops walking
Tongue protrusion	Mouth closed	Occasional opening of mouth	Frequent appearance of tongue	Continuous appearance of tongue	Tongue fully out

* R_o, H_o, T_o are resting values of respiration, heart rate and rectal temperature respectively

APPENDIX 8B

FIELD DATA SHEETS

a) **Data sheet for instantaneous maximum forces**

Forward Speed (m/s)	Maximum Instantaneous Force (N)					
	Repetition					
	1	2	3	4	5	mean

b) **Data sheet for the maximum force sustainable throughout the working day**

Day No.	Mean Draft Force (N)	Evidence of Fatigue
1	0.1W	
2		
3		
4		
5		

c) **Data sheet for the short test of maximum sustainable draft force**

30 Min Period No.	Mean Draft Force (N)	Evidence of Fatigue
1	0.1W	
2		
3		
4		
5		

d) **Data sheet for the maximum speed sustainable throughout the working day**

Day No.	Forward Speed (m/s)	Evidence of Fatigue
1		
2		
3		
4		
5		

e) **Data sheet for the short test of maximum sustainable speed**

30 Min Period No.	Forward Speed (m/s)	Evidence of Fatigue
1		
2		
3		
4		
5		

f) **Data sheet for the effect of working day length**

Weight of each animal before the test: kg
Weight of each animal after the test: kg
Draft force: N

Day No.	Length of Working Day (h)	Evidence of Fatigue
1	T[1]	
2	T+0.5	
3	T+1.0	
4	T+1.5	
5	T+2.0	
6	T+2.5	
7	T+3.0	

1) T = The normal working day length in the region.

9 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR PRIMARY CULTIVATION

CONTENTS

9.1 Scope 122

9.2 Test Procedure 123

9.2.1 Implement for Test 123
9.2.2 Laboratory Work 123
9.2.3 Field Work 123
9.2.3.1 Test Conditions 123
9.2.3.2 Preliminary Trials 123
9.2.3.3 Performance Tests 124
9.2.3.4 Durability Trials 124
9.2.3.5 Trials on Farmers Fields 124

9.3 Test Report 125

9.3.1 Diagram/Photograph 125
9.3.2 Specification 125
9.3.2.1 Type of implement: 125
9.3.2.3 Overall dimensions: 125
9.3.2.4 Weight 125
9.3.2.5 Details of soil working parts 125
9.3.2.6 Coulter 125
9.3.2.7 Details of wheel of implement 125
9.3.2.8 Details of frame 125
9.3.2.9 Details of beam 125
9.3.2.10 Details of handle 126
9.3.2.11 Details of hitch 126
9.3.2.12 Type and range of adjustment of cutting width, depth and level 126
9.3.2.13 Recommended working speed 126
9.3.2.14 Working capacity (stated by manufacturer) 126
9.3.3 Results of Performance Tests 126
9.3.3.1 Details of animals or tractor used for tests. 126
9.3.3.2 Summary of test conditions and results 126
9.3.3.3 Comments on aspects of performance 127
9.3.4 Results of Durability Trials 127
9.3.5 Trials on Farmers Fields 127
9.3.6 Repairs and Adjustments and Recommendations for Modifications 127

APPENDIX 9A Field work sheets 128

APPENDIX 9B Test calculations sheet 129

9 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR PRIMARY CULTIVATION

9.1 Scope

This procedure is applicable for the evaluation of various types of animal and tractor drawn mouldboard and disc ploughs. (Figs 9.1 and 9.2)

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for the task of primary cultivation.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the implement.

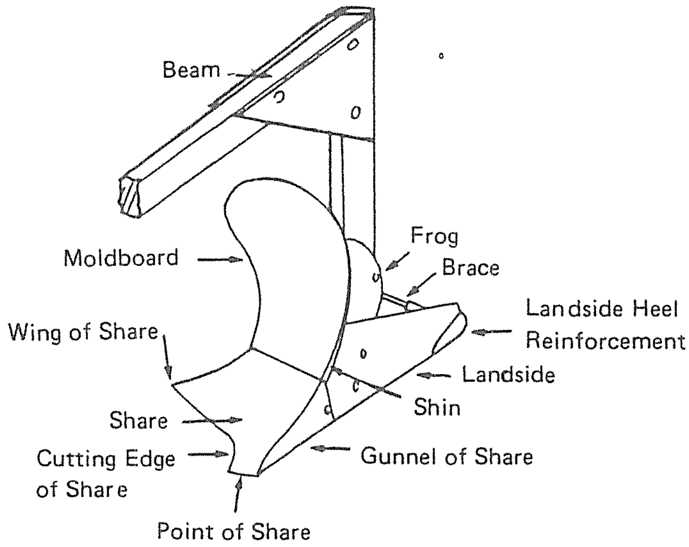


Figure 9.1 Parts of mouldboard plough
Source: FAO in RNAM, 1983

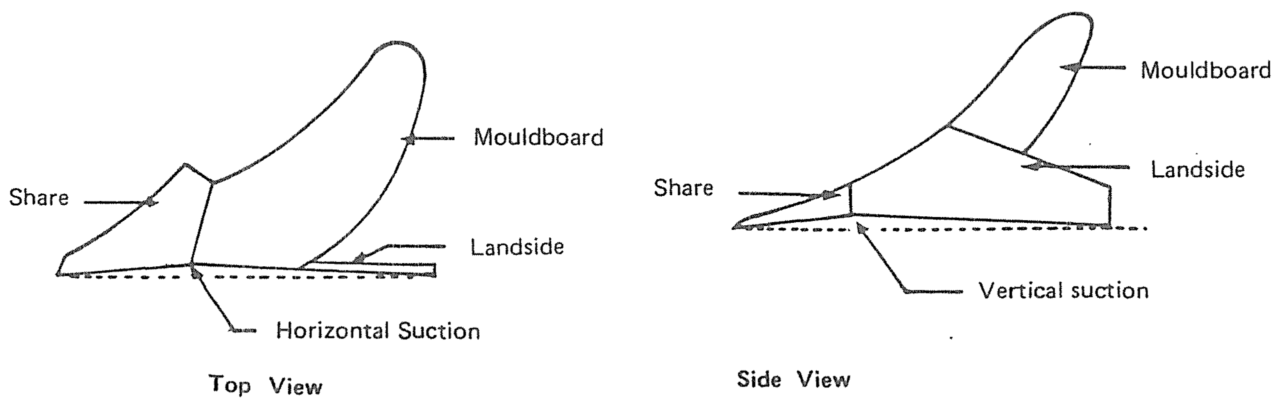


Figure 9.2(a)

Figure 9.2(b)

Figure 9.2 Clearance (suction) of mouldboard plough
Source: RNAM, 1983

9.2 Test Procedure

9.2.1 Implement for Test

Prior to any test work, the manufacturer shall supply the implement complete and in working order together with specifications concerning materials, construction, expected performance and range of adjustments. A complete specification will be given in the report.

9.2.2 Laboratory Work

The main objectives of work in the laboratory are to study and confirm the specifications and essential components comparing them to those given by the manufacturer and to undertake such studies that may assist in modification and improvement of the implement design.

a) Adjustment of working width, depth and level;
b) Type of coulter available;
c) Vertical adjustment of the coulter;
d) Material of plough share, mouldboard or disc;
e) Safety aspect;
f) Weight of soil working parts before and after test;
g) Towing arrangements.

Other items are listed in the specification form.

9.2.3 Field Work

9.2.3.1 Test Conditions

9.2.3.1.1 Tractors and draft animals

Tractors used for the test should be compatible with the implement under test and be driven by experienced operators. Draft animals and their handlers should be highly trained and if possible, familiar with the type of implement under test. The animals should be in good condition and records of their health and feeding regime should be available. The number of animals required will depend on the implement draft and consideration that an animal will pull approximately 10% of its body weight.

9.2.3.1.2 Fields

The performance of ploughs varies considerably according to the type of soil, its moisture content, weed growth, crop residue and shape of fields. The following conditions will require to be clearly stated in the test report.

a) Area and shape of test field;
b) Type and character of soil;
c) Topography;
d) Last crop in the field;
e) Height of stubble of last crop;
f) Condition of weed (degree of weed infestation);
g) Soil conditions (Section 4.2)

9.2.3.2 Preliminary Trials

Preliminary trials should be carried out on land adjacent to the test plots in order that adjustments may be made to the plough and testing equipment checked for correct operation. It is also an opportunity for engineers and operators to familiarise themselves with the operation of the plough especially where draft animals are used.

9.2.3.3 Performance Tests

The main objectives of the performance tests are to obtain reliable data on the implement such as capacity and quality of work, ease of operation and maintenance requirements and adaptability to varied soil conditions.

At least three series of tests should be made under different soil conditions. When the test plots have been marked out and prior to any tests being carried out, soil samples should be taken for measurement in the laboratory of soil type, moisture content, bulk density, and mean clod diameter. Cone index and shear strength measurements and weed counts should also be made.
Each plot should be completed without stopping unless this is necessary due to adjustments, breakdowns or animal rest periods.

The following measurements should be recorded:-

a) Width of ploughing* (Section 2.1.3)
b) Depth of ploughing* (Section 2.1.3)
c) Total area of ploughing
d) Travelling speed (Section 2.2.5)
e) Draft* and draft angle or geometry (Section 4.6.1.2)
f) Wheelslip (Section 4.3.2.2)
g) Time spent turning at headlands
h) Time spent for any other reason
i) Total operating time

* These are mean figures of a number of readings taken along each furrow. (Examples of work sheets are given in Appendix 9A).

At the end of the test, measurement will again be made of weed cover and clod diameter.

During the test, the following observations should also be made and any comments recorded.

a) Ease of handling
b) Ease of adjustment
c) Maintenance of depth
d) Adhesion of soil to shares, mouldboards or discs
e) Blocking with weeds or trash
f) Visible deformation
g) Wear of soil working parts

9.2.3.4 Durability Trials

In order to obtain more accurate measurements of wear of working parts and highlight any possible problems of maintenance and operation, trials may be made covering longer periods of work.

It is envisaged that these should last for about 100 hours and due to the area of land required, it may be desirable to use farmers fields instead of test station sites.

All details of plot conditions and measurements specified in the performance tests should be recorded throughout the trials together with comments on operating characteristics.

9.2.3.5 Trials on Farmers Fields

A series of trials may be undertaken on farmers fields to enable the implement to be evaluated in varied field and soil conditions. All the conditions and measurements specified in the performance and durability trials will apply.

9.3 Test Report

9.3.1 Diagram/Photograph

A line drawing or photograph showing principal details of the implement should be provided.

9.3.2 Specification

9.3.2.1 Type of implement:
Source of draft power:

9.3.2.2 Make:
Model:
Serial No:
Manufacturers name and address:

9.3.2.3 Overall dimensions:

	Length	cm
	Width	cm
	Height	cm
9.3.2.4	Weight	kg

9.3.2.5 Details of soil working parts

Type:	
Number of bottoms or discs:	
Working width of each bottom or disc:	cm
Type of mouldboard:	
Disc diameter and concavity:	cm
Materials of share or disc:	
Thickness of share, mouldboard and disc:	mm
Hardness:	
Horizontal suction:	cm
Vertical suction:	cm

9.3.2.6 Coulter

Type:	
Size:	
Adjustment:	cm

9.3.2.7 Details of wheel of implement

9.3.2.8 Details of frame

Construction:	
Dimension of major member and material:	mm x mm

9.3.2.9 Details of beam

Construction:	
Dimension of major member and material:	mm x mm

9.3.2.10 Details of handle

Construction
Height of handle from ground cm
Details of adjustment

9.3.2.11 Details of hitch

Shape and construction
(In case of tractor mounted unit, category of three point linkage)

9.3.2.12 Type and range of adjustment of cutting width, depth and level cm

9.3.2.13 Recommended working speed km/h

9.3.2.14 Working capacity (stated by manufacturer) ha/h

9.3.3 Results of Performance Tests

9.3.3.1 Details of animals or tractor used for tests.

9.3.3.2 Summary of test conditions and results

Test No.						
Date Location Plot size (m x m) Topography Soil description Previous cultivation Previous crop Crop residue Weed count (n/m^2) Cultivation after last harvest Soil moisture (% DB) Dry bulk density (g/cm^3) Penetrometer reading (kPa) Shear strength (kPa)						
Operational pattern Working depth (cm) Working width (cm) Draft (kgf or N) Speed (m/s) Power (W) Tractor wheel slip (%) Time taken to complete operation (min) Field efficiency (%) (Section 4.6.1.3) Soil inversion (%) (Section 4.6.1.4)						

9.3.3.3 Comments on aspects of performance

Ease of handling
Ease of adjustment
Maintenance of depth
Adhesion of soil to shares, mouldboards or discs
Blocking with weeds or trash
Visible deformation
Wear of soil working parts
General

9.3.4 Results of Durability Trials

All details given 9.3.3.2. and 9.3.3.3. will apply to results of durability trials.

9.3.5 Trials on Farmers Fields

All details given in 9.3.3.2. and 9.3.3.3. will apply to results of trials on farmers fields.

9.3.6 Repairs and Adjustments and Recommendations for Modifications

APPENDIX 9A

1 Field work sheets

1.1 Test conditions

Implement: Make: Test No:
Type: Date:

Location of site:
Topography:
Soil description:
Previous cultivation:
Previous crop:
Crop residue:
Plot size: (m length x m width)

Weeds in m^2 area before test						
Weeds in m^2 area after test						
Cone penetrometer reading (kPa)						
Soil shear strength (kPa)						
Bulk density samples	1	2	3	4	5	6
Soil moisture samples	1	2	3	4	5	6

1.2 Test results

Implement: Make: Test No:
Type: Date:

Number, type and condition of draught animals:

Make, type and size of tractor:
Distance for 5 revolutions of tractor wheel unloaded: m

Time at start of test: h min

		1	2	3	4	5	6	Mean
Working width (cm)	1 2 3							
Working depth (cm)	1 2 3							
Dynamometer readings (kgf or N)	1 2 3							
Angle of dynamometer link (°)								
Time for 20m working length (sec)								
Time for 2 complete rows (min, sec)								
Distance for 5 revolutions of tractor wheel under load (m)								

Time for stoppages:-

	From	To	Reason, Remarks
1			
2			
3			
4			
5			

Time at completion of test: h min

Number of furrows or passes in plot width:

1.3 Comments on performance

Ease of handling:
Ease of adjustment:
Maintenance of depth:
Adhesion of soil to working parts:
Blocking with weeds or trash:
Visible deformation:
Wear of soil working parts:
General:

APPENDIX 9B

Test calculations sheet.

Note:* Denotes Average Value	Unit	Symbol	Value
Plot size completed (area) Cone index* Shear strength* Bulk density* Soil moisture* (D.B.)	m^2 kPa kPa g/cm^3 %	M C	
Working speed* Working width* Working depth* Total time to complete area M Effective field capacity = $\frac{M}{10\ 000T}$ Theoretical field capacity = 0.0036 WS Field efficiency = $\frac{A}{G}$ x 100 Distance for 5 revs of driving wheel without load Distance for 5 revs of driving wheel when loaded Wheel slip - $\frac{H - J}{H}$ x 100 Average turning and stoppage time per row	m/s cm cm hr ha/h ha/h % m m % sec	S W d T A G H J	
Measured draft* Dynamometer link angle* Horizontal draft = B cos Θ Power input = $\frac{F\ (kgf)S}{0.10197}$ or F(N)S Cross section area cut on each pass* Maximum depth*	kgf(N) ° kgf(N) W cm^2 cm	B Θ F K X D	
Ploughing evenness efficiency = $\frac{d}{D}$ Weeds before test* Weeds after test* Weeding efficiency = $\frac{W_1 - W_2}{W_1}$ x 100 Unit resistance = $\frac{F}{X}$	 n/m^2 n/m^2 % $kgf(N)/cm^2$	E_E W_1 W_2 E_1	

10 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR SECONDARY CULTIVATION

CONTENTS

10.1 Scope 132

10.2 Test Procedure 134

10.2.1 Implement for Test 134
10.2.2 Laboratory Work 134
10.2.3 Field Work 134
10.2.3.1 Test Conditions 134
10.2.3.2 Preliminary Trials 134
10.2.3.3 Performance Tests 135
10.2.3.4 Durability Trials 135
10.2.3.5 Trials on Farmers Fields 135

10.3 Test Report 136

10.3.1 Diagram/Photograph 136
10.3.2 Specification 136
10.3.2.1 Type of implement: 136
10.3.2.2 Make: 136
10.3.2.3 Overall dimensions 136
10.3.2.4 Weight 136
10.3.2.5 Details of soil working parts (disc harrows) 136
10.3.2.6 Details of soil working parts (cultivators) 136
10.3.2.7 Details of wheel of implement 136
10.3.2.8 Details of frame 136
10.3.2.9 Details of beam 136
10.3.2.10 Details of handle 137
10.3.2.11 Details of hitch 137
10.3.2.12 Type and range of adjustment of cutting width, depth and level 137
10.3.2.13 Means of transport 137
10.3.2.14 Recommended working speed 137
10.3.2.15 Working capacity (stated by manufacturer) 137
10.3.3 Results of Performance Tests 137
10.3.3.1 Details of animals or tractor used for tests 137
10.3.3.2 Summary of test conditions and results 137
10.3.3.3 Comments on aspects of performance 138
10.3.4 Results of durability trials 138
10.3.5 Trials on farmers fields 138
10.3.6 Repairs and adjustments and recommendations for modifications 138

APPENDIX 10A Field work sheets 139

APPENDIX 10B Test calculations sheet 141

10 PROCEDURE FOR EVALUATION OF IMPLEMENTS FOR SECONDARY CULTIVATION

10.1 Scope

This procedure is applicable for the evaluation of various types of animal and tractor drawn disc and tine cultivators. (Figs 10.1 to 10.5)

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for the task of secondary cultivation.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the implement.

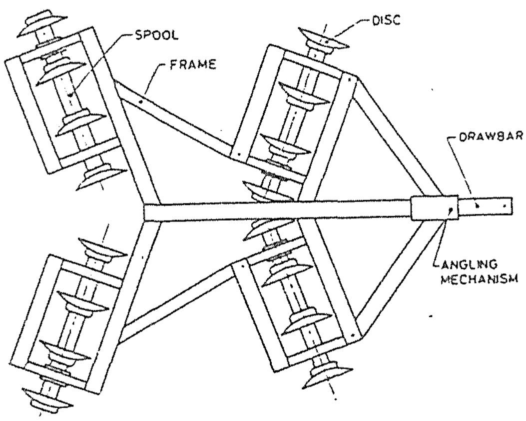


Figure 10.1 Tandem Disc Harrow
(Source: Indian Standards Institution, 1972)

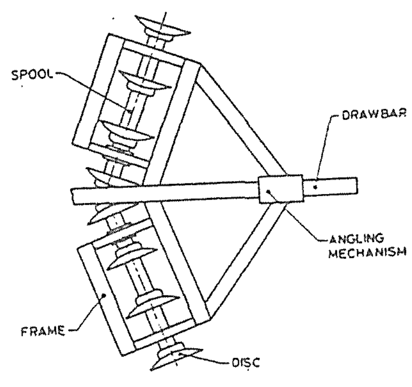


Figure 10.2 Offset Disc Harrow
(Source: Indian Standards Institution, 1972)

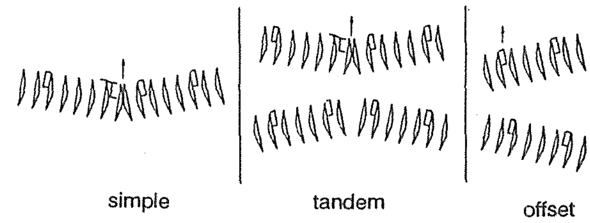


Figure 10.3 Three types of Disc Harrows according to gang arrangement
(Source: RNAM, 1983)

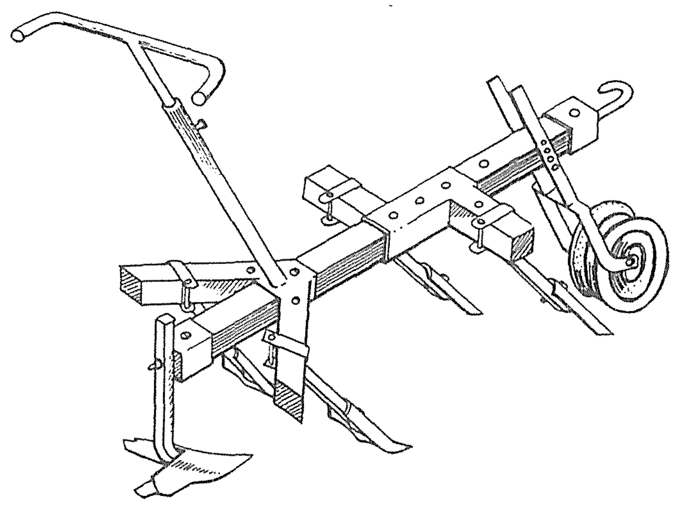


Figure 10.4 Animal Drawn Cultivator
(Source: RNAM, 1983)

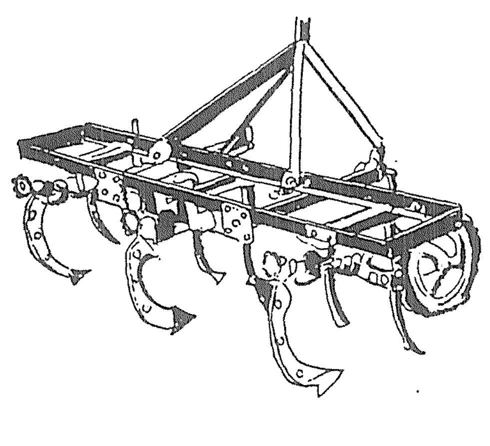


Figure 10.5 Tined Cultivator
(Source: RNAM, 1983)

10.2 Test Procedure

10.2.1 Implement for Test

Prior to any test work, the manufacturer shall supply the implement complete and in working order together with specifications concerning materials, construction, expected performance and range of adjustments.

A complete specification will be given in the report.

10.2.2 Laboratory Work

The main objectives of work in the laboratory are to study and confirm the specifications and essential components comparing them to those given by the manufacturer and to undertake such studies that may assist in modification and improvement of the implement design.

a) Adjustment of working width, depth and level;
b) Type of discs or tines and arrangement;
c) Material of soil engaging parts;
d) Weight of soil working parts before and after test;
e) Towing arrangements.

Other items are listed in the specification form.

10.2.3 Field Work

10.2.3.1 Test Conditions

10.2.3.1.1 Tractors and draft animals

Tractors used for the test should be compatible with the implement under test and be driven by experienced operators.

Draft animals and their handlers should be highly trained and if possible, familiar with the type of implement under test. The animals should be in good condition and records of their health and feeding regime should be available. The number of animals required will depend on the implement draft and consideration that an animal will pull approximately 10% of its body weight.

10.2.3.1.2 Fields

The performance of cultivators varies considerably according to the type of soil, its moisture content, weed growth, crop residue and shape of fields. The following conditions will require to be clearly stated in the test report.

a) Area and shape of test field;
b) Type and character of soil;
c) Topography;
d) Last crop in the field;
e) Height of stubble of last crop;
f) Condition of weed (degree of weed infestation);
g) Soil conditions (Section 4.2)

10.2.3.2 Preliminary Trials

Preliminary trials should be carried out on land adjacent to the test plots in order that adjustments may be made to the cultivator and testing equipment checked for correct operation. It is also an opportunity for engineers and operators to familiarise themselves with the operation of the cultivator especially where draft animals are used.

10.2.3.3 Performance Tests

The main objectives of the performance tests are to obtain reliable data on the implement such as capacity and quality of work, ease of operation and maintenance requirements and adaptability to varied soil conditions.

At least three series of tests should be made under different soil conditions. When the test plots have been marked out and prior to any tests being carried out, soil samples should be taken for measurement in the laboratory of soil type, moisture content, bulk density, and mean clod diameter. Cone index and shear strength measurements, weed counts and evenness measurements should also be made.

Each plot should be completed without stopping unless this is necessary due to adjustments, breakdowns or animal rest periods.

The following measurements should be recorded:-

a) Width of cultivating* (Section 2.1.3)
b) Depth of cultivating* (Section 2.1.3)
c) Total area of cultivation
d) Travelling speed (Section 2.2.5)
e) Draft* and draft angle or geometry (Section 4.6.1.2)
f) Wheelslip (Section 4.3.2.2)
g) Time spent turning at headlands
h) Time spent for any other reason
i) Total operating time

* These are mean figures of a number of readings taken along each furrow. (Examples of work sheets are given in Appendix 10A).

At the end of the test, measurement will again be made of weed cover and clod diameter and evenness.

During the test, the following observations should also be made and any comments recorded.

a) Ease of handling
b) Ease of adjustment
c) Maintenance of depth
d) Adhesion of soil to tines or discs
e) Blocking with weeds or trash
f) Visible deformation
g) Wear of soil working parts

10.2.3.4 Durability Trials

In order to obtain more accurate measurements of wear of working parts and highlight any possible problems of maintenance and operation, trials may be made covering longer periods of work.

It is envisaged that these should last for about 100 hours and due to the area of land required, it may be desirable to use farmers fields instead of test station sites.

All details of plot conditions and measurements specified in the performance tests should be recorded throughout the trials together with comments on operating characteristics.

10.2.3.5 Trials on Farmers Fields

A series of trials may be undertaken on farmers fields to enable the implement to be evaluated in varied field and soil conditions. All the conditions and measurements specified in the performance and durability trials will apply.

10.3 Test Report

10.3.1 Diagram/Photograph

A line drawing or photograph showing principal details of the implement should be provided.

10.3.2 Specification

10.3.2.1 Type of implement:
Source of draft power:

10.3.2.2 Make:
Model:
Serial No:
Manufacturers name and address:

10.3.2.3 Overall dimensions

Length	cm
Width	cm
Height	cm

10.3.2.4 Weight — kg

10.3.2.5 Details of soil working parts (disc harrows)

Type:
Number of gangs:
Number of discs per gang:
Type of disc (plain or notched):
Disc diameter and concavity: — cm
Materials of disc:
Thickness of disc:
Hardness:

10.3.2.6 Details of soil working parts (cultivators)

Type:
Number of row spacing:
Material:
Hardness:

10.3.2.7 Details of wheel of implement

10.3.2.8 Details of frame

Construction:
Dimension of major member and material — mm x mm

10.3.2.9 Details of beam

Construction:
Dimension of major member and material — mm x mm

10.3.2.10 Details of handle

Construction
Height of handle from ground — cm
Details of adjustment

10.3.2.11 Details of hitch

Shape and construction
(In case of tractor mounted unit, category of three point linkage)

10.3.2.12 Type and range of adjustment of cutting width, depth and level

10.3.2.13 Means of transport.

10.3.2.14 Recommended working speed — km/h

10.3.2.15 Working capacity (stated by manufacturer) — ha/h

10.3.3 Results of Performance Tests

10.3.3.1 Details of animals or tractor used for tests.

10.3.3.2 Summary of test conditions and results

Test No.						
Date Location Plot size (m x m) Topography Soil description Previous cultivation Previous crop Crop residue Weed count (n/m^2) Cultivation after last harvest Soil moisture (DB %) Dry bulk density (g/cm^3) Penetrometer reading (kPa) Shear strength (kPa)						
Operational pattern Working depth (cm) Working width (cm) Draft (kgf or N) Speed (m/s) Power (W) Tractor wheel slip (%) Time taken to complete operation (min) Field efficiency (%) (Section 4.6.1.3) Soil inversion (%) (Section 4.6.1.4) Evenness of cultivating						

10.3.3.3 Comments on aspects of performance

Ease of handling
Ease of adjustment
Maintenance of depth
Adhesion of soil to tines or discs
Blocking with weeds or trash
Visible deformation
Wear of soil working parts
General

10.3.4 Results of durability trials

All details given 10.3.3.2. and 10.3.3.3. will apply to results of durability trials.

10.3.5 Trials on farmers fields

All details given in 10.3.3.2. and 10.3.3.3. will apply to results of trials on farmers fields.

10.3.6 Repairs and adjustments and recommendations for modifications

APPENDIX 10A

1 Field work sheets

1.1 Test conditions

Implement: Make: Test No:
Type: Date:

Location of site:
Topography:
Soil description:
Previous cultivation:
Previous crop:
Crop residue:
Plot size: m length x m width

Weeds in m^2 area before test						
Weeds in m^2 area after test						
Cone penetrometer reading (kPa)						
Soil shear strength (kPa)						
Bulk density samples	1	2	3	4	5	6
Soil moisture samples	1	2	3	4	5	6
Surface evenness measurement before test						
Surface evenness measurement after test						

1.2 Test Results

Implement: Make: Test No:
Type: Date:

Number, type and condition of draught animals:

Make, type and size of tractor:
Distance for 5 revolutions of tractor wheel unloaded: m

Time at start of test: h min

		1	2	3	4	5	6	Mean
Working width (cm)	1							
	2							
	3							
Working depth (cm)	1							
	2							
	3							
Dynamometer readings (kgf or N)	1							
	2							
	3							
Angle of dynamometer link (°)								
Time for 20m working length (sec)								
Time for 2 complete rows (min, sec)								
Distance for 5 revolutions of tractor wheel under load (m)								

Time for stoppages:-

	FROM	TO	REASON, REMARKS
1			
2			
3			
4			
5			

Time at completion of test: h min

Number of furrows or passes in plot width:

1.3 Comments on performance

Ease of handling:
Ease of adjustment:
Maintenance of depth:
Adhesion of soil to working parts:
Blocking with weeds or trash:
Visible deformation:
Wear of soil working parts:
General:

APPENDIX 10B

Test calculations sheet.

Note:* Denotes average value	**Unit**	**Symbol**	**Value**
Plot size completed (area)	m^2	M	
Cone index*	kPa	C	
Shear strength*	kPa		
Bulk density*	g/cm^3		
Soil moisture* (D.B.)	%		
Working speed	m/s	S	
Working width*	cm	W	
Working depth*	cm	d	
Total time to complete area M	h	T	
Effective field capacity = $\frac{M}{10,000\ T}$	ha/h	A	
Theoretical field capacity = 0.0036 WS	ha/h	G	
Field efficiency = $\frac{A}{G}$ x 100	%		
Distance for 5 revs of driving wheel without load	m	H	
Distance for 5 revs of driving wheel when loaded	m	J	
Wheel slip - $\frac{H - J}{H}$ x 100	%		
Average turning and stoppage time per row	sec		
Measured draft*	kgf(N)	B	
Dynamometer link angle*	°	Θ	
Horizontal draft = B cos Θ	kgf(N)	F	
Power input = $\frac{F\ (kgf)S}{0.10197}$ or F(N)S	W	K	
Weeds before test*	n/m^2	W_1	
Weeds after test*	n/m^2	W_1	
Weeding efficiency = $\frac{W_1 - W_2}{W_1}$ x 100	%	E_1	

11 PROCEDURE FOR EVALUATION OF HAND HOES

CONTENTS

11.1 Scope 143

11.2 Examples of hoe types 143

11.3 Test Procedure 144

11.3.1 Implement for test 144
11.3.2 Laboratory work 144
11.3.3 Field work 144
11.3.3.1 Test conditions 144
11.3.3.2 Preliminary trials 144
11.3.3.3 Performance tests 144
11.3.3.4 Comparative tests 145
11.3.3.5 On-farm durability tests 145

11.4 Test report 145

11.4.1 Diagram/Photograph 145
11.4.2 Specification 145
11.4.2.1 Type of implement: 145
11.4.2.2 Make: 145
11.4.2.3 Blade 145
11.4.2.4 Blade mounting 145
11.4.2.5 Handle 145
11.4.2.6 Support wheel 145
11.4.2.7 Total weight of hoe 146
11.4.3 Results of tests 146
11.4.3.1 Details of operators 146
11.4.3.2 Summary of test conditions and results 146
11.4.3.3 Comments on aspects of performance 146
11.4.4 Results of on-farm durability trials 146
11.4.5 Trials on farmers fields 146
11.4.6 Repairs and adjustments and recommendations for modifications 146

APPENDIX 11A Field work sheets 147

11 PROCEDURE FOR EVALUATION OF HAND HOES

11.1 Scope

This procedure is applicable for the evaluation of various types of hand hoes. The procedure gives general terms and prescribes measurements and assessments to be made to establish rates and quality of work, and to evaluate ergonomics aspects of hoe use.

It will be the responsibility of the Test Engineer to decide which measurements should be made to best judge the work output and suitability of the implement.

11.2 Examples of hoe types

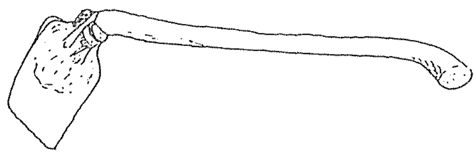


Figure 11.1 Digging hoe
(Source: Suzuki, 1982)

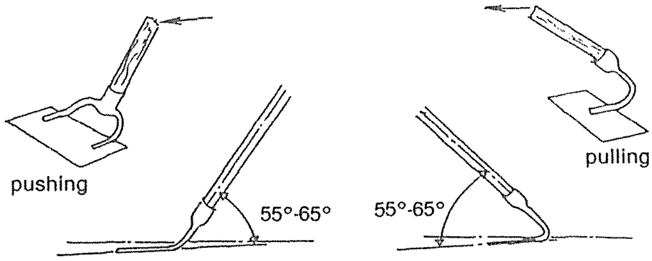


Figure 11.2 Pushing and pulling hoes, showing working angles
(Source: Inns, 1985)

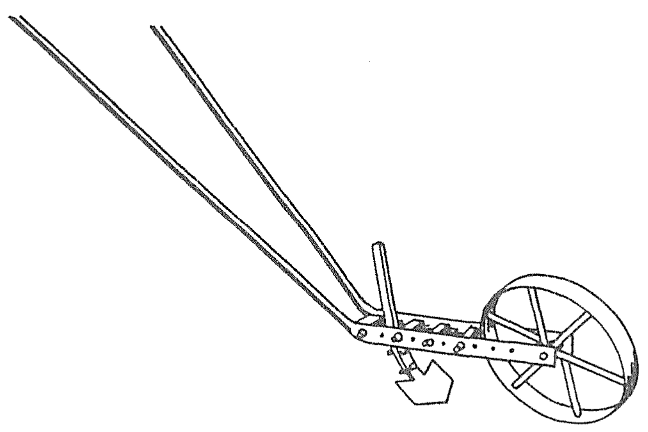


Figure 11.3 Wheeled hoe. (Maharashtra Agro Ind. Dev. Corporation, Bombay, India).
(Source: IT Publications, 1985)

11.3 Test Procedure

11.3.1 Implement for test

The manufacturer shall supply the hoe complete and fully assembled together with instructions for its use. Specifications giving dimensional data and materials used in the construction shall also be provided.

11.3.2 Laboratory work

Prior to any field tests, the manufacturer's specification should be checked. The hoe should be examined for quality of materials and construction, especially the method of blade attachment and the condition of the handle(s) (free from splinters and cracks, securely attached and offering a good grip).

If a hardness tester is available, the hardness of the cutting element of the blade(s) should be measured and checked with the specification.

11.3.3 Field work

11.3.3.1 Test conditions

11.3.3.1.1 Operators

Operators selected for the tests should be representative of potential users. For example, if it is women who usually perform hoeing tasks, they will be used as operators. The operators chosen must be prepared to allow their physical dimensions to be measured and where necessary to cooperate with the recording of heart rate, respiration and subjective responses during work periods.

11.3.3.1.2 Fields

The rates of work achieved with a hand hoe will vary with the type and condition of the soil, the crop layout and the weed population. The test report should give soil details as specified in Section 4.2 and weed population details as in Section 4.6.1.4. The land chosen for the tests should be typical for the region.

11.3.3.2 Preliminary trials

Trials should be carried out adjacent to the test plots to allow operators to familiarise themselves with the test implement and give some indication of the expected work rate. A plot size consistent with a total work time of approximately 4 hours should then be determined.

11.3.3.3 Performance tests

The main objectives of the performance tests are to obtain the sustainable work rate and to evaluate the demands made of the operator during the work period.

Tests should be made on plots having a range of typical crop, soil and weed conditions. All operators should work on all the conditions included.

When the test plots have been marked out, soil samples should be taken and weed counts made.

Each plot should be weeded in one session and the following measurements should be recorded:

a) Total operating time
b) Time taken for stoppages apart from essential rest periods
c) Depth of work
d) Total area of work

If the appropriate equipment and expertise is available, measurements may be made which indicate the energy expended by the operator during tests and the results used to rate the implement (see Section 5.3). If the instrumentation is not available, a subjective assessment of work load and the physical discomfort associated with the use of the hoe may be made by the operators (Sections 5.3 and 5.5).

At the conclusion of the test subjects may be informally interviewed to gain their overall opinions of the hoe. Soil and weed measurements should be repeated to establish clod size, inversion and mixing and final weed population.

11.3.3.4 Comparative tests

Where possible, the hoe should be tested against a standard "reference" hoe (perhaps the hoe traditionally used in the region), or in a group test with a number of other hoes. It is then possible rank the hoes against the criteria specified (eg: work rate and quality; energy requirement; subjective assessments; quality of manufacture).

11.3.3.5 On-farm durability tests

A series of trials may be undertaken on farmers' fields to enable the hoe to be evaluated in more varied field and soil conditions. They should be carried out over a complete weeding season to obtain more accurate measurements of blade wear and highlight any problems of operation or robustness. All the conditions specified in the performance tests will apply

11.4 Test report

11.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the implement should be provided.

11.4.2 Specification

11.4.2.1 Type of implement:

11.4.2.2 Make:
Model:
Serial No:
Manufacturers name and address:

11.4.2.3 Blade

Width of cut	mm
Material	
Hardness (Standard if applicable)	

11.4.2.4 Blade mounting

Material	
Throat width	mm
Method of fixing blade	
Angle related to handle	

11.4.2.5 Handle

Material	
Length	cm
Size	mm dia or mm x mm
Working height	cm
Method of attachment	

11.4.2.6 Support wheel (if applicable)

Material	
Diameter	mm
Width	mm

11.4.2.7 Total weight of hoe kg

11.4.3 Results of tests

11.4.3.1 Details of operators

Sex - male/female
Age
Weight kg
Height cm

11.4.3.2 Summary of test conditions and results

Test No.						
Test conditions Date Location Plot size (m x m) Topography Soil description Previous cultivation Crop Weed count (n/m^2) Soil moisture (DB %) Dry bulk density (g/cm^3) Penetrometer reading (kPa) Shear strength (kPa)						
Test results Working depth (cm) Working width (cm) Time taken to complete operation (h min) Field efficiency (%) Soil inversion (%) Evenness of cultivating						

If physiological variables (heart rate or respiration) and subjective measures (ratings of perceived exertion and postural discomfort) are recorded, results should be included separately.

11.4.3.3 Comments on aspects of performance

Ease of handling
Ease of adjustment
Maintenance of depth
Adhesion of soil to tines or blades
Blocking with weeds or trash
Visible deformation
Wear of soil working parts
General

11.4.4 Results of on-farm durability trials

All details given in 11.4.3.2 and 11.4.3.3 will apply to results of durability trials.

11.4.5 Trials on farmers fields

All details given in 11.4.3.2 and 11.4.3.3 will apply to results of trials on farmers fields.

11.4.6 Repairs and adjustments and recommendations for modifications

APPENDIX 11A

1 Field work sheets

1.1 Test conditions

Implement: Make: Test No:
Type: Date:

Location of site:
Topography:
Soil description:
Previous cultivation:
Crop:
Plot size: m length x m width

Weeds in m^2 area before test						
Weeds in m^2 area after test						
Cone penetrometer reading (kPa)						
Soil shear strength (kPa)						
Bulk density samples	1	2	3	4	5	6
Soil moisture samples	1	2	3	4	5	6

1.2 Time for stoppages:-

	FROM	TO	REASON, REMARKS
1			
2			
3			
4			
5			

Time at completion of test: h min

12 PROCEDURE FOR EVALUATION OF SEEDERS AND PLANTERS

CONTENTS

12.1 Scope 150

12.2 Definitions and General Procedures 150

12.2.1 Seeders and Planters 150
12.2.1.1 Hand Seeder 150
12.2.1.2 Seed Drill 150
12.2.1.3 Planter 151
12.2.1.4 Field Distributor 151
12.2.2 Test Measurements 151
12.2.2.1 Theoretical Working Width 151
12.2.2.2 Effective Working Width 152
12.2.2.3 Working Depth 152
12.2.2.4 Wheel skid 152
12.2.2.5 Seed Spacing Evenness 152
12.2.2.6 Seed Weight 152
12.2.2.7 Seed Size 152

12.3 Test Procedure 152

12.3.1 Machine for Test 152
12.3.2 Laboratory Work 153
12.3.2.1 Specification 153
12.3.2.2 Tests of Metering Mechanism 153
12.3.3 Field Work 154
12.3.3.1 Test Conditions 154
12.3.3.2 Test Procedure 154
12.3.3.3 Fertiliser Application 156

12.4 Test Report 156

12.4.1 Diagram/Photograph 156
12.4.2 Specification 156
12.4.2.1 Type of implement 156
12.4.2.2 Make: 157
12.4.2.3 Number of rows and row spacing 157
12.4.2.4 Nominal working width 157
12.4.2.5 Hill distance 157
12.4.2.6 Seeds and their condition for which the equipment is suitable 157
12.4.2.7 Number of fertiliser opening and fertilisers for which the equipment is suitable 157
12.4.2.8 Suitable field condition 157
12.4.2.9 Overall dimensions 157
12.4.2.10 Overall weight without seed and fertiliser 157
12.4.2.11 Travelling 157
12.4.2.12 Metering mechanism 157
12.4.2.13 Hill dropping mechanism 157
12.4.2.14 Hopper 157
12.4.2.15 Clutch for metering mechanism 158
12.4.2.16 Furrow or hole opener 158

12.4.2.17 Covering device 158
12.4.2.18 Location of fertiliser outlet related to seed outlet 158
12.4.2.19 Ground wheel 158
12.4.2.20 Handle of animal trailed equipment 158
12.4.2.21 Marking device (marker) 158
12.4.2.22 Hitch 158
12.4.2.23 Safety Arrangements 158
12.4.2.24 Recommended travelling speed 158
12.4.2.25 Working capacity (given by the manufacturer) 158
12.4.2.26 Any other detail 158
12.4.3 Summary of Test Conditions and Results 158
12.4.3.1 Laboratory Tests 158
12.4.3.1.1 Seed Metering 159
12.4.3.1.2 Fertiliser metering 161
12.4.3.2 Field Tests 162
12.4.4 Comments on ease of adjustments, operation 163
12.4.5 Repairs and adjustment during tests 163
12.4.6 Any other comments 163

APPENDIX 12A Laboratory Tests for Seeding Rate 164

APPENDIX 12B Laboratory Test for Seed Distribution 165

APPENDIX 12C Field Data Form (Seed Drills & Planters) for Animal Power 166

APPENDIX 12D Test Calculations Form - Seed Drills and Planters for Animal Traction 168

APPENDIX 12E Seeding Efficiencies Calculation Form - for Seed Drills and Planters 169

12 PROCEDURE FOR EVALUATION OF SEEDERS AND PLANTERS

12.1 Scope

This procedure is applicable for the evaluation of various types of manually-operated, animal-drawn and power driven drills and planters.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for use with various types of seeds in varied soil conditions.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the machine.

12.2 Definitions and General Procedures

12.2.1 Seeders and Planters

12.2.1.1 Hand Seeder

A hand seeder deposits seeds in holes dug by it with spacing set by the operator who carries it in his hand.

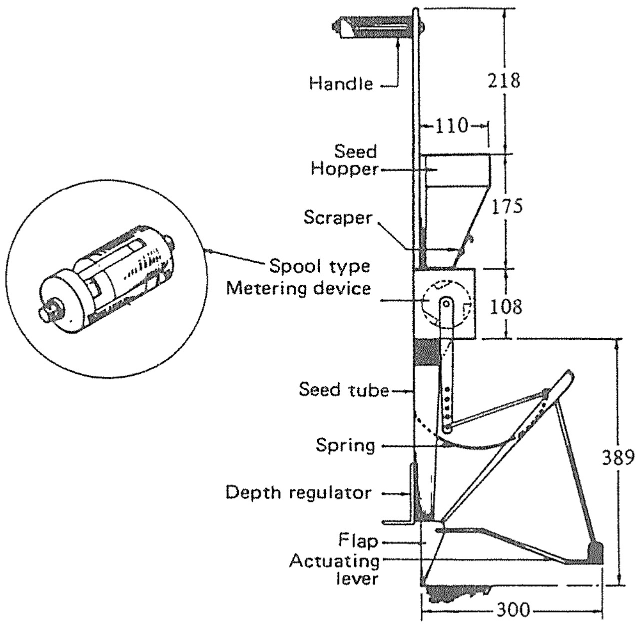


Figure 12.1 Hand Jabber
Source: RNAM, 1983

12.2.1.2 Seed Drill

A seed drill sows seeds at specified rates and at the proper depth and in rows. It is not designed to deposit seeds in hills.

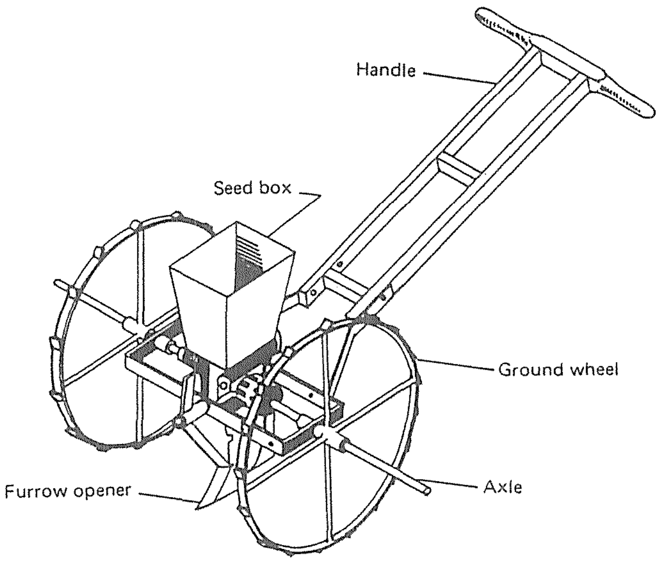


Figure 12.2 Single row push type seeder
Source: RNAM, 1983

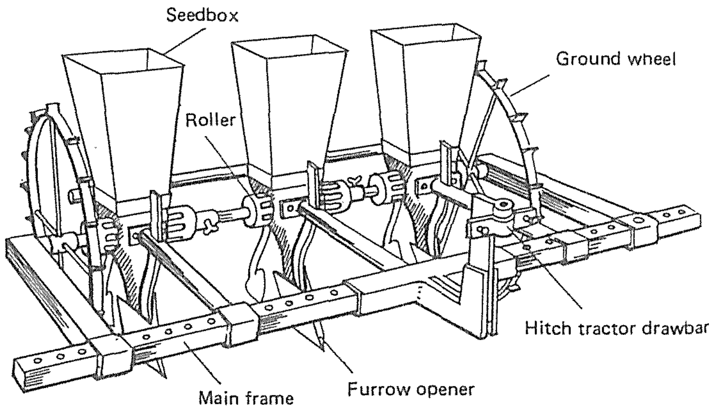


Figure 12.3 Three row small tractor mounted seeder
Source: RNAM, 1983

12.2.1.3 Planter

A planter can deposit seeds at a specified rate in hills or rows spaced to permit interrow cultivation. It will also function as a seed drill if required.

12.2.1.4 Field Distributor

A field distributor drops seeds in the same width as the seed box without any preparation of the field. A separate field operation is required to cover the seed. The distributor may also be used for fertiliser.

12.2.2 Test Measurements

12.2.2.1 Theoretical Working Width

This is the measured width of the implement.

12.2.2.2 Effective Working Width

This is obtained by dividing the width of the plot by the number of passes of the implement.

12.2.2.3 Working Depth

This can generally be taken as the depth of the drill. However, actual seeding depth will vary as to whether the seeds fall at the bottom of the furrow or not, how much soil cover is put on and whether this is compacted.

More accurate seeding depths may be obtained by digging up plants after germination.

12.2.2.4 Wheel skid

If the machine is land wheel driven, wheel skid will occur in normal work. The distance that the machine moves forward for a given number of revolutions of the drive wheel will increase when the wheels skid. The machine will be slowly towed or pushed forward out of work and the distance travelled for 5 wheel revolutions recorded (B). During field work, the distance for 5 wheel revolutions will again be measured (A).

The percentage wheel skid will be calculated as follows :-

$$\text{Wheel skid (\%)} = \frac{A - B}{B} \times 100$$

12.2.2.5 Seed Spacing Evenness

Measurements taken in the laboratory or in the field of distances between seeds or hills will be used to evaluate the evenness of spacing.

Evenness of spacing =

$$\frac{\text{Seed spacing (average) - Standard deviation of seed spacing}}{\text{Seed spacing (Average)}}$$

12.2.2.6 Seed Weight

The weight of different types of seed are classified by their 1000 grain weight. This is determined by weighing at least 8 samples of 100 grains. From this figure the average weight for 1000 grains is calculated and included in the report.

12.2.2.7 Seed Size

The length, thickness or diameter of the seed shall be measured. The averages of at least 50 seeds are calculated and included in the report.

12.3 Test Procedure

12.3.1 Machine for Test

Prior to any test work, the manufacturer shall supply the machine complete and in working order together with specifications concerning materials, construction, range of adjustments and expected performance with various types of seeds. A complete specification will be given in the test report.

12.3.2 Laboratory Work

12.3.2.1 Specification

The specifications and setting details given by the manufacturer shall be checked and confirmed.

Some of the items to be examined are :-

a) Metering mechanism and method of changing rate of seed delivery
b) Types of soil openers and covering devices
c) Type of hill dropping mechanism
d) Type of drive mechanism
e) Depth control device

Other items are listed in the specification form.

12.3.2.2 Tests of Metering Mechanism

The object of these tests is to examine the performance of the metering mechanism, the result of which can provide the basic data for field performance.

12.3.2.2.1 Seeds for tests

The tests should be carried out using three different sizes of seeds for which the machine is suitable as specified by the manufacturer. Seeds shall be specified by type, 1000 grain weight, mean size and moisture content.

Seeds used for tests should not contain any damaged seed grains in order that any damage caused by the machine may be established.

12.3.2.2.2 Seeding range

Machines capable of planting seeds at different rates should be assessed at seed rate settings of the maximum, medium and the lowest practical minimum.

All tests should be repeated with hoppers full, half full and quarter full.

a) **Hand seeders** - For the hand seeder, the number of seeds delivered by one action of the operator with the appropriate adjustment of the metering mechanism should be confirmed for each kind of seed and hopper filling level.

b) **Powered seeders** - Powered seeders are jacked clear of the ground and the metering mechanisms are driven by turning the ground wheels or by power take-off from a tractor at speeds recommended for field operation. The amount of seed metered from each outlet for a given time (say 3 minutes) is weighed and together with the number of revolutions of the drive wheels or power shaft and the width of the machine, the weight of seed delivered per hectare is calculated.

   An alternative method is to rotate the wheels for the number of revolutions required to cover a given area. The number of revolutions of each metering wheel if the machine travels say $^1/_{100}$ hectare is:

$$N = \frac{10\,000}{100 \times x \times n \times \pi d}$$

where x = row spacing in metres
n = numbers of rows of the seeder or planter
d = rolling diameter of the metering wheel in metres

12.3.2.2.3 Seed damage

After each of the test runs, 3 random samples are weighed. Damaged seeds are separated and their weight expressed as a percentage of the total sample.

12.3.2.2.4 Seed distribution pattern

In order to simulate field conditions the seeder is run over a level track of at least 10 metres at the speed recommended for field operation.

The area beneath the seeder is covered with a surface to prevent the seeds from bouncing. Satisfactory surfaces are clean sand, coconut matting, thick felt or paper coated with grease or heavy oil.

Runs are made for each variety of seed to be used at 3 different seed rate settings. Following each run, the spacings and distribution of separate seeds is examined and recorded. The average seed spacing, seed spacing standard deviation and evenness are calculated.

12.3.3 Field Work

The effective performance of seeders and planters can only be determined by trials in the field. Reliable data can be obtained on how the application rate and spacing of seeds may be affected by movement and vibration and on ease of operation and maintenance and adjustment requirements to varied seed type and soil conditions.

12.3.3.1 Test Conditions

12.3.3.1.1 Tractors and draft animals

Tractors used for the test should be compatible with the implement under test and be driven by experienced operators. Draft animals and their handlers should be highly trained and if possible, familiar with the type of implement under test. The animals should be in good condition and records of their health and feeding regime should be available. The number of animals required will depend on the implement draft and consideration that an animal will pull approximately 10% of its body weight.

12.3.3.1.2 Fields

Seed drills and planters are soil engaging implements and performance will vary according to the type and condition of the field soils. The following conditions will require to be clearly stated in the test report.

a) Area and shape of test field
b) Type and character of soil
c) Topography
d) Type of cultivation (if any)
e) Soil conditions (Section 4.2)

The land chosen for the tests should reflect the objectives of the test and may include a range of typical farm conditions. Plots laid out within fields should be rectangular with the ratio of sides not less than 2:1. Plots of 40 m length and by 20 m wide are recommended.

12.3.3.2 Test Procedure

Tests should be made with at least 3 types of seed on 3 soil conditions. Using the information obtained during the laboratory tests, the metering mechanism should be adjusted to give the rate required for each type of seed used. Hoppers should be filled with weighed amounts of seed prior to the test run.

12.3.3.2.1 Output

In order to assess the total output, the plot should be completed without stopping unless this is necessary due to adjustments, breakdowns or animal rest periods.

During the test, care must be taken to ensure that the metering mechanism is working correctly and that the seed outlets do not become blocked. At the end of the test run, the hoppers are emptied and the remaining seed weighed. The following measurements should also be made :-

a) Number of passes
b) Number of rows per pass
c) Row spacing
d) Depth of furrow openers
e) Forward speed (Section 2.2.5)
f) Draft and draft angle (Section 4.6.1.2)
g) Wheel skid where applicable
h) Time spent on turning
i) Time spent for any other reason
j) Total operating time

Observations will also be made on the following :-

a) Ease of handling
b) Ease of adjustment
c) Maintenance of depth
d) Blockage of working parts

12.3.3.2.2 Seed distribution pattern

Seed placement measurements will need to be done five times per plot, so that it is advisable to operate firstly for a definite small number of rows, do the necessary timing and draft measurements and then stop at the end of a row, noting the time taken for the completion of this sub-plot. The next one (or two) rows will then be used for measurement relating to seed placement. When this has been completed, another small sub-plot may be done, and the process continued till the end as that there are five replications of output measurements and five of seed placement.

Where the implement produces a small furrow or drill in which the seed is deposited, to take this measurement it is necessary that the furrow should be kept open and not covered, so that the seeds are exposed. It may be necessary to make special deflectors which can be quickly fitted on to the furrow opener to ensure this. Coverers should be removed.

A sufficient length for measuring purposes is 2m (5 replications). A stretched tape or specially marked rod should be placed alongside the drill, coincident with the start of the two metre length, and the distance from this zero line of every seed planted should be recorded. The average seed spacing and the standard deviation of this spacing can then be calculated.

This method is also suitable for hill planting in drills. With an implement such as a rotary injection planter, there is usually an indication of where the prongs entered the soil. The average hill spacing and standard deviation can be found by measuring the distance of 10 successive plantings in 5 replications.

When seeds are planted in hills in drills, the number of seeds per hill can be obtained from measurements as above. With the rotary injection planter, the number of seeds per hill can only be counted by digging up each hill planted. A total of 20 hills per plot should be examined, for both seeding depth and seeds per hill.

12.3.3.2.3 Germination method

Plant emergence may be used as an indicator of the performance of a seeder or planter. However, it must be understood that there are many other factors which can cause failure of crop emergence, as well as poor machine performance. Prior to the field tests, the germination rate of the seed to be used must be established by laboratory tests on at least 5 samples.

The germination rate is the percentage of seeds from the sample which have germinated. This figure will enable the seeding rate for the test to be established as follows :-

$$\text{Test setting (kg/ha)} = A + A\,\frac{(100 - G)}{100}$$

Where A = Recommended rate in Kg/ha
G = Germination rate in %

The metering mechanism should be adjusted as described for laboratory tests. The field work should be carried out and measurements taken as in section 12.3.3.2. and 12.3.3.2.1. About two-three weeks after seeding or planting, a plant count of the field is taken. The number of plants is counted in 10 randomly placed 2m long rows. From the average figure, the total number of plants in the field is estimated. The percentage of original population can be expressed and included in the test report.

12.3.3.3 Fertiliser Application

Where drills are fitted with units to allow fertiliser to be applied, tests similar to those for seed application are carried out in the laboratory and in the field.

12.3.3.3.1 Laboratory tests

The machine will be run over a 5m long level track at the speed recommended for field work. The area beneath the machine is covered with canvas and the quantity of fertiliser deposited every 500mm length is measured, appropriate sized containers may also be used.

This will allow total application rates to be calculated and histograms of distribution patterns to be drawn. Tests are made with granular fertiliser at 3 application rate settings and 3 hopper levels. The type of fertiliser used and the results are summarised in the report.

12.3.3.3.2 Field tests

Output tests are made at the same time as those for seeding mechanisms using the same procedures. If an assessment of depth of application and placement is carried out, brightly coloured plastic granules should be used and also a high rate of application. This will allow easier identification when digging. Observations on aspects of operation, maintenance, adjustments and blockages will also be made.

12.4 Test Report

12.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the implement should be provided.

12.4.2 Specification

12.4.2.1 Type of implement:
Source of power:

12.4.2.2	Make: Model: Serial No.: Manufacturers name and address:	
12.4.2.3	Number of rows and row spacing:	cm
12.4.2.4	Nominal working width:	m
12.4.2.5	Hill distance, if applicable:	cm
12.4.2.6	Seeds and their condition for which the equipment is suitable[1]:	
12.4.2.7	Number of fertiliser openings and fertilisers for which the equipment is suitable	
12.4.2.8	Suitable field condition[2]:	
12.4.2.9	Overall dimensions	
	Length: Width: Height:	cm cm cm
12.4.2.10	Overall weight without seed and fertiliser:	kg
12.4.2.11	Travelling	
	Source of power (for carrying, trailing or mounting equipment): Recommended output of power tiller or tractor if applicable:	 kW
12.4.2.12	Metering mechanism	
	Type and method of changing delivery rate: Seed: Fertiliser:	
	Source of power for driving metering mechanism (Ground wheel or PTO of power tiller or tractor) Recommended PTO speed (if applicable):	 rev/min
	Transmission mechanism and speed ratio of metering shaft to input shaft (ground wheel or PTO shaft)	
12.4.2.13	Hill dropping mechanism	
12.4.2.14	Hopper	

Number:	(Seed)	(Fertiliser)	
Capacity:	"	"	litres
Material:	"	"	

[1]Pregerminated or not

[2]Not tilled, tilled, submerged paddy field

12.4.2.15 Clutch for metering mechanism

Type:
Location:

12.4.2.16 Furrow or hole opener

Type:
Material:

12.4.2.17 Covering device

Type:
Material:

12.4.2.18 Location of fertiliser outlet related to seed outlet

12.4.2.19 Ground wheel

Size: cm
Material:

12.4.2.20 Handle of animal trailed equipment

Construction:
Height of handle from ground level: cm
Detail of adjustment:

12.4.2.21 Marking device (marker)

Detail of marking:

12.4.2.22 Hitch

Shape and construction (In case of tractor mounted unit, category of three point linkage)

12.4.2.23 Safety Arrangements

Cover:
Power transmission:
Other moving parts:

Other details:

12.4.2.24 Recommended travelling speed: km/h

12.4.2.25 Working capacity (given by the manufacturer): ha/h

12.4.2.26 Any other detail

12.4.3 Summary of Test Conditions and Results

12.4.3.1 Laboratory Tests

Tests shall be made with 3 different types of seeds and fertilisers and data sheets below prepared for each.

12.4.3.1.1 Seed Metering

Date of tests

(a) Test condition

(1) Condition of seed

i)	Name of seed	
ii)	Variety	
iii)	Shape	
iv)	Size of seed	
	Length	mm
	Width	mm
	Thickness	mm
v)	Weight of 1000 grains	g
vi)	Moisture Content	%
vii)	Bulk density	g/cm^3
viii)	Preparation of seed	
ix)	Cleanliness, uniformity of size etc	

(2) Condition of machine

i) Metering shaft speed adjustment (if any), mechanism and speed
ii) Delivery opening adjustment

b) Delivery rate

			Delivery Rate Setting								
			Maximum			Intermediate			Minimum		
			Quantity of seed in hopper			Quantity of seed in hopper			Quantity of seed in hopper		
			1/1	½	¼	1/1	½	¼	1/1	½	¼
1.	Hand operated metering (dibbler, jabber)										
i)	Number of seeds delivered by one hand action										
ii)	Estimated delivery rate at row spacing hill distance	kg/ha cm cm									
iii)	Rate of damaged seed by metering mechanism	%									
2.	Ground wheel-driven metering										
i)	Effective rolling diameter of ground wheel	m									
ii)	Revolution of ground wheel for measuring delivery										
iii)	Delivery for ii) above	kg									
iv)	Delivery rate	kg/ha									
v)	Rate of damaged seed by metering mechanism	%									
vi)	Mean seed spacing	mm									
vii)	Seed spacing evenness										
3.	PTO driven metering										
i)	PTO speed	rev/min									
ii)	Travelling speed relative to i) above	km/h									
iii)	Time for measuring delivery	s									
iv)	Delivery for iii) above	kg									
v)	Delivery rate	kg/ha									
vi)	Rate of damaged seed by metering mechanism	%									
vii)	Mean seed spacing	mm									
viii)	Seed spacing evenness										

12.4.3.1.2 Fertiliser metering

(a) Test Conditions

(1) Condition of Fertiliser

- i) Kind
- ii) Name
- iii) Shape
- iv) Size distribution of fertiliser
- v) Moisture content %
- vi) Bulk density g/cm^3

(2) Condition of machine

- i) Metering shaft speed adjustment (if any) mechanism and speed
- ii) Delivery opening adjustment

b) Delivery rate

	Delivery Rate Setting								
	Maximum			Intermediate			Minimum		
	Quantity of fertiliser in hopper			Quantity of fertiliser in hopper			Quantity of fertiliser in hopper		
	1/1	½	¼	1/1	½	¼	1/1	½	¼
1. Ground wheel-driven metering									
i) Effective rolling dia. of ground wheel m									
ii) Revolution of ground wheel for measuring delivery									
iii) Delivery for ii) above kg									
iv) Delivery rate kg/ha									
2. PTO-driven metering									
i) PTO speed rev/min									
ii) Tractor travelling speed in relation to i) abovekm/h									
iii) Time for measuring delivery s									
iv) Delivery rate kg/ha									
v) Observations									
3. Pattern of fertilizer deposition (line, band, spaced, etc.)									

12.4.3.2 Field Tests

Tests should be made on 3 soil conditions with 3 different types of seed and fertiliser and data record sheets prepared for each.

		Test Number					
		Performance test			Practical field test		
		1	2	3	1	2	3
Date of Test							
1. Test Condition							
(a) Condition of seed							
1) Name of seed							
2) Variety							
3) Shape of seed							
4) Size of seed							
Length	mm						
Width	mm						
Thickness	mm						
5) Weight of 1000 grains	g						
6) Moisture content (wet basis)	%						
7) Bulk density	g/cm^3						
8) Preparation of seed							
9) Laboratory germination rate	%						
(b) Condition of fertiliser							
1) Name of fertiliser							
2) Kind of fertiliser							
3) Shape of fertiliser							
4) Size distribution							
5) Moisture content (wet basis)	%						
6) Bulk density	kg/l						
(c) Condition of field							
1) Location							
2) Field and soil brief description							
3) Previous cultivation							
4) Plot size	m^2						
5) Penetrometer reading	kPa						
6) Surface evenness							
7) Mean clod size							
8) Soil moisture	%						

		Test Number					
		Performance test			Practical field test		
		1	2	3	1	2	3
2. Test Results							
1) Number of rows per pass							
2) Row spacing							
3) Initial setting of seed metering mechanism	kg/ha						
4) Speed	m/sec						
5) Working width	cm						
6) Working depth	cm						
7) Field capacity	ha/hr						
8) Field efficiency	%						
9) Horizontal draft	N						
10) Power input	kW						
11) Wheelslip of tractor	%						
12) Wheelslip of seeder	%						
13) Overall seeding rate	kg/ha						
14) Seed spacing	cm						
15) Seed spacing evenness							
16) Seed depth	cm						
17) Seed depth evenness							
18) Hill spacing	cm						
19) Hill spacing evenness							
20) Seeds per hill							
21) Seeds per hill evenness							
22) Rate of missing hills	%						
23) In case of drill (sampling)							
i) Established plant per ha at 2 to 3 leaf stage after emergence							
ii) Ratio of established plants to seed sown	%						

12.4.4 Comments on ease of adjustments, operation

12.4.5 Repairs and adjustment during tests

12.4.6 Any other comments

APPENDIX 12A

(Source: AIRIC, 1987)

Laboratory Tests for Seeding Rate

Implement:		Test No.:	
Power:	(kW)	Date:	
Seed Type:		Turning time:	(sec)
1000 gr. w.:	(g)	Revolutions of ground wheel:	(rev)

	Weight of Seed Metered								
	Outlet 1			Outlet 2			Outlet 3		
Hopper Level	Full	½ Full	¼ Full	Full	½ Full	¼ Full	Full	½ Full	¼ Full
Maximum Setting									
Medium Setting									

Seed damage

Samples from above	1	2	3
Sample weight (g)			
Damaged seeds (g)			

Seed rate[3]*	Maximum	kg/ha
	Minimum	kg/ha

[3] * Denotes average value

APPENDIX 12B

Laboratory Test for Seed Distribution

Seed type: Seed Rate* kg/ha 1000 grain weight: g

Row spacing: cm No. of seeds/m[4]*:

Seeder speed: Time for travelling 4m: sec

Measured seed distribution per m. row length[5]**

Distance between 2 seeds (mm)	No. of distances (in 1m row)	No. of distances (in 1m row)	(No. of distances (in 1m row)
2			
10			
15			
20			
55			
30			
35			
40			
45			
50			
55			
60			
65			
70			
75			
80			
85			
90			
95			
100			
105			
-			
-			
-			
-			
-			
-			

[4] * use recommended figures

[5] ** in case of hill planting, indicate average number of seeds per hill in brackets behind the number of distances in a certain distance class.

APPENDIX 12C

Field Data Form (Seed Drills & Planters) for Animal Power

TEST NO:

DATE:

IMPLEMENT:

LABORATORY: Germination count: Viability %

Advised seed rate: kg/ha

Actual seed rate: kg/ha

FIELD: Location & Site:

Topography description and soil:

Condition of field and previous cultivation:

Plot size: Length m Width m

Cone Penetrometer resistance (kPa)						
Samples for clod analysis (before test)	1	2	3	4	5	6
Soil Moisture samples	1	2	3	4	5	6

Field levels before test:

Setting of metering mechanism:	
No. Of rows per pass:	
Row spacing:	cm
Depth of furrow openers below ground level:	cm

Weight of seed put into hoppers before and during test (kg):	..... +	.....=	.....	Condition of animals

Time of start of test:				h	m	s
	1	2	3	4	5	6
Time for m work length (sec)						
Time for 2 complete rows (mm)						
Dynamometer reading (kgf or N)						
Angle of dynamometer (°)						

Time for stoppages:

	From	To	Reason, Remarks.
1			
2			
3			
4			

Depth of seed

Time of test completion

h	m	s

Total no. of passes:

Weight of seed left in hopper(s)

kg

Planting in Drills: Seed spacings in 2m rowlength - 5 replications(cm)

Hill planting: Number of seeds per hill

General assessment:

Work Quality, evenness, etc

Operator's assessment:

Ease of control, load on animals, etc

Other comments:

APPENDIX 12D

Test Calculations Form - Seed Drills and Planters for Animal Traction

Test No: ....

Date: ....

* Denotes average value	Unit	Symbol	Value
Plot size completed	m^2	M	
Cone index*	kPa	C	
Surface evenness ratio*	-	E_s	
Mean clod diameter*	cm	MCD	
Soil moisture*	%		
Working speed*	m/s	S	
Working width*	cm	W	
Total time to complete area M	h	T	
Actual field capacity = M/(10,000T)	ha/h	A	
Theoretical field capacity = 0.0036WS	ha/h		
Field efficiency = 2,778 M/TWS	%		
Average turning and stoppage time per row	s		
Measured draught*	kgf(N)	B	
Dynamometer link angle*	°	Θ	
Horizontal draught - BcosΘ	kgf(N)	F	
Power input = $\frac{F(kgf)S}{0.10197}$ or F(N)S	W	K	
Seeding depth*	cm	d^1	

APPENDIX 12E

Seeding Efficiencies Calculation Form - for Seed Drills and Planters

Laboratory and Field	Unit	Symbol	Value	
			Lab	Field
Seed spacing*	cm	SS		
Seed spacing standard deviation	cm	SSD		
Seed spacing evenness = (SS-SSD)/SS	-	E_u		
Seeding depth*	cm	d^1		
Seeding depth standard deviation	cm	d^1_d		
Seeding depth evenness = $(d^1-d^1_d)/d^1$	-	E_d		
Hill spacing*	cm	HS		
Hill spacing standard deviation	cm	HSD		
Hill spacing evenness = (HS-HSD)/HS	-	E_h		
Number of seeds per hill*	-	h		
Number of seeds standard deviation	-	hSD		
Seeds per hill evenness	-	E_n		
From the laboratory:				
1000 grain weight	g	1000gw		
seed dimensions	mm			
germination rate				
weight of seed sample having passed through the metering mechanism	g	w^1		
weight of broken seeds in this sample	g	b^1		
seed breakage efficiency = $(w^1-b^1)/w^1$	-	E_b		

* Denotes average value

13 PROCEDURE FOR EVALUATION OF FERTILISER DISTRIBUTORS

CONTENTS

13.1 Scope 171

13.2 Definitions and General Procedures 171

13.2.1 Types of Distributors 171
13.2.1.1 Full Width Machines 171
13.2.1.2 Broadcasters 171
13.2.2 Moisture Content 172
13.2.3 Wheelskid 172

13.3 Test Procedure 173

13.3.1 Machine for Test 173
13.3.2 Laboratory Work 173
13.3.2.1 Specification 173
13.3.2.2 Tests of Metering Mechanisms 173
13.3.3 Field Work 175
13.3.3.1 Application Rate 175
13.3.3.2 Wheelskid 175
13.3.3.3 Wheel Sinkage 175
13.3.3.4 Draft 175
13.3.3.5 Fertiliser Placement 175
13.3.3.6 Comments 175

13.4 Test Report 175

13.4.1 Diagram/Photograph 175
13.4.2 Specification 175
13.4.2.1 Type of distributor 175
13.4.2.2 Overall dimensions 176
13.4.2.3 Overall weight without fertiliser 176
13.4.2.4 Full width machines 176
13.4.2.5 Broadcasters 176
13.4.2.6 Travelling 176
13.4.2.7 Metering mechanism 176
13.4.2.8 Hopper 176
13.4.2.9 Control for metering mechanism 176
13.4.2.10 Ground wheel 176
13.4.2.11 Handle of animal trailed equipment 176
13.4.2.12 Marker device 177
13.4.2.13 Hitch 177
13.4.2.14 Safety arrangements 177
13.4.2.15 Manufacturer's recommended working capacity 177
13.4.2.16 Any other details 177
13.4.3 Summary of Test Conditions and Results 177
13.4.3.1 Laboratory tests 177
13.4.3.2 Field tests 178
13.4.3.3 Repairs and adjustments during tests 178
13.4.3.4 Comments on performance 178

APPENDIX 13A Test Record Sheet 179

13 PROCEDURE FOR EVALUATION OF FERTILISER DISTRIBUTORS

13.1 Scope

This procedure is applicable for the evaluation of various types of animal-drawn and power-driven fertiliser distributors.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for use with various types of fertiliser and field conditions.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the machine.

13.2 Definitions and General Procedures

13.2.1 Types of Distributors

13.2.1.1 Full Width Machines

Fertiliser is carried in a hopper covering the full width of the machine. Land-wheel driven feed mechanisms of the studded roller, agitator or plate and flicker type meter the fertiliser to outlets beneath the hopper. The unit may be an integral part of a seed drill where fertiliser is directed into spouts attached to coulters where it is deposited with or adjacent to the seeds.

13.2.1.2 Broadcasters

These machines have a hopper for fertiliser often of truncated cone shape above a spinning disc or oscillating spout type of spreader. The unit may be land-wheel driven or tractor mounted and power take-off driven.

1) Hopper
2) Hopperbase
3) Dose rate lever
4) Fertilizer path
5) Distribution mechanism shaft
6) Agitators
7) Feeders
8) Mesh

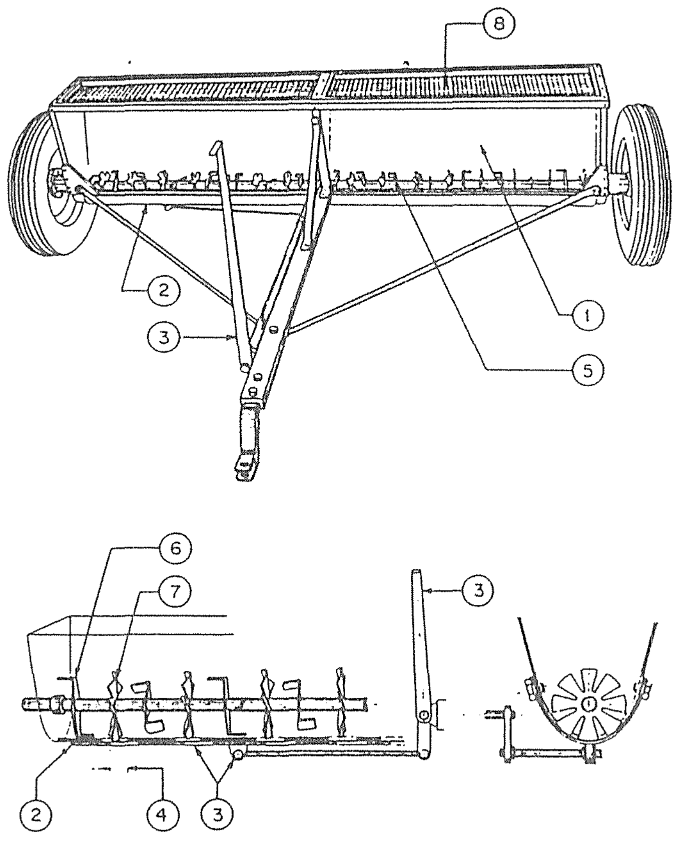


Figure 13.1 Full width fertilizer distributor
Source: Berlijn, 1978

1) Hopper
2) Agitator
3) Dosage mechanism
4) Adjustment lever
5) Distribution mechanism
6) Drive shaft
7) Distribution pattern adjustment

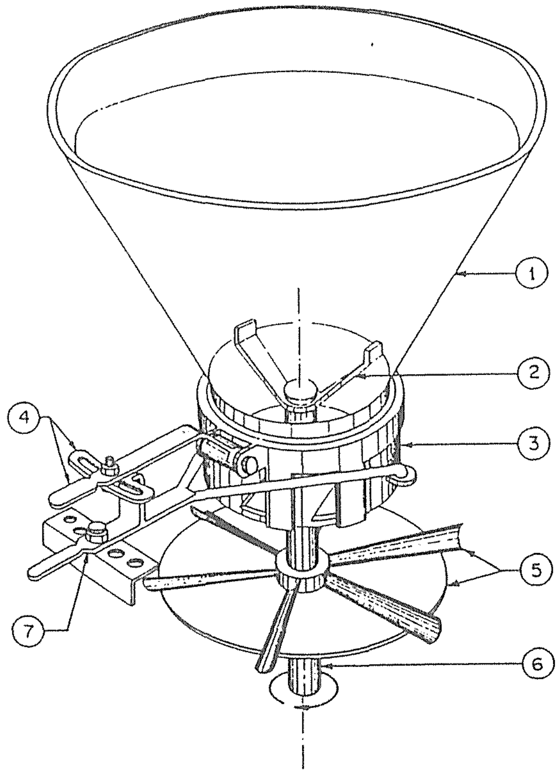


Figure 13.2 Centrifugal fertiliser distributor
Source: Berlijn, 1978

13.2.2 Moisture Content

At least 5 samples are to be taken at random from batches of each type of fertiliser used for the tests. After weighing, quantities of 25 to 35 grams are oven dried at 100°C for 24 hours. The samples are cooled and then re-weighed.

$$\text{Moisture content, \% (wet basis)} = \frac{\text{(Weight of wet sample - weight of dry sample)}}{\text{Weight of wet sample}} \times 100$$

13.2.3 Wheelskid

If the machine is land wheel driven, wheelskid will occur in normal work. The distance that the machine moves forward for a given number of revolutions of the drive wheel will increase when the wheels skid.

The machine will be slowly towed or pushed forward out of work and the distance travelled for 5 wheel revolutions recorded (B).

During field work, the distance for 5 wheel revolutions will again be measured (A). The percentage wheelslip is calculated as follows:

$$\text{Wheelskid (\%)} = \frac{A - B}{B} \times 100$$

13.3 Test Procedure

13.3.1 Machine for Test

Prior to any test work, the manufacturer shall supply the machine complete and in working order together with specifications concerning materials, construction, range of adjustments and expected performance with various types of fertiliser. A complete specification will be given in the test report.

13.3.2 Laboratory Work

13.3.2.1 Specification

The specifications and setting details given by the manufacturer shall be checked and confirmed. Some of the items to be examined are :-

a) Metering mechanism and method of changing feed rate
b) Type of drive mechanism
c) Method of distribution
d) Height and depth controls
e) Hopper sizes

Other items are listed in the specification form.

13.3.2.2 Tests of Metering Mechanisms

The object of these tests is to examine the performance of the metering mechanism, the result of which can provide the basic data for field performance and confirm the manufacturer's claims.

13.3.2.2.1 Fertiliser for tests

The fertiliser used will be that readily available. Each type used will be specified by its particle size distribution, bulk density and moisture content, and comply with the machine manufacturers recommendations.

13.3.2.2.2 Full width distributors

13.3.2.2.2.1 Application rate

Application rates in kg/ha will be calculated from rates measured in the laboratory over 1/100 ha. The distance for each test run is calculated as follows:-

$$\text{Length of test run in metres} = \frac{100}{\text{Nominal width of machine in metres}}$$

The machine will be operated over a level floor area for the distance required at the speed recommended by the manufacturer and with the hopper half full. At least two runs will be made at maximum, minimum and average application rate settings.

If the manufacturer recommends a range of forward speeds, further tests will be made to establish effects of forward speed on the application rate. Runs may also be made to establish effects of depth of fertiliser in the hopper.

When the distributor is part of a combine seed drill and has delivery spouts, the coulters are removed and during the test runs, fertiliser is collected in bags tied over each spout. If spouts are not fitted, the floor area is covered in canvas or plastic sheeting to allow all the fertiliser to be collected during each test run.

In each case, the total weight of the fertiliser collected during the test run is used to calculate the application rate in kg/ha.

13.3.2.2.2.2 Transverse distribution

During tests for the application rate, at the average feed rate setting and with the hopper half full, the delivery from each spout will be recorded. For other machines, the spread material will be divided in longitudinal strips equal to the number of outlets and the amounts weighed.

The results of weighings will be presented as a histogram (Section 4.6.3) and the percentage variation from the average of the highest and lowest outputs will be recorded.

13.3.2.2.2.3 Longitudinal distribution

At the nominal speed used for the application rate tests and with the average feed rate setting, test runs will be made over a distance of 5 m. Using four individual outlets, one will be tested at a time and the fertiliser distributed over each 50cm length will be aggregated.

The results of weighings will be presented in histograms and the percentage variation of the highest and lowest values from the average will be recorded.

13.3.2.2.2.4 Effect of vibration

This test will be a repetition of the longitudinal distribution test with the addition of standard bumps 4cm in height placed at 1m intervals beneath alternate wheels. Runs of 15 m will be made and the results will be compared with those of the longitudinal distribution test.

13.3.2.2.3 Broadcasters

13.3.2.2.3.1 Application rate

The application rate of a broadcaster machine at a given feed setting and forward speed can only be determined when the optimum bout width has been established. Bout width is dependent on the degree of overlap required for the machine to produce an even distribution and is determined by tests for transverse distribution. If the broadcaster is pto driven, the application rate is established by running the machine for a calculated time equivalent to covering one hectare. The time is calculated as follows:-

$$\text{Time (min)} = \frac{600}{\text{Bout width (m) x Forward speed (km/h)}}$$

For land-wheel driven machines, the distance travelled is calculated as for the full width machines. The hopper is filled and the broadcaster is run for the calculated time or distance. The weight of fertiliser to refill the hopper is measured and the rate in kg/ha is calculated. At least two runs will be made at maximum, minimum and average feed settings. If the manufacturer recommends a range of pto drive or forward speeds, further tests will be made to establish effects of speed on the application rate.

13.3.2.2.3.2 Transverse distribution

The machine will be operated over a level floor area at normal speed and feed rate settings. During the run, fertiliser is collected in a series of trays (150mm x 1000mm x 150mm deep) placed at right angles to the line of travel. Following each run, the contents of each tray is weighed and histograms of the distribution pattern are drawn (Section 4.6.3) If trays are not available, an alternative method is to spread the fertiliser on to a clean floor area and to sweep up equal strips parallel to the direction of travel and to weigh the amounts collected.

13.3.2.2.3.3 Optimum bout width

Using the results of the transverse distribution tests, histograms of the total spreading rate at various points of overlap across the bout can be drawn (Section 4.6.3). From these results, the optimum bout width can be established.

13.3.3 Field Work

Tests under field conditions will be carried out covering at least 1/10 ha on three soil conditions using various fertilisers to enable observations to be made on practical aspects of use of the machine.

13.3.3.1 Application Rate

The hopper will be filled level full (or up to a convenient mark) and the machine run for a short time to settle the fertiliser. It will then be re-filled and with the delivery set to the average value, and at nominal speed the machine will be used to cover the required area. The weight of fertiliser required to refill the hopper will be measured and the application rate in kg/ha recorded.

13.3.3.2 Wheelskid

During the test runs with land-wheel driven machines, wheelskid will be measured as detailed in item 13.2.3 of this procedure.

13.3.3.3 Wheel Sinkage

The depth of penetration of the drive wheels of the machine shall be measured with the hopper full and empty.

13.3.3.4 Draft

The draft of the fully loaded machine shall be measured during normal work.

13.3.3.5 Fertiliser Placement

If the machine is part of a combine drill and is designed to place the fertiliser with or near the seed, the following test will be made. Seeds will be sown but brightly coloured plastic granules will be used in place of the fertiliser.

The drill will be run at a nominal speed at the recommended depth and the pattern of placement observed along the drilled lines. At least 100 measurements will be made of the depth of seeds and granules and the horizontal distance between the seeds and granules.

13.3.3.6 Comments

Comments will be made on the effects of vibration and wheelskid on the feed rate together with those of ease of loading, setting and cleaning.

13.4 Test Report

13.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the machine should be provided.

13.4.2 Specification

13.4.2.1 Type of distributor:
Source of power:

Make:
Model:
Serial No.:
Manufacturer's name and address:

13.4.2.2	Overall dimensions	
	Length:	m
	Width:	m
	Height:	m
13.4.2.3	Overall weight without fertiliser:	kg
13.4.2.4	Full width machines	
	Nominal working width:	cm
	Number of openings:	
	Spacing of openings:	cm
	Location of fertiliser outlet in relation to seed outlet	cm
13.4.2.5	Broadcasters	
	Number of discs or spouts:	
	Size of discs or spouts:	cm
13.4.2.6	Travelling	
	Source of power (for carrying, trailing or mounting machine):	
	Recommended travelling speed:	m/s
	Recommended output of power source:	kW
13.4.2.7	Metering mechanism	
	Type and method of changing delivery rate:	
	Source of power for driving metering mechanism:	
	Recommended pto speed:	rev/min
	Transmission mechanism and speed ratio for metering shaft to input shaft:	
13.4.2.8	Hopper	
	Number:	
	Capacity:	kg(m^3)
	Material:	
13.4.2.9	Control for metering mechanism	
	Type:	
	Location:	
13.4.2.10	Ground wheel	
	Size:	
	Material:	
13.4.2.11	Handle of animal trailed equipment	
	Construction:	
	Height from ground level:	cm
	Detail of adjustment:	

13.4.2.12 Marker device

Type:
Detail of marking:

13.4.2.13 Hitch

Type and construction:
Category of three-point linkage:

13.4.2.14 Safety arrangements

Power transmission:
Other parts:

13.4.2.15 Manufacturer's recommended working capacity: ha/h & kg/ha

13.4.2.16 Any other details

13.4.3 Summary of Test Conditions and Results

13.4.3.1 Laboratory tests

Separate data sheets should be prepared for each type of fertiliser used.

13.4.3.1.1 Application rate

Date of tests:

13.4.3.1.1.1 Test conditions

a) Fertiliser

Kind:
Name:
Shape:
Size distribution:
Moisture content: %
Bulk density: kg/l

b) Machine

Metering shaft speed adjustment: rev/min
Delivery opening adjustment

13.4.3.1.1.2 Delivery rate

		Feed Rate Setting								
		Maximum			Average			Minimum		
		Speed km/h			Speed km/h			Speed km/h		
a)	Ground Wheel Drive Distance for 1/100 ha m Total weight of fertiliser collected, kg Application rate, kg/ha Variations from average, Transverse, max +% min -% Longitudinal, max +% min -%									
b)	PTO drive Pto speed, rev/min Measuring time, min Total weight of fertiliser collected, kg Optimum bout width, m Application rate, kg/ha									

13.4.3.2 Field Tests

		Test Number					
		1	2	3	4	5	6
a)	Fertiliser Kind Name Moisture content, % Bulk density, kg/l						
b)	Soil Type and condition Previous cultivation Surface evenness						
c)	Distributor PTO speed, rev/min Forward speed, km/h Bout width, m Application rate, kg/ha Wheelskid, % Wheel sinkage, mm Draft N						

13.4.3.3 Repairs and adjustments during tests

13.4.3.4 Comments on performance

13.4.3.4.1 Ease of loading

13.4.3.4.2 Ease of setting delivery rates

13.4.3.4.3 Variations in transverse and longitudinal distribution

13.4.3.4.4 Ease of cleaning machine and components

13.4.3.4.5 Possible effects of corrosion

APPENDIX 13A

A. Test record sheet

Laboratory tests. Full width machine.

Date of tests:

Location of tests:

Fertiliser:

Name:

Bulk density: kg/l

Moisture content: %

Machine:

Make:

Feed setting:

Forward speed: km/h

Distance travelled: m

Time for run: min

		Outlet or Strip Number												Total	Average
		1	2	3	4	5	6	7	8	9	10	11	12		
Run 1	Weight collected, kg % of average														
Run 2	Weight collected, kg % of average														
Run 3	Weight collected, kg % of average														

B. Test record sheet

Laboratory tests. Broadcasters.

Date of tests:

Location of tests:

Fertiliser:

Name:

Bulk density: kg/l

Moisture content: %

Machine:

Make:

Feed setting:

Forward speed: km/h

Distance travelled: m

Time for run: min

		Outlet or Strip Number												Total	Average
		1	2	3	4	5	6	7	8	9	10	11	12		
Run 1	Weight collected, kg % of average														
Run 2	Weight collected, kg % of average														
Run 3	Weight collected, kg % of average														

C. Test record sheet

Field tests

		Test Number							
		1	2	3	4	5	6	7	8
Date of tests Location of tests									
Soil	- type - condition - previous cultivation								
Fertiliser	- type - name - bulk density, kg/l - moisture content, %								
Machine	- type - name - feed setting - pto speed								
Results	- area covered, ha - forward speed, km/h - bout width, m - weight of fertiliser used, kg - wheelskid, % - wheel sinkage, mm - draft, N								

Comments
- vibration
- wheelslip
- loading
- setting
- cleaning

14 PROCEDURE FOR EVALUATION OF KNAPSACK SPRAYERS

CONTENTS

14.1 Scope 182

14.2 Definitions 182

14.2.1 Hand Operated Sprayers 182
14.2.1.1 Knapsack sprayer 182
14.2.1.2 Shoulder sprayer 182
14.2.1.3 Continuous sprayer 182
14.2.1.4 Compression sprayer 182
14.2.1.5 Compression sprayer-non-pressure retaining type 182
14.2.2 Motorised Blowers 182
14.2.3 Examples of Knapsack Sprayer 182
14.2.3.1 Continuous Sprayer 182
14.2.3.2 Compression Sprayer Non-Pressure Retaining Type 183
14.2.3.3 Motorised Blower 183

14.3 Test Procedure 184

14.3.1 Machine for Test 184
14.3.2 Laboratory Work 184
14.3.2.1 Specification 184
14.3.2.2 Test Procedures 184
14.3.3 Field Work 186
14.3.3.1 Test Conditions 186
14.3.3.2 Test Procedure 187

14.4 Test Report 187

14.4.1 Diagram/Photograph 187
14.4.2 Specification 187
14.4.2.1 Type of unit and brief description including source of power 187
14.4.2.2 Make 187
14.4.2.3 Dimensions (in transport position including handle and lance or blower tube) 187
14.4.2.4 Overall weight 187
14.4.2.5 Hand-operated sprayer 187
14.4.2.6 Motorised blower 188
14.4.3 Test Results 188
14.4.3.1 Laboratory tests 188
14.4.3.2 Field Tests 191

14 PROCEDURE FOR EVALUATION OF KNAPSACK SPRAYERS

14.1 Scope

This procedure is applicable for the evaluation of various types of knapsack and shoulder carried sprayers.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and use in various field conditions.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the unit.

14.2 Definitions

14.2.1 Hand Operated Sprayers

14.2.1.1 **Knapsack sprayer** - A sprayer which can be mounted on the back of an operator for spraying.

14.2.1.2 **Shoulder sprayer** - A sprayer which can be suspended from the shoulder of an operator for spraying.

14.2.1.3 **Continuous sprayer** - A sprayer, the pump of which has to be operated continuously while liquid is discharged.

14.2.1.4 **Compression sprayer** - A sprayer, the liquid tank of which is a pressure vessel and in which the discharge is carried out with the air pressure created in advance by built-in pump or from outside.

14.2.1.5 **Compression sprayer-non-pressure retaining type** - A compression sprayer in which the working pressure does not remain constant but decreases gradually during discharge.

14.2.2 Motorised Blowers

A knapsack unit comprising a small 2 stroke engine driving a fan, air being directed through a flexible blower tube. Pesticide from a tank mounted on the engine is injected through a variable nozzle into the air stream.

14.2.3 Examples of Knapsack Sprayer

14.2.3.1 Continuous Sprayer

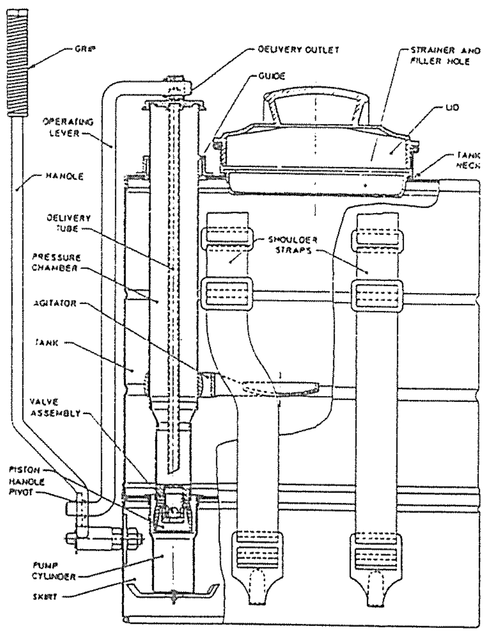


Figure 14.1 Continuous Sprayer
Source: RNAM, 1963

14.2.3.2 Compression Sprayer Non-Pressure Retaining Type

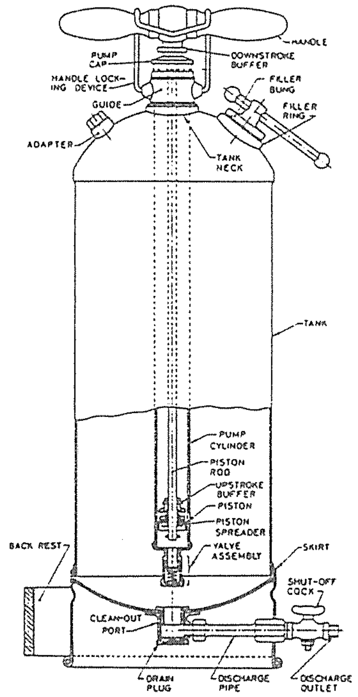


Figure 14.2 Compression Sprayer
Source: RNAM, 1983

14.2.3.3 Motorised Blower

1. Chassis with strips
2. Tank
3. Feed mechanism*
4. Regulator*
5. Motor driven blower*
6. Air entrance for duster*
7. Tank for liquid**
8. Liquid outlet and stopper for powder outlet**
9. Hermetically sealed tank**
10. Regulator**

* parts for duster
** parts for mister

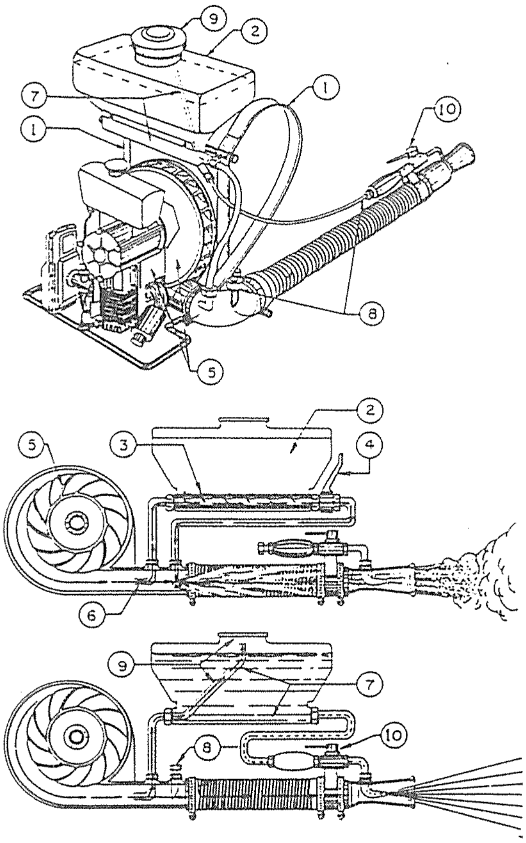


Figure 14.3 Duster/Mister
Source: Berlijn, 1978

14.3 Test Procedure

14.3.1 Machine for Test

Prior to any test work, the manufacturer shall supply the sprayer complete and in working order together with specifications concerning materials, construction, range of adjustments and expected performance under various conditions.

A complete specification will be given in the test report.

14.3.2 Laboratory Work

14.3.2.1 Specification

The specifications and setting details given by the manufacturer shall be checked and confirmed.

Some of the items to be examined are :-

a) Method of applying and maintaining pressure on spray liquid
b) Capacity of liquid containers
c) Size of pump or diaphragm
d) Size and capacity of engine
e) Weight of unit

Other items are listed in the specification form.

14.3.2.2 Test Procedures

14.3.2.2.1 Continuous sprayer

14.3.2.2.1.1 Volume efficiency test

This test is carried out to determine the ratio of the volume of fluid discharged to that of the piston or plunger displacement. The tank shall be filled with clean water. A suitable nozzle or a pressure regulator is fitted to the lance enabling the recommended working pressure to be developed. The pressure gauge shall be fitted as near to the nozzle as possible. With the pump handle operated at the speed recommended by the manufacturer and the pressure stabilised, the discharge for 20 successive strokes shall be measured. At least 5 replications should be made to allow a mean value of volume of fluid discharged to be calculated. Using the calculated piston or plunger displacement, volumetric efficiency is determined as follows :-

$$\text{Volumetric efficiency, \%} = \frac{\text{Volume discharged/stroke}}{\text{Piston displacement}} \times 100$$

14.3.2.2.1.2 Test of pressure chamber

If the sprayer is fitted with an external pressure chamber, this must be tested for leaks or deformation. The chamber shall be pressurised to a static hydraulic pressure of at least twice the maximum recommended working pressure, which shall be maintained for a minimum period of 5 minutes. During this period, the chamber shall be examined for leaks or deformation.

14.3.2.2.2 Compression sprayers

14.3.2.2.2.1 Output test

The tank shall be filled with clean water. The lance and standard accessory nozzle shall be connected and the pressure gauge fixed on the tank.

The tank shall be pressurised with 100 strokes when not specified or a given number of strokes of the handle or up to the pressure specified by the manufacturer.

After protecting the nozzle to prevent loss of liquid by drift, the discharge during one minute at every 5 minute interval shall be collected and measured 5 times for all standard accessory nozzles.

14.3.2.2.2.2 Test of pressure tank

The tank shall be pressurised to a static hydraulic pressure of at least twice the maximum recommended working pressure, which shall be maintained for a minimum period of 5 minutes. During this period, the chamber shall be examined for leaks or deformation.

14.3.2.2.3 Nozzles

14.3.2.2.3.1 Discharge test

The discharge from the nozzle shall be measured at the maximum and minimum pressures recommended by the sprayer manufacturer over a period of one minute.

Measurements shall only be made when the required pressure has stabilised and the mean of five replications shall be recorded for each type of nozzle used.

14.3.2.2.3.2 Spray distribution

Spray distribution is measured using a "Patternator" (Section 4.6.4).

The nozzle shall be positioned above the bench in its normal working attitude to direct its spray on to the troughs of the distribution bench.

If the manufacturer indicates an optimum working height, the test shall be made at this height as well as 150mm above and below this height.

If the manufacturer does not indicate a working height, the test should be carried out at heights of 300, 400 and 500mm. The heights shall be measured from the ridges of the distribution bench to the nozzle orifices.

Tests shall be made at the maximum and minimum pressures recommended by the manufacturer and in the case of a compression sprayer of the non-pressure retaining type, at the beginning, in the middle and just before the end of discharge.

Test runs shall be made over a period of one minute or until the liquid collected in one of the tubes reaches 90% of its capacity. The amount collected from each groove shall be recorded and shown in the report as a table or a graph (Fig 4.32). The graph will show the volume collected for each groove as a percentage of the mean volume. The co-efficient of variation shall be calculated for each test.

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Mean value}} \times 100$$

14.3.2.2.4 Motorised blowers

14.3.2.2.4.1 Output test

A known volume of liquid is placed in the spray tank and with the engine at full throttle setting, the time taken to emit the whole volume of spray is recorded. Tests are repeated with various nozzles and nozzle settings if applicable.

14.3.2.2.4.2 Horizontal throw

Target cards are fixed to a series of ten rows of seven pegs, 1 metre above the ground. The pegs are 1.5 m apart between rows and 0.75 m within rows, the first being 3 m from the sprayer nozzle set at the same height as the target cards. The layout of the targets should be screened from prevailing winds and tests carried out when wind speeds are negligible. The targets are sprayed for 5 seconds with a suitable dyed liquid.

The horizontal throw can be more simply determined by spraying clean water on to a dry concrete floor in a wind-free area and measuring the distance covered by the spray (Section 4.6.4). Tests at various nozzle settings should be carried out.

14.3.2.2.4.3 Vertical throw

Table tennis ball or card targets are fixed at 300mm intervals to a rope which can be raised so that the highest target is 12 m and the lowest is 4 m above the ground (Section 4.6.4). A suitable dyed spray is applied with the nozzle held at an angle 1.5 m above the ground and 3 metres from the rope so that natural air movement does not carry the spray droplets away from the rope. Tests at various nozzle settings should be carried out.

14.3.2.2.4.4 Noise levels

With the blower carried by the operator in the normal position and engine running at full throttle, the noise level is measured in decibels (A rating) at the operator's ear positions (Fig 4.35).

14.3.2.2.4.5 Fuel Consumption

The sprayer unit is operated for several minutes, then stopped and the fuel tank and carburettor drained. A measured volume of fuel is put in the tank.

With the pesticide tank full of water and maximum liquid feed to the nozzle, the sprayer is operated and the time until the engine stops through lack of fuel is recorded.

14.3.3 Field Work

The effective performance of knapsack type sprayers and blowers can only be determined by practical trials in the field.

14.3.3.1 Test Conditions

14.3.3.1.1 Sprayers and blowers

For each type and size of crop, the manufacturers recommended nozzle type and size and system pressure shall be used on sprayers and nozzle and engine speed settings on motorised blowers.

14.3.3.1.2 Operators

Operators should be experienced in the use of knapsack type sprayers and blowers and be able to comment on various aspects of their performance.

14.3.3.1.3 Field conditions

The following conditions will require to be clearly stated for each type of plot :-

a) Size of plot
b) Type of crop
c) Height of crop
d) Distance between plants and rows
e) Ambient conditions

14.3.3.2 Test Procedure

14.3.3.2 Test Procedure

The sprayer or blower shall be operated in accordance with the manufacturers instructions on various plots and types of crop for a total time of about 20 hours using at least 2 operators.

The following items shall be measured or observed :-

a) Rate of work
b) Pesticide application rate
c) Comfort and fatigue of operator
d) Ease of filling, dismantling and maintenance
e) Ease of operation of lance or blower nozzle
f) Leakage from tanks, pipes or valves
g) Ease of control and maintenance of engine
h) Vibration of unit

14.4 Test Report

14.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the sprayer or blower should be provided.

14.4.2 Specification

14.4.2.1 Type of unit and brief description including source of power

14.4.2.2 Make:
Model:
Serial No:
Manufacturer's name and address:

14.4.2.3 Dimensions (in transport position including handle and lance or blower tube)

Length:	mm
Width:	mm
Height:	mm

14.4.2.4 Overall weight

Tank(s) empty:	kg
Tank(s) full:	kg

14.4.2.5 Hand-operated sprayer

Tank capacity:	l
Diameter of pump plunger, piston or diaphragm:	mm
Diameter of cylinder:	mm
Length of stroke:	mm
Range of working pressure:	Pa(kgf/cm^2)
Volume of pressure chamber:	cm^3
Type of agitator:	
Size of filler hole:	mm dia
Strainer mesh:- Filler:	
Pump inlet:	
Type of standard nozzle:	
Type of optional nozzles:	
Diameter of nozzle orifice:	mm
Length of hose:	m
Length of lance:	m

14.4.2.6 Motorised blower

Type and size of engine:	
Recommended engine speed:	rev/min
Fuel tank capacity:	l
Fuel tank filler hole:	mm dia
Fuel tank strainer:	
Pesticide tank capacity:	l
Pesticide tank filler hole:	mm dia
Pesticide tank strainer:	
Length and diameter of air tube:	m x mm
Type and size of spray nozzle:	

14.4.3 Test Results

14.4.3.1 Laboratory tests

14.4.3.1.1 Continuous sprayer

14.4.3.1.1.1 Volume efficiency test

	Test Number				
	1	2	3	4	5
1. Method of operating the handle					
2. Working pressure, Pa (kgf/cm^2)					
3. Number of strokes					
4. Discharge, l					
5. Litre/stroke					
6. Piston displacement l					
7. Volume efficiency, %					

14.4.3.1.1.2 Pressure chamber test

1. Maximum working pressure, Pa (kgf/cm^2)					
2. Pressure applied to chamber, Pa (kgf/cm^2)					
3. Period of test, min					
4. Observation on leakage & deformation					

14.4.3.1.2 Compression sprayers

14.4.3.1.2.1 Discharge test

	Test Number				
	1	2	3	4	5
1. Number of strokes of handle					
2. Pressure applied, Pa (kgf/cm^2)					
3. Type of nozzle					
4. Discharge per min, l					
5. Corresponding pressure, Pa (kgf/cm^2)					

14.4.3.1.2.2 Pressure tank test

1. Maximum working pressure, Pa (kgf/cm²)					
2. Pressure applied to tank Pa (kgf/cm²)					
3. Period of test, min					
4. Observation on leakage & deformation					

14.4.3.1.3 Nozzle test

14.4.3.1.3.1 Discharge test

1. Type of nozzle					
2. Working pressure, Pa (kgf/cm²)					
3. Period of test, min					
4. Discharge, l					
4. Discharge rate, l/min					

14.4.3.1.3.2 Spray distribution

1. Type of nozzle
2. Working pressure, kg/cm^2
3. Height above distribution bench, mm
4. Table of results

Position of the Grooves in Relation to the Axis of the Nozzle			
To the Left		To the Right	
Distance mm	Volume % of the mean volume	Distance mm	Volume % of the mean volume
0-50 50-100 100-150 500-550 550-600		0-50 50-100 100-150 500-550 550-600	

(See Fig 4.32 for graph of spray distribution)

5. Coefficient of variation

14.4.3.1.4 Motorised blowers

14.4.3.1.4.1 Output test

	Test Number				
	1	2	3	4	5
1. Type of nozzle					
2. Nozzle setting					
3. Engine speed, rev/min					
4. Output rate, l/min					

14.4.3.1.4.2 Horizontal throw

		1	2	3	4	5
1. Type of nozzle						
2. Nozzle setting						
3. Engine speed,	rev/min					
4. Height of nozzle above ground	m					
5. Range of spray from nozzle,	min, m					
	max, m					

14.4.3.1.4.3 Vertical throw

		Test Number				
		1	2	3	4	5
1. Type of nozzle						
2. Nozzle setting						
3. Engine speed,	rev/min					
4. Height of nozzle above ground,	m					
5. Angle of nozzle in relation to vertical,	°					
6. Range of spray above ground	min, m					
	max, m					

14.4.3.1.4.4 Noise levels

1. Engine speed, rev/min
2. Noise level, dBA - right hand ear position
   - left hand ear position

14.4.3.1.4.5 Fuel consumption

		1	2	3	4	5
1. Type of nozzle						
2. Nozzle setting						
3. Engine speed,	rev/min					
4. Fuel consumption,	l/h					

14.4.3.2 Field Tests

14.4.3.2.1 Field conditions

1. Location					
2. Length and width of plot, m					
3. Type of crop					
4. Height of crop, m					
5. Distance between plants, m					
6. Distance between rows, m					

14.4.3.2.2 Sprayer or blower

	Test Number				
	1	2	3	4	5
1. Type of nozzle					
2. Nozzle setting					
3. Working pressure, Pa (kgf/cm^2)					
4. Engine speed, rev/min					

14.4.3.2.3 Ambient conditions

1. Temperature, °C					
2. Wind velocity, km/h					
3. Description of weather					

14.4.3.2.4 Results of tests

1. Rate of work l/h					
2. Application rate, l/ha					

14.4.3.2.5 Observations during tests

14.4.3.2.5.1 Comfort and fatigue of operator

14.4.3.2.5.2 Ease of filling, dismantling and maintenance

14.4.3.2.5.3 Ease of operation of lance or blower nozzle

14.4.3.2.5.4 Leakage from tanks, pipes or valves

14.4.3.2.5.5 Ease of control and maintenance of engine

14.4.3.2.5.6 Operator's safety

14.4.3.2.5.7 Any other comments

15 PROCEDURE FOR EVALUATION OF FIELD SPRAYERS

CONTENTS

15.1 Scope 193

15.2 Definitions 193

15.2.1 Field Sprayers 193

15.3 Test Procedure 193

15.3.1 Machine for Test 193
15.3.2 Laboratory Work 194
15.3.2.1 Specification 194
15.3.2.2 Test Procedure 194
15.3.3 Field Tests 195
15.3.3.1 Test Conditions 195
15.3.3.2 Test Procedure 195

15.4 Test Report 195

15.4.1 Diagram/Photograph 195
15.4.2 Specification 195
15.4.2.1 Type of machine and brief description 195
15.4.2.2 Dimensions (in transport and in working condition) 196
15.4.2.3 Overall weight 196
15.4.2.4 Boom 196
15.4.2.5 Travelling 196
15.4.2.6 Pressure Pump 196
15.4.2.7 Spray Tank 196
15.4.2.8 Marker Device 196
15.4.2.9 Hitch 196
15.4.2.10 Safety Arrangements 196
15.4.2.11 Manufacturer's recommended working capacity 196
15.4.3 Test Results 197
15.4.3.1 Laboratory Tests 197
15.4.3.2 Field Tests 198

15 PROCEDURE FOR EVALUATION OF FIELD SPRAYERS

15.1 Scope

This procedure is applicable for the evaluation of various types of power-driven field sprayers.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and use in various field conditions.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the machine.

15.2 Definitions

15.2.1 Field Sprayers

Field sprayers are used to apply chemicals, diluted with water to control weeds and pests in ground crops.

Sprayers may be tractor mounted or trailed and consist of a tank and a power driven pump supplying liquid through a control valve to a boom carrying a number of nozzles.

Output is dependent on travel speed, pressure and number, size and type of nozzles.

1) Tank
2) Chassis with shoe
3) Three point linkage
4) Pump
5) Suction line
6) Tractor PTO
7) Main valve
8) Pressure regulator
9) Accumulator with pressure gauge
10) Valve for tank filling
11) Suction line for tank valve
12) Valves for boom sections
13) Spray boom
14) Boom height adjustment

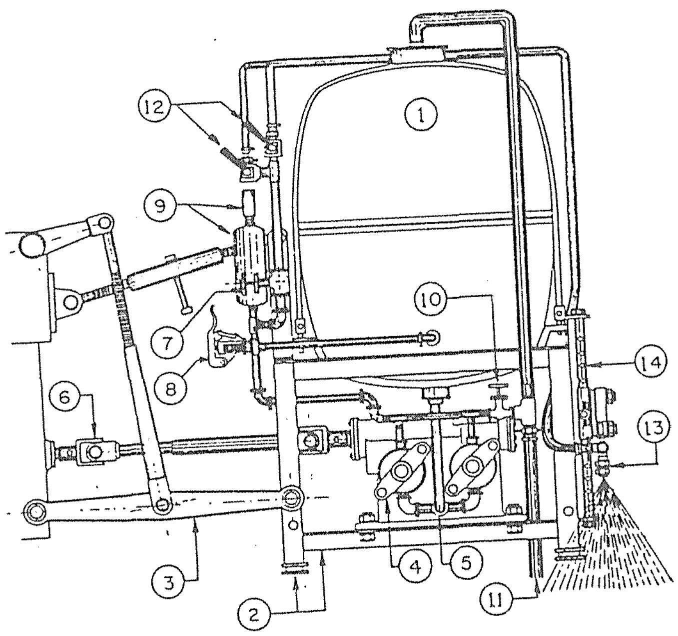


Figure 15.1 General construction of a field sprayer
Source: Berlijn, 1978

15.3 Test Procedure

15.3.1 Machine for Test

Prior to any test work, the manufacturer shall supply the machine complete and in working order together with specifications concerning materials, construction, range of adjustments and expected performance in various crops.

A complete specification will be given in the test report.

15.3.2 Laboratory Work

15.3.2.1 Specification

The specifications and setting details given by the manufacturer shall be checked and confirmed. Some of the items to be examined are :-

a) Power source for pump and transport
b) Capacity of liquid containers
c) Size of boom and number and position of nozzles
d) Size and weight of machine

Other items are listed in the specification form.

15.3.2.2 Test Procedure

15.3.2.2.1 Pump tests

The discharge from the pump shall be measured at the pump speed recommended by the manufacturer at the maximum and minimum service pressure. Measurements shall be made with pump mounted in its normal position on the sprayer and at the intake height corresponding to a half-full tank.

The results shall be expressed in litres/minute in the form of a table or graph.

15.3.2.2.2 Nozzle tests

The discharge and distribution tests are identical to those described for knapsack sprayers (Section 14.3.2.2.3).

15.3.2.2.3 Performance of complete boom

15.3.2.2.3.1 Discharge

Tests shall be made with sets of each type of nozzle specified for the machine and at the maximum pressure recommended by the manufacturer.

When the pressure has been stabilised, the liquid discharged by each nozzle for a chosen period is collected and the results presented in a table or graph, as a percentage of the mean volume.

The period of time equivalent to the machine covering one hectare may be calculated as follows :-

$$\text{Time (min)} = \frac{600}{\text{Bout width (m)} \times \text{Forward speed (km/h)}}$$

For a spray boom, the bout width may be calculated by multiplying the number of nozzles by the nozzle spacing.

The results may be presented as litres/min and litres/hectare.

15.3.2.2.3.2 Spray distribution

This test shall be carried out using the distribution bench as for nozzle tests.

Tests shall cover the full width of the boom but may be made section by section. If this method is used, the whole spray boom shall discharge during a test on one section and the time of discharge shall be the same for each section.

The spray boom shall be in its normal working position and if the manufacturer indicates an optimum working height, tests shall be made at this height as well as 150mm above and below this height.

If the manufacturer does not indicate a working height, tests should be carried out at heights of 400, 500, 600 and 700mm and optionally at 300 and 800mm. The heights shall be measured from the ridges of the distribution bench to the nozzle orifices.

Tests shall be made at the maximum and minimum pressures recommended by the manufacturer. The liquid from each 100mm groove shall be collected during a period which is determined according to the discharge from the nozzle which gave the greatest volume during the discharge test. The amount of liquid collected from each groove shall be recorded and shown in the report as a table or a graph. The graph will show the volume collected for each groove as a percentage of the mean volume. The co-efficient of variation shall be calculated for each test.

15.3.3 Field Tests

The effective performance of field sprayers can only be determined by practical trials in the field on various types of crop. These trials will enable observations to be made on aspects of control, adjustments and maintenance.

15.3.3.1 Test Conditions

15.3.3.1.1 Sprayers

For each type and size of crop, the manufacturers recommended nozzle type and size, system pressure, boom height and forward speed shall be used.

15.3.3.1.2 Field conditions

The following conditions will require to be clearly stated for each type of plot :-

a) Size of plot
b) Type and height of crop
c) Ambient conditions.

15.3.3.2 Test procedure

The sprayer shall be operated in accordance with the manufacturer's instructions in at least 5 different plot and crop conditions for a time to allow the following measurements and observations to be made.

a) Rate of work
b) Application rate
c) Travelling and pump speeds
d) Boom height setting
e) Ease of filling, adjustment and maintenance
f) Ease of control
g) Repairs and adjustments or leakages

15.4 Test Report

15.4.1 Diagram/Photograph

A line drawing or photograph showing the principal details of the sprayer shall be provided.

15.4.2 Specification

15.4.2.1 Type of machine and brief description

Make:
Model:
Serial No.:
Manufacturer's name and address:

15.4.2.2	Dimensions (in transport and in working condition)	
	Length:	m
	Width:	m
	Height:	m
15.4.2.3	Overall weight	
	Tank(s) empty:	kg
	Tank(s) full:	kg
15.4.2.4	Boom	
	Nominal working width:	m
	Number of nozzles:	
	Type of standard nozzles:	
	Type of alternative nozzles:	
	Nozzle spacing:	cm
	Type of suspension:	
	Method of retraction:	
15.4.2.5	Travelling	
	Source of power (for carrying, trailing or mounting machine):	
	Recommended travelling speed:	m/s
	Recommended output of power source:	kW
	Ground wheel type:	
	Size:	
	Material:	
15.4.2.6	Pressure Pump	
	Source of power for driving pump:	
	Recommended power requirement for pump:	kW
	If tractor pto driven, pto speed:	rev/min
	Range of working pressure:	Pa (kgf/cm^2)
15.4.2.7	Spray Tank	
	Capacity:	l
	Method of filling:	
	Method of agitation:	
	Number and size of filters:	
15.4.2.8	Marker Device	
	Type:	
	Method of marking:	
15.4.2.9	Hitch	
	Type and construction:	
	Category of three-point linkage:	
15.4.2.10	Safety Arrangements	
	Power transmission:	
	Other parts:	
15.4.2.11	Manufacturer's recommended working capacity:	l/h & ha/h
15.4.2.12	Any Other Details	

15.4.3 Test Results

15.4.3.1 Laboratory Tests

15.4.3.1.1 Pump tests

		Test Number					
		1	2	3	4	5	6
1. Pump speed,	rev/min						
2. Service pressure,	Pa (kgf/cm^2)						
3. Discharge,	l/min						

15.4.3.1.2 Nozzle tests

15.4.3.1.2.1 Discharge test

		1	2	3	4	5	6
1. Type of nozzle							
2. Working pressure,	Pa (kgf/cm^2)						
3. Test period,	min						
4. Discharge,	l						
5. Discharge rate,	l/min						

15.4.3.1.2.2 Spray distribution

1. Type of nozzle
2. Working pressure, Pa (kgf/m^3)
3. Height from distribution bench, mm
4. Table of results

Position of the Grooves in Relation to the Axis of the Nozzle			
To the Left		To the Right	
Distance mm	Volume % of the mean volume	Distance mm	Volume % of the mean volume
0-50 50-100 100-150		0-50 50-100 100-150	
500-550 550-600		500-550 550-600	

(See Fig 4.32 for graph of spray distribution)

5. Coefficient of variation

15.4.3.1.3 Boom Tests

15.4.3.1.3.1 Discharge test

		TEST NUMBER					
		1	2	3	4	5	6
1. Type of nozzles							
2. Number of nozzles							
3. Nozzle spacing,	m						
4. Working pressure,	Pa (kgf/cm^2)						
5. Test period,	min						
6. Total discharge,	l						
7. Discharge rate,	l/min						
8. Discharge rate,	l/ha						

15.4.3.1.3.2 Spray distribution

1. Type of nozzles
2. Number of nozzles
3. Nozzle spacing m
4. Working pressure Pa (kgf/cm^2)
5. Height of boom mm
6. Table of results

Postion of the Grooves in Relation to the Centre Line of the Boom			
To the Left		To the Right	
Distance mm	Volume % of the mean volume	Distance mm	Volume % of the mean volume
0-100 100-200 200-300		0-100 100-200 200-300	
800-900 900-1000		800-900 900-1000	

7. Coefficient of variation

15.4.3.2 Field Tests

15.4.3.2.1 Field conditions

		Test Number				
		1	2	3	4	5
1. Location						
2. Length and width of plot,	m					
3. Type of crop						
4. Height of crop,	m					
5. Distance between rows,	m					

15.4.3.2.2 Sprayer

1.	Type of nozzles						
2.	Number of nozzles						
3.	Nozzle spacing,	cm					
4.	Height of boom,	cm					
5.	Working pressure,	Pa (kgf/cm^2)					
6.	Pump speed,	rev/min					
7.	Travelling speed,	km/h					

15.4.3.2.3 Ambient conditions

1.	Temperature,	°C					
2.	Wind velocity,	km/h					
3.	Description of weather						

15.4.3.2.4 Results of tests

1.	Rate of work,	ha/h					
2.	Application rate,	l/ha					

15.4.3.2.5 Observations during tests

15.4.3.2.5.1 Ease of filling, dismantling and maintenance

15.4.3.2.5.2 Ease of control of power unit and sprayer

15.4.3.2.5.3 Leakage from tanks, pipes or valves

15.4.3.2.5.4 Operator's safety

15.4.3.2.5.5 Repairs and adjustments

15.4.3.2.5.6 Any other comments

16 PROCEDURE FOR EVALUATION OF MANUALLY-OPERATED PUMPS

CONTENTS

16.1 Scope 201

16.2 Definitions 201

16.2.1 Types of Manually Operated Pumps 201
16.2.2 Terms 202
16.2.2.1 Reference Plane 202
16.2.2.2 Static Suction and Delivery Head 202
16.2.2.3 Actual Head or Total Static Head 202

16.3 Test Procedure 202

16.3.1 Unit for Test 202
16.3.2 Laboratory Work 202
16.3.2.1 Specification 202
16.3.3 Performance Test 202
16.3.3.1 Water Source 202
16.3.3.2 Operators 202
16.3.3.3 Test Conditions and Equipment 203
16.3.3.4 Test Method 203
16.3.3.5 Test Measurements and Calculation 204
16.3.4 Practical Tests 204

16.4 Report 204

16.4.1 Diagram/Photograph 204
16.4.2 Specification 204
16.4.2.1 Brief description of pump and method of operation 204
16.4.2.2 Overall Dimensions 205
16.4.2.3 Weight 205
16.4.2.4 Size of piston(s) or rotor 205
16.4.2.5 Recommended angle of installation if not horizontal or vertical 205
16.4.2.6 Maximum recommended suction head 205
16.4.2.7 Rated discharge capacity 205
16.4.3 Results of Performance Tests 205
16.4.3.1 Summary of Performance Test Conditions and Results 205
16.4.3.2 Performance curves 205
16.4.3.3 Repairs and adjustments and comments made during performance tests 205
16.4.4 Results of Practical Tests 205

APPENDIX 16A Test record sheet 206

16 PROCEDURE FOR EVALUATION OF MANUALLY-OPERATED PUMPS

16.1 Scope

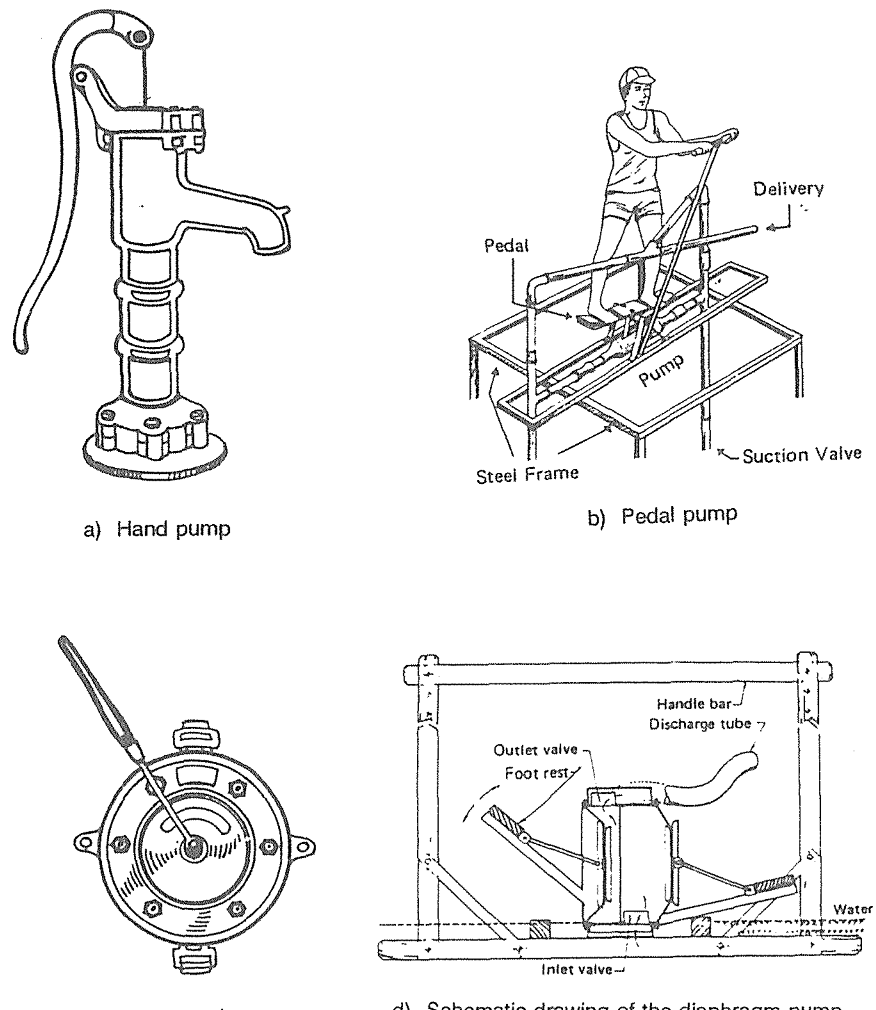
This procedure is applicable for the evaluation of manually operated water pumps.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, and suitability for operation under various conditions.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the pump.

16.2 Definitions

16.2.1 Types of Manually Operated Pumps



a) Hand pump

b) Pedal pump

c) Semi-rotary hand pump

d) Schematic drawing of the diaphragm pump

Figure 16.1 Types of manually operated pumps
Source: RNAM, 1983

16.3.3.5 Test Measurements and Calculation

At each setting, the following measurements and calculations will be made. Sample record sheets are given in the appendix.

		Unit	Symbol	Calculation
a)	Measured suction head	m	H_s	
b)	Measured discharge head	m	H_d	
c)	Suction gauge pressure	kgf/m^2	P_s	
d)	Density of liquid pumped	kgf/m^3	ρ	
e)	Head corresponding to suction gauge pressure	m		$\frac{P_s}{\rho}$
f)	Vertical distance between the reference plane and point where suction pressure is measured	m	h_s	
g)	Rate of discharge	m^3/s	Q	
h)	Speed of pumping	rev/min strokes/min		

The total head in metres is obtained by one of the following :-

$$H = H_s + H_d$$

or

$$H = H_d + \frac{P_s}{\rho} + h_s$$

16.3.4 Practical Tests

In addition to the performance test, practical tests shall be made at various sites and conditions. The duration of each test should be not be less than one hour. The objectives of this test are to investigate the adaptability to practical conditions, the work intensity imposed to the operators, the possibility of long periods of work and the ease of operation. Items to be measured and examined during these tests shall be the same as in the performance tests.

16.4 Report

16.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the pump and its attendant pipe work should be provided.

16.4.2 Specification

16.4.2.1 Brief description of pump and method of operation.

Make:
Model:
Serial No.:
Manufacturers name and address:

16.4.2.2 Overall Dimensions

Height of discharge: m
Length of suction pipe: m
Length and height of operating handle or lever: m

16.4.2.3 Weight: kg

16.4.2.4 Size of piston(s) or rotor: mm

16.4.2.5 Recommended angle of installation if not horizontal or vertical: o

16.4.2.6 Maximum recommended suction head: m

16.4.2.7 Rated discharge capacity: m^3/h

16.4.3 Results of Performance Tests

16.4.3.1 Summary of Performance Test Conditions and Results

Test Number					
Date					
Location					
Source of water					
Ambient temperature	°C				
Pump strokes or revolutions per minute					
Static suction head,	m				
Static delivery head,	m				
Total static head,	m				
Discharge rate,	m^3/h				

16.4.3.2 Performance curves (Fig 4.39)

Suction head/discharge
Total head/discharge
Pumping speed/discharge

16.4.3.3 Repairs and adjustments and comments made during performance tests.

16.4.4 Results of Practical Tests

Test measurements and calculations made during performance tests will also apply to the practical tests. Comments will be made on the suitability of the pump under various conditions, the ease of operation and suggestions for future modifications if required.

APPENDIX 16A

Test record sheet
Make and type of pump

Date								
Test number								
Pump speed Rev/min Strokes/min								
Measured suction head,	m(Hs)							
Measured discharge head,	m(Hd)							
Suction gauge pressure,	kgf/m^2(Ps)							
Distance of suction pressure gauge from reference plane,	m(hs)							
Rate of discharge	m^3/sec(Q)							
Density of liquid pumped,	kgf/m^3(ρ)							

16.4.2.2 Overall Dimensions

Height of discharge: m
Length of suction pipe: m
Length and height of operating handle or lever: m

16.4.2.3 Weight: kg

16.4.2.4 Size of piston(s) or rotor: mm

16.4.2.5 Recommended angle of installation if not horizontal or vertical: o

16.4.2.6 Maximum recommended suction head: m

16.4.2.7 Rated discharge capacity: m^3/h

16.4.3 Results of Performance Tests

16.4.3.1 Summary of Performance Test Conditions and Results

Test Number					
Date					
Location					
Source of water					
Ambient temperature	°C				
Pump strokes or revolutions per minute					
Static suction head,	m				
Static delivery head,	m				
Total static head,	m				
Discharge rate,	m^3/h				

16.4.3.2 Performance curves (Fig 4.39)

Suction head/discharge
Total head/discharge
Pumping speed/discharge

16.4.3.3 Repairs and adjustments and comments made during performance tests.

16.4.4 Results of Practical Tests

Test measurements and calculations made during performance tests will also apply to the practical tests. Comments will be made on the suitability of the pump under various conditions, the ease of operation and suggestions for future modifications if required.

APPENDIX 16A

Test record sheet
Make and type of pump

Date								
Test number								
Pump speed Rev/min Strokes/min								
Measured suction head,	m(Hs)							
Measured discharge head,	m(Hd)							
Suction gauge pressure,	kgf/m^2(Ps)							
Distance of suction pressure gauge from reference plane,	m(hs)							
Rate of discharge	m^3/sec(Q)							
Density of liquid pumped,	kgf/m^3(ρ)							

17 PROCEDURE FOR EVALUATION OF POWER OPERATED PUMPS

CONTENTS

17.1 Scope 208

17.2 Definitions 208

17.2.1 Types of Power Operated Pumps 208
17.2.2 Terms 209
17.2.2.1 Reference Plane 209
17.2.2.2 Static Suction and Delivery Head 209
17.2.2.3 Actual Head or Total Static Head 209
17.2.2.4 Total Dynamic Head 209
17.2.2.5 Pump Input Power 209
17.2.2.6 Pump Outlet Power 209
17.2.2.7 Overall Efficiency 209

17.3 Test Procedure 209

17.3.1 Unit for Test 209
17.3.2 Preliminary Work 209
17.3.2.1 Specification 209
17.3.2.2 Power of Engines or Tractors 210
17.3.3 Performance Test 210
17.3.3.1 Water Source 210
17.3.3.2 Test Conditions and Equipment 210
17.3.3.3 Test Method 211
17.3.4 Durability Tests 213

17.4 Report 213

17.4.1 Diagram/Photograph 213
17.4.2 Specification 213
17.4.2.1 Brief description of pump and method of operation 213
17.4.2.2 Overall Dimensions 213
17.4.2.3 Weight 213
17.4.2.4 Size of piston(s) or rotor 213
17.4.2.5 Recommended power and speed of integral or separate prime mover 213
17.4.2.6 Maximum recommended static head 213
17.4.2.7 Recommended angle of installation if not horizontal or vertical 213
17.4.2.8 Rated capacity at maximum efficiency 213
17.4.3 Results of Performance Tests 214
17.4.3.1 Summary of Performance Tests Conditions and Results 214
17.4.3.2 Performance curves 214
17.4.3.3 Repairs and adjustments and comments made during performance tests 214
17.4.4 Results of Durability Trials 214

APPENDIX 17A Test record sheet 215

17 PROCEDURE FOR EVALUATION OF POWER OPERATED PUMPS

17.1 Scope

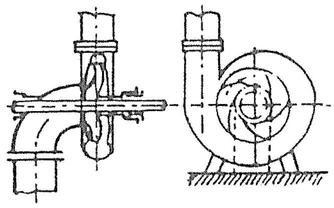
This procedure is applicable for the evaluation of power operated water pumps.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, and suitability for operation under various conditions.

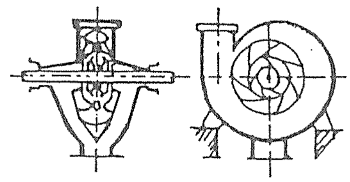
It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the pump.

17.2 Definitions

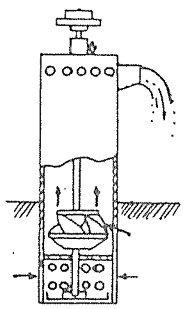
17.2.1 Types of Power Operated Pumps



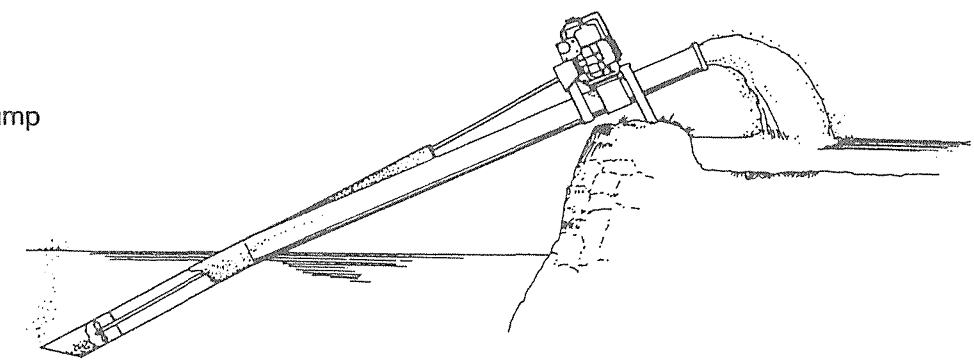
a) Single suction volute pump



b) Double suction turbine pump



c) Vertical pump



d) Propeller pump

Figure 17.1 Motor driven pumps
Source: RNAM, 1983

17.2.2 Terms

17.2.2.1 Reference Plane

For a pump with a horizontal shaft, the reference plane is the horizontal plane containing the centre line of the shaft. The reference plane of a pump with a vertical shaft is the horizontal plane containing the centre of the entrance edge of the vane in a centrifugal or mixed flow pump and the centre of the vane in a propeller pump.

17.2.2.2 Static Suction and Delivery Head

These are expressed as the vertical downward distance from the reference plane to the water source level and the vertical upward distance from the reference plane to the delivery level respectively.

17.2.2.3 Actual Head or Total Static Head

Vertical distance between the water source level and the water outlet. It is the sum of the static suction and delivery heads.

17.2.2.4 Total Dynamic Head

This is the measure of energy increase imparted to the water by the pump and the algebraic difference between the total discharge head and the total suction head. On test, the total suction head is the pressure gauge reading at the inlet converted to water column and referred to the reference plane plus the velocity head. The total discharge head is the pressure gauge reading at the outlet converted to water column and referred to the reference plane plus the velocity head.

17.2.2.5 Pump Input Power

The power required by the pump measured at the input shaft by a torque and speed measuring device. If this is not possible, in the case of an electric motor, a watt meter may be used. If the pump is engine or tractor driven, power may be estimated by one of the methods described in Section 4.3.

17.2.2.6 Pump Outlet Power

The power transferred to the liquid at its passage through the pump and is calculated from the discharge and the total head.

17.2.2.7 Overall Efficiency

The relationship of the output power to the input power.

17.3 Test Procedure

17.3.1 Unit for Test

Prior to any test work, the manufacturer shall supply the pump complete coupled to the appropriate power source in working order together with specifications giving constructional details, expected performance and range of applications. A complete specification will be given in the report.

17.3.2 Preliminary Work

17.3.2.1 Specification

The main objective is to study and confirm the specifications and essential components comparing them with those supplied by the manufacturer.

Items will include:

a) Dimensions
b) Weight
c) Size of suction and discharge pipes
d) Rotor type and size
e) Connection to power source.

17.3.2.2 Power of Engines or Tractors

If the pump is driven by an engine or tractor and it is not possible to fit a torque measuring device in the drive line, preliminary power tests should be made. These tests are described in Section 4.3 and use inlet manifold depression, exhaust gas temperature or fuel consumption in relation to engine speed as a means of power estimation.

17.3.3 Performance Test

17.3.3.1 Water Source

The tests should be made where clean water of sufficient quantity is available, this may be a water tank if natural sources are not available. Means should be provided to vary the suction head.

17.3.3.2 Test Conditions and Equipment

The pump should be mounted with the reference plane horizontal and coupled to its power source. Suction and discharge pipes should be attached to the pump to allow pressure tappings to be made as shown in Figure 17.2.

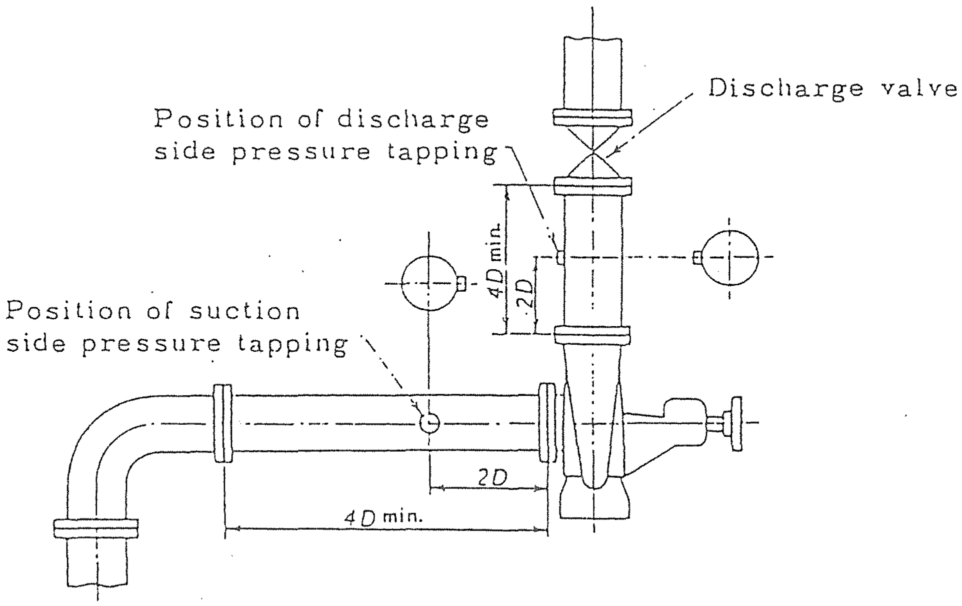


Figure 17.2 Location of pressure tapping points
Source: AMTEC, undated.

The appropriate suction pipes and filters are attached to the suction side and valves and pipes are fitted to the discharge to allow flow measurements to be made. There are various methods of measuring the rate of discharge:

a) **Flow meter** - This may be fitted into the discharge line in such a position that flow disturbances produced by the pump or pipe fittings will have no effect on the meter. The size and capacity of the meter shall be compatible with the rated output of the pump.

b) **Tank and weir** - The discharge pipe may be directed into a tank which has a V-notched weir overflowing to the water source.

c) **Measured tank** - The discharge pipe shall be arranged to enable the flow to be directed into a large tank of known size. The time taken to fill the tank is measured.

If the static head of the suction and discharge cannot be changed by re-positioning the pump, valves may be fitted into the suction and discharge pipes to vary the pressure. The general arrangement of the system is shown in Fig 17.3.

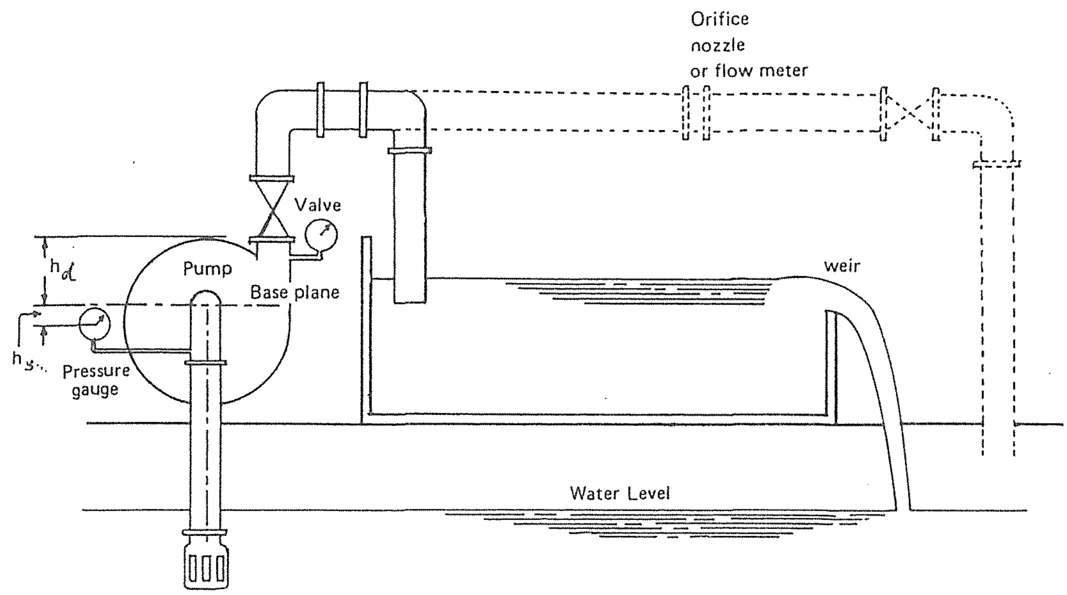


Figure 17.3 Arrangement for pump testing
Source: RNAM, 1983

17.3.3.3 Test Method

17.3.3.3.1 Rate of Discharge

The rate of discharge shall be measured at pump speeds recommended by the manufacturer at various suction and discharge heads to allow the following performance curves to be drawn. Duplicate measurements will be made at each setting to ensure accuracy, further replications may be necessary.

17.3.3.3.2 Performance Curves

Total head as a function of discharge
Speed as a function of discharge
Power input as a function of discharge
Efficiency as a function of discharge

17.3.3.3.3 Test Measurements and Calculations

At each setting, the following measurements and calculations will be made. Sample record sheets are given in the appendix.

		Unit	Symbol	Calculation
a)	Discharge gauge pressure	kgf/m^2	Pd	
b)	Suction gauge pressure	kgf/m^2	Ps	
c)	Density of liquid pumped	kgf/m^3	ρ	
d)	Head corresponding to discharge gauge pressure	m		$\frac{Pd}{\rho}$
e)	Head corresponding to suction gauge pressure	m		$\frac{Ps}{\rho}$
f)	Vertical distance between the reference plane and point where suction pressure is measured	m	hs	
g)	Vertical distance between the reference plane and point where discharge pressure is measured	m	hd	
h)	Rate of discharge	m^3/s	Q	
j)	Cross-section area of suction pipe	m^2	As	
k)	Cross-section area of discharge pipe	m^2	Ad	
l)	Velocity of liquid at suction	m/s	Vs	Q/As
m)	Velocity of liquid at discharge	m/s	Vd	Q/Ad
n)	Acceleration due to gravity	m/s^2	g	
o)	Input power	kW		
p)	Pump speed	rev/min		

The total head in metres is obtained from the following equation. If both the suction and delivery pipes are of the same diameter and the discharge and suction pressure gauges are on the same level, the last two terms in the equation will disappear.

Total head

$$H = \frac{Pd - Ps}{\rho} + \frac{Vd^2 - Vs^2}{2g} + hs + hd$$

Output Power

$$kW = \frac{H x Q x \rho}{102}$$

Pump efficiency

$$\% = \frac{\text{Output power}}{\text{Input power}} \times 100$$

17.3.4 Durability Tests

Although pumps are designed to work satisfactorily for long periods, there may be mechanical faults in the pump or the pump mounting and drive arrangements. In order that any problems may be investigated, the pump will be run intermittently at maximum speed and power input for a period of 100 hours. Lake or stream water containing matter in suspension may be used for this purpose, the percentage of solids shall be quoted in the report.

The measurements listed in the performance test will be made at intervals throughout the running period to ensure that maximum conditions are maintained. During the tests, any repairs or adjustments should be noted together with comments on ease of operation and maintenance of performance.

17.4 Report

17.4.1 Diagram/Photograph

A line drawing or photograph showing principal details of the pump and power unit should be provided.

17.4.2 Specification

17.4.2.1 Brief description of pump and method of operation

Make:
Model:
Serial No.:
Manufacturers name and address:

17.4.2.2 Overall Dimensions

Length: mm
Width: mm
Height: mm

17.4.2.3 Weight: kg

17.4.2.4 Size of piston(s) or rotor: mm

17.4.2.5 Recommended power and speed of integral or separate prime mover: kW rev/min

17.4.2.6 Maximum recommended static head: m

17.4.2.7 Recommended angle of installation if not horizontal or vertical: °

17.4.2.8 Rated capacity at maximum efficiency: m^3/h

17.4.3 Results of Performance Tests

17.4.3.1 Summary of Performance Tests Conditions and Results

Test Number					
Date					
Location					
Source of water					
Ambient temperature	°C				
Pump strokes or revolutions per minute					
Static suction head,	m				
Static delivery head,	m				
Total static head,	m				
Total dynamic head,	m				
Discharge rate,	m^3/hour				
Water power,	kW				
Power of prime mover,	kW				
Pump efficiency,	%				

17.4.3.2 Performance curves

Total head/discharge
Speed/discharge
Suction head/discharge
Power input/discharge
Efficiency/discharge

17.4.3.3 Repairs and adjustments and comments made during performance tests

17.4.4 Results of Durability Trials

All test measurements and calculations given in 17.3.3.3.3 and 17.4.3.1 will apply to the durability trials. Comments will be made on repairs and adjustments and times of operation and ease of operation and maintenance of performance.

APPENDIX 17A

Test record sheet
Make and type of pump

Date								
Test number								
Pump speed Rev/min Strokes/min								
Input power,	kW							
Discharge gauge pressure,	$kgf/m^2(Pd)$							
Suction gauge pressure,	$kgf/m^2(Ps)$							
Distance of discharge pressure gauge from reference plane,	m(hd)							
Distance of suction pressure gauge from reference plane.	m(hs)							
Area of discharge pipe,	$m^2(Ad)$							
Area of suction pipe,	$m^2(As)$							
Rate of discharge,	$m^3/s(Q)$							
Density of liquid pumped,	$kgf/m^3(\rho)$							

18 PROCEDURE FOR EVALUATION OF GRAIN THRESHERS

CONTENTS

18.1 Scope 217

18.2 Definitions 217

18.2.1 Classification of Threshers 217
18.2.1.1 Hold-on type 217
18.2.1.2 Throw-in type 217
18.2.2 Moisture Content 218
18.2.3 Grain/Straw Ratio 218
18.2.4 Size of Grains 218
18.2.5 Damage of Grains 218

18.3 Test Procedure 218

18.3.1 Machine for Test 218
18.3.2 Crop Conditions 218
18.3.3 Measuring Equipment 219
18.3.3.1 Power measurement 219
18.3.3.2 Weighing 219
18.3.4 Preliminary Running 219
18.3.5 Performance Tests 219

18.4 Durability Tests 220

18.5 Report 220

18.5.1 Diagram/Photograph 220
18.5.2 Brief Description 220
18.5.3 Specification 220
18.5.3.1 Overall Dimensions 221
18.5.3.2 Weight 221
18.5.3.3 Power Source 221
18.5.3.4 Power Transmission system 221
18.5.3.5 Feeding Arrangements 221
18.5.3.6 Threshing Drum or Cylinder 221
18.5.3.7 Concave 221
18.5.3.8 Sieve(s) 221
18.5.3.9 Blower 221
18.5.3.10 Elevator 222
18.5.3.11 Transport system 222
18.5.3.12 Safety devices 222
18.5.3.13 Output capacity 222
18.5.4 Results of Performance Tests 222
18.5.4.1 Crop 222
18.5.4.2 Summary of test results 222
18.5.4.3 Repairs or adjustments during tests 222
28.5.4.4 Comments and observations 222

APPENDIX 18A Test Data sheets 223

18 PROCEDURE FOR EVALUATION OF GRAIN THRESHERS

18.1 Scope

This procedure is applicable for the evaluation of stationary powered grain threshers.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for the task.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance of the thresher.

18.2 Definitions

18.2.1 Classification of Threshers

18.2.1.1 Hold-on type

A type of thresher where the heads of the cut crop are fed into the threshing drum with the lower part of the straw being manually or mechanically held.

1. Threshing drum
2. Threshing teeth
3. Feeding table
4. Concave
5. Fan (inside)
6. Main grain outlet
7. Immature grain outlet
8. Chaff outlet
9. Cover

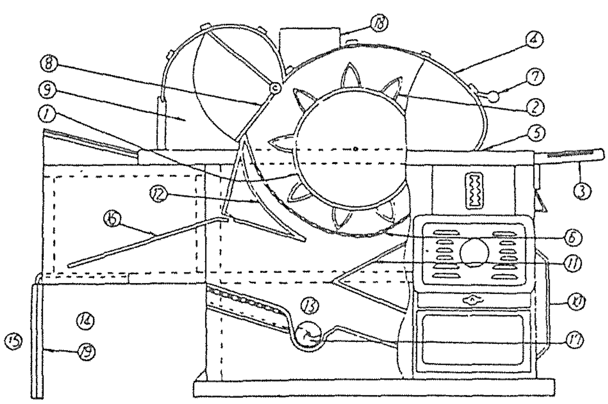


Figure 18.1 Hold-on type threshers
Source: RNAM, 1983

18.2.1.2 Throw-in type

A type of thresher where the cut crops are fed into the machine in full.

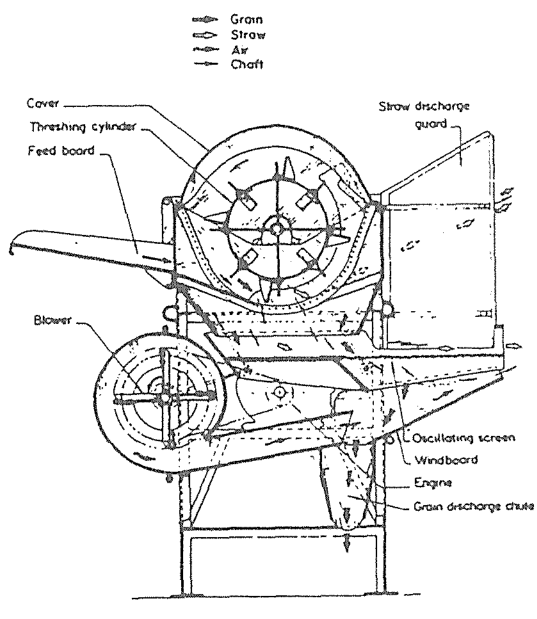


Figure 18.2 Throw-in type thresher
Source: RNAM, 1983

18.2.2 Moisture Content

From the material which is to be threshed, 3 samples are randomly taken of approximately 0.5kg each. The samples are placed in sealed plastic containers and taken to the laboratory where the grains and straw are separated by hand. The straw and grains from each sample are kept paired. After weighing, the samples are oven dried at 130°C for at least 15 hours and then reweighed. The moisture content on dry basis, %:-

$$M = \frac{\text{Weight of wet sample - weight of dry sample}}{\text{Weight of dry sample}} \times 100$$

The mean value is taken as representative of the test sample.

18.2.3 Grain/Straw Ratio

After determining the weight of the dry samples from 2.2, the results of the paired samples are used to calculate the mean grain/straw ratio. The grain/straw ratio :-

$$K = \frac{\text{Weight of dry grain}}{\text{Weight of dry straw}}$$

18.2.4 Size of Grains

From a representative sample of the test material the grains and straw are separated by hand and the size of 50 grains is measured. From these measurements, the average diameter and length is calculated.

18.2.5 Damage of Grains

Prior to the test, 3 samples of 100 grains are inspected for damage and the damage is calculated as a percentage of the total number of grains sampled.

18.3 Test Procedure

18.3.1 Machine for Test

The manufacturer shall supply the machine complete and in working order together with specifications concerning construction, adjustment details and expected performance for various types of crop. Prior to any test work, the manufacturer's specification shall be confirmed and details listed for inclusion in the test report.

a) Overall dimensions and weights
b) Power source and transmission system
c) Details of feeding arrangements
d) Details of threshing unit
e) Type of sieve(s)
f) Details of fan(s)
g) Type of elevator
h) Method of transport
i) Safety arrangements

18.3.2 Crop Conditions

Sufficient quantity of at least 2 varieties of grain shall be provided in order to carry out the complete test series. Samples shall be taken from each batch in order that the following can be specified:-

a) Type/variety
b) Moisture content
c) Grain/straw ratio
d) Grains size
e) Damage of grains.

When the expected throughput of the machine has been established, smaller quantities of the crop are pre-weighed.

18.3.3 Measuring Equipment

18.3.3.1 Power measurement

Means shall be provided to establish the power required to drive the thresher. When an electric motor is used, a torque meter may be fitted into the drive line. If this is not possible, a watt-meter should be used, connected in accordance with the manufacturer's instructions.

When an engine is used, a torque meter may be fitted into the drive line. If this is not possible, tests should be made as outlined in Section 4.3 to establish power in relation to speed and inlet depression, fuel consumption or exhaust temperature. These results may then be used to estimate the power requirement of the machine during the tests.

18.3.3.2 Weighing

Balances of appropriate accuracy for weighing crop and grain samples shall be provided.

18.3.4 Preliminary Running

With the machine set up in accordance with the manufacturers instructions, and the threshing mechanism adjusted for the type of crop, runs are made at various input rates and speeds if applicable. These runs will enable feed rates to be established and allow operators and engineers to familiarise themselves with the operation of the machine.

18.3.5 Performance Tests

Test runs of 30 minutes duration will be carried out using 2 varieties of crop and 3 feeding rates for 3 different thresher speeds if applicable. During the 30 minute test period, 3 samples of threshed grain, straw and chaff shall be taken at their respective outlets. The time over which the sampling is done shall be recorded. Power readings shall also be taken.

Any times for stoppages will be recorded, together with the total testing time. Observations on factors affecting the operation of the machine shall be recorded together with any adjustments and repairs. At the end of the test, the machine shall be operated idle for 2 to 3 minutes to clear residue from the outlets.

The following measurements shall be made. Examples of test record sheets are given in the appendix.

		Units	Symbol
a)	Time of test runs	Mins	T
b)	Weight of threshed grain at main outlet per unit time	kg	B
c)	Weight of threshed grain at all other outlets per unit time	kg	C
d)	Weight of unthreshed grain at all outlets per unit time	kg	D
e)	Weight of damaged grain collected at all outlets per unit time	kg	E
f)	Percentage of damaged grains in total input before threshing	%	F
g)	Weight of whole grains collected at chaff and straw outlets per unit time	kg	G
h)	Weight of all grains (whole, damaged and un-threshed) at chaff and straw outlets per unit time	kg	H
j)	Weight of unthreshed grain at all outlets per unit time	kg	J
k)	Weight of whole grain at main grain outlet per unit time	kg	K
l)	Weight of whole material at main outlet per unit time	kg	L

From the average results of the replications, the following calculations are made.

		Units	Symbol	Calculation
a)	Total grain input	kg	A	B+C+D
b)	Percentage of unthreshed grain	%	N	$\frac{J}{A} \times 100$
c)	Threshing efficiency	%		100 - N
d)	Cleaning efficiency	%		$\frac{K}{L} \times 100$
e)	Increase in percentage of damaged grains	%		$\left[\frac{E \times 100}{A}\right] - F$
f)	Percentage of blown grain	%		$\frac{G}{A} \times 100$
g)	Percentage of grain loss	%		$\frac{H}{A} \times 100$
h)	Threshing recovery	%		$\frac{B}{A} \times 100$
j)	Output capacity	kg/h	W	$\frac{B}{T} \times 60$
k)	Corrected output capacity to standard moisture content (SMC) and standard grain ratio (RS)	kg/h	W_c	$W \times \frac{(100-MC)}{(100-SMC)} \times \frac{RS}{R}$

18.4 Durability Tests

The thresher should be operated for at least 20 hours under load with continuous runs of at least 5 hours. During these tests, particular attention should be made to adjustments, repairs, ease of operation, clogging and maintenance of feed rate.

18.5 Report

18.5.1 Diagram/Photograph

A line drawing and a photograph showing the principal details of the construction and layout of the machine shall be provided.

18.5.2 Brief Description

A brief description shall be provided of the power transmission system, the threshing mechanism and the cleaning arrangements.

18.5.3 Specification

Make:
Model:
Serial No.:
Manufacturers name and address:

18.5.3.1 Overall Dimensions

	For operation	For transport
Length:	mm	mm
Width:	mm	mm
Height:	mm	mm

18.5.3.2 Weight: kg

18.5.3.3 Power Source

Type:
Make:
Model:
Rated output: kW
Rated speed: rev/min

18.5.3.4 Power Transmission system

18.5.3.5 Feeding Arrangements

Type:
Arrangement of mechanical feed:
Length and width of feeding table: mm/mm
Height of feeding table above ground: mm
Feed rate(s): kg/h

18.5.3.6 Threshing Drum or Cylinder

Type:
Diameter: mm
Length: mm
Speed(s): rev/min
Number and size of spikes, pegs or bars:

18.5.3.7 Concave

Type:
Size of opening of concave or slot: mm/mm
Method of clearance adjustment:

18.5.3.8 Sieve(s)

Type:
Number:
Clearance: mm
Slope range: °
Variation in available sizes:

18.5.3.9 Blower

Type:
Number:
Size: mm/mm
Method of changing air volume:

18.5.3.10 Elevator

Type:
Method of drive:
Height of grain spout: mm

18.5.3.11 Transport system

Type:
Number and size of wheels:

18.5.3.12 Safety devices:

18.5.3.13 Output capacity (as specified by manufacturer): kg/h

18.5.4 Results of Performance Tests

18.5.4.1 Crop

Variety:
Moisture content: %
Grain/straw ratio:
Size of grains: mm/mm
Damage to grains: %

18.5.4.2 Summary of test results

Threshing drum speed or setting									
Crop feed rate, kg/h									
Total grain input, kg									
Threshing efficiency, %									
Cleaning efficiency, %									
Increase in percentage of damaged grains %									
Percentage of blown grains %									
Percentage of grain loss %									
Threshing recovery %									
Output capacity kg/h									
Output capacity corrected to % moisture content and standard grain ratio kg/h									
Power requirements, kWh/tonne									
Labour requirements, man h/tonne									

18.5.4.3 Repairs or adjustments during tests

18.5.4.4 Comments and observations

APPENDIX 18A

1. Data sheet for crop samples

		Sample 1	Sample 2	Sample 3
Variety				
Moisture content	%			
Grain/straw ratio				
Size of grains	mm x mm			
Damage to grains				

2. Data sheet for analysis of test samples

Sample No	Feed rate kg/h	Thresher speed rev/min	Sample from	Total mass of sample, kg	Mass, kg			
					Clean grain	Broken grain	Un-threshed grain	Foreign material
			Main outlet					
			Sieve overflow					
			Chaff outlet					

3. Test Data Sheet

Test No.	Date	Starting time h min	Stopping time h min	Duration of test h min	Drive speed rev/min	Feed rate, kg/h	Power requirements kW	Number of samples	Quantity of samples, kg		
									Main grain outlet	Sieve overflow	Chaff outlet

4. Stoppages during test

Test Number:

Time			Reason for Stoppage
From	To	Total	

5. General observations

19 PROCEDURE FOR EVALUATION OF MAIZE SHELLERS

CONTENTS

19.1 Scope 226

19.2 Definitions 226

- 19.2.1 Classification of Shellers 226
- 19.2.1.1 Shellers Without Blower 226
- 19.2.1.2 Shellers With Blower and Sieves 226
- 19.2.2 Moisture Content 227
- 19.2.3 Maize Grains/Spent Cob Ratio 227
- 19.2.4 Cob and Grains 228
- 19.2.4.1 Cobs 228
- 19.2.4.2 Grains 228
- 19.2.5 Damage of Grains 228
- 19.2.6 Size of Cobs 228
- 19.2.7 Size of Grains 228

19.3 Test Procedure 228

- 19.3.1 Machine for Test 228
- 19.3.2 Crop Conditions 228
- 19.3.3 Measuring Equipment 229
- 19.3.3.1 Power Measurement 229
- 19.3.3.2 Weighing 229
- 19.3.4 Preliminary Running 229
- 19.3.5 Performance Tests 229

19.4 Durability Tests 230

19.5 Report 230

- 19.5.1 Diagram/Photograph 230
- 19.5.2 Brief Description 230
- 19.5.3 Specification 230
- 19.5.3.1 Overall Dimensions 230
- 19.5.3.2 Weight 231
- 19.5.3.3 Power Source 231
- 19.5.3.4 Power transmission system 231
- 19.5.3.5 Feeding Arrangements 231
- 19.5.3.6 Shelling Unit 231
- 19.5.3.7 Concave 231
- 19.5.3.8 Sieve(s) 231
- 19.5.3.9 Blower 231
- 19.5.3.10 Maize Outlet 231
- 19.5.3.11 Transport system 231
- 19.5.3.12 Safety devices 231
- 19.5.3.13 Output capacity (as specified by manufacturer) 231
- 19.5.4 Results of Performance Tests 232
- 19.5.4.1 Crop 232
- 19.5.4.2 Summary of test results 232
- 19.5.4.3 Repairs or adjustments during tests 232
- 19.5.4.4 Comments and observations 232

APPENDIX 19a Test data sheets 233

19 PROCEDURE FOR EVALUATION OF MAIZE SHELLERS

19.1 Scope

This procedure is applicable for the evaluation of stationary powered maize shellers.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, and suitability for the task.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance of the sheller.

19.2 Definitions

19.2.1 Classification of Shellers

19.2.1.1 Shellers Without Blower

For a sheller without a blower attachment, the separation of spent cob pieces and husks is done in successive different operations, such as sieving and winnowing.

1. Engine
2. Frame
3. Rasp bar cylinder
4. Concave
5. Transmission
6. Feed hopper
7. Sieve
8. Guard screen
9. Cob guide
10. Concave extension

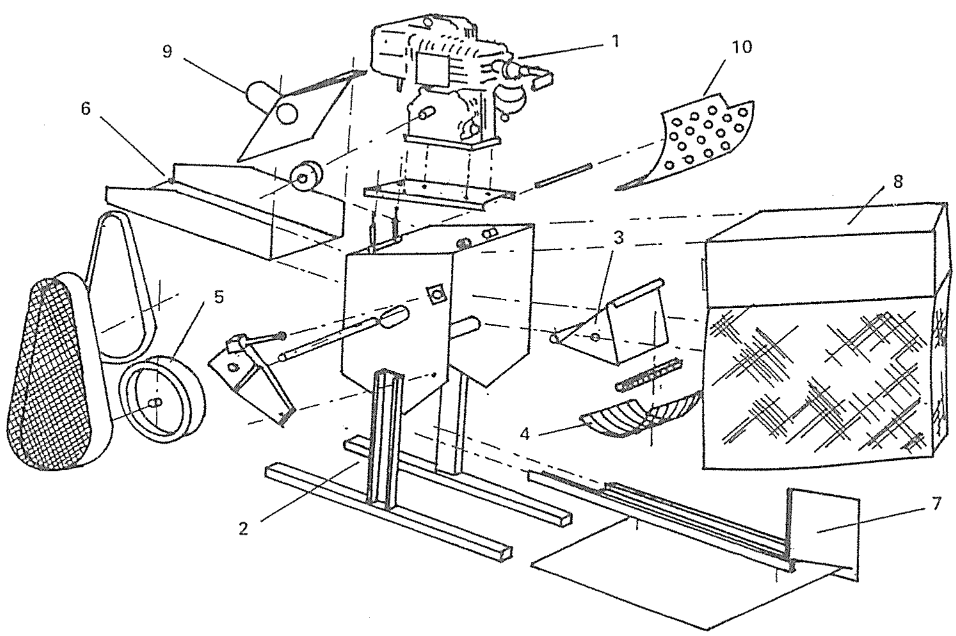


Figure 19.1 Parts of a thresher without blower
Source: Campos Magaña, 1987

19.2.1.2 Shellers With Blower and Sieves

In this type, the small spent cob pieces and husks are blown out at a separate outlet, the larger spent cob pieces are also separated from the grains.

1. Frame
2. Feed hopper
3. Shelling drums
4. Shelling disc
5. Adjustable guides
6. Blower

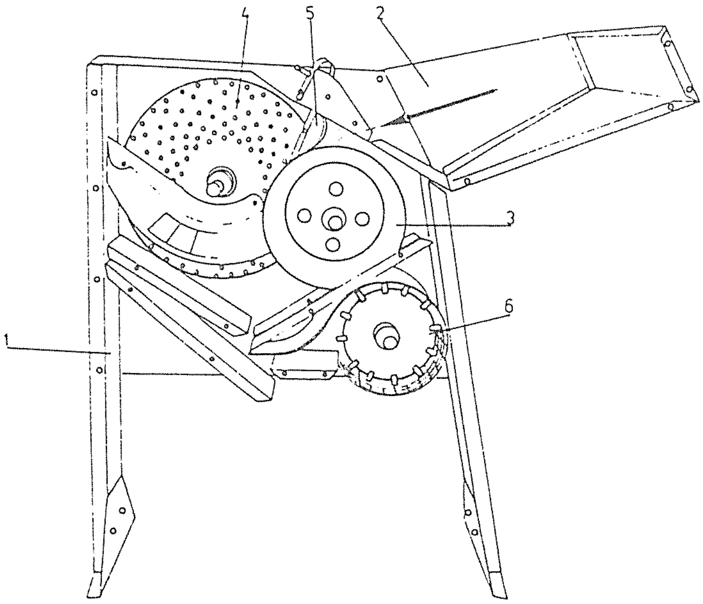


Figure 19.2 Maize sheller with blower
Source: Campos Magaña, 1987

19.2.2 Moisture Content

From the material which is to be shelled, 3 cobs are randomly selected. The samples are placed in sealed plastic containers and taken to the laboratory. After weighing, they are oven dried at 103°C for at least 72 hours and then re-weighed. The moisture content on dry basis, % :-

$$M = \frac{\text{Weight of wet sample - weight of dry sample}}{\text{Weight of dry sample}} \times 100$$

The mean value is taken as representative of the test sample.

19.2.3 Maize Grains/Spent Cob Ratio

After determining the weight of the dry samples from 19.2.2, the cobs and maize grains are manually separated and weighed. The grains/spent cob ratio:-

$$K = \frac{\text{Weight of maize grains}}{\text{Weight of cob}}$$

19.2.4 Cob and Grains

19.2.4.1 Cobs

10 cobs are randomly selected from the test material and weighed to establish the average weight per cob.

19.2.4.2 Grains

After weighing, the cobs are manually stripped and 8 samples of 100 grains are weighed. The average sample weight is multiplied by 10 to establish the 1000 grain weight.

19.2.5 Damage of Grains

Prior to the tests 10 cobs are randomly selected from the test sample and manually shelled. The grains are inspected for damage and the damage is calculated as a percentage of the total number of maize grains sampled.

19.2.6 Size of Cobs

Cob size is the average length and diameter measurement of 10 cobs randomly selected from the test sample.

19.2.7 Size of Grains

Grain size is the average diameter and thickness of 50 grains shelled from randomly selected cobs taken from the test sample.

19.3 Test Procedure

19.3.1 Machine for Test

The manufacturer shall supply the machine complete and in working order together with specifications concerning construction, adjustment details and expected performance for various types of maize crop. Prior to any test work, the manufacturer's specification shall be confirmed and details listed for inclusion in the test report.

a) Overall dimensions and weights
b Power source and transmission system
c) Details of feeding arrangements
d) Details of shelling unit
e) Type of sieve
f) Type of blower
g) Type of elevator
h) Method of transport
i) Safety arrangements

19.3.2 Crop Conditions

Sufficient quantity of at least 2 varieties of maize shall be provided in order to carry out the complete test series. Samples shall be taken from each batch in order that the following can be specified :-

a) Type
b) Moisture content
c) Grains/spent cob ratio
d) Cob and grains weights
e) Sizes of cobs and grains
f) Damage to grains

When the expected throughput of the machine has been established, smaller quantities of cobs are pre-weighed.

19.3.3 Measuring Equipment

19.3.3.1 Power Measurement

Means shall be provided to establish the power required to drive the sheller. When an electric motor is used, a torque meter may be fitted into the drive line. If this is not possible, a watt-meter should be used, connected in accordance with the manufacturer's instructions.

When an engine is used, a torque meter may be fitted into the drive line. If this is not possible, tests should be made as outlined in Section 4.3 to establish power in relation to speed and inlet depression, fuel consumption or exhaust temperature. These results may then be used to estimate the power requirement of the machine during the tests.

19.3.3.2 Weighing

Balances of appropriate accuracy for weighing cobs and grains shall be provided.

19.3.4 Preliminary Running

With the machine set up in accordance with the manufacturers instructions and the shelling mechanism adjusted for the crop, runs are made at various input rates and sheller settings if applicable. These runs will enable feed rates to be established and allow operators and engineers to familiarise themselves with the operation of the machine.

19.3.5 Performance Tests

Test runs of 30 minutes duration will be made using 2 varieties of crop and 3 rates of feeding cobs for 3 sheller drum speeds, if applicable. There shall be 3 replications of each test.

During the 30 minute test period, 3 samples of maize grains, spent cobs and husks are taken at the respective outlets. The time over which the sampling is done shall be recorded. Power readings shall also be taken. Any times for stoppages will be recorded together with the total testing time.

Observations on factors affecting the operation of the machine shall be recorded together with any adjustments and repairs. At the end of the test the machine shall be operated idle for 2 to 3 minutes to clear residue from the outlets.

The following measurements shall be made:

Examples of test record sheets are given in the appendix.

		Units	Symbol
a)	Time of test run	Mins	T
b)	Maize grains per cob	kg	H
c)	Feed rate of cobs per unit time	kg	Q
d)	Weight of shelled grains at all outlets per unit time	kg	B
e)	Weight of shelled grains at main outlet per unit time	kg	C
f)	Weight of grain and residue mixture per unit time	kg	D
g)	Weight of shelled damaged grains at all outlets per unit time	kg	E
h)	Percentage of damaged grains in total cob input before shelling	%	F
j)	Weight of shelled and unshelled grains at cob outlet per unit time	kg	G

From the average results of the replications, the following calculations are made.

		Units	Symbols	Calculation
a)	Total maize grains input	kg	A	Q x H
b)	Shelling efficiency	%		$\frac{B}{A} \times 100$
c)	Cleaning efficiency	%		$\frac{C}{D} \times 100$
d)	Increase in percentage of damaged grains	%		$\frac{(E \times 100)}{A} - F$
e)	Percentage of grains lost at cob outlet	%		$\frac{G}{A} \times 100$
f)	Output capacity	kg/h	W	$\frac{B}{T} \times 60$
k)	Corrected output capacity to standard moisture content (SMC)	kg/h	W_c	$W \times \frac{(100-M)}{(100-SMC)}$

19.4 Durability Tests

The sheller should be operated for at least 20 hours under load with continuous runs of at least 5 hours. During these tests, particular attention should be made to adjustments, repairs, ease of operation, clogging and maintenance of feed rate.

19.5 Report

19.5.1 Diagram/Photograph

A line drawing and a photograph showing principal details of the construction and layout of the machine shall be provided.

19.5.2 Brief Description

A brief description shall be provided of the power transmission system, the shelling mechanism and the cleaning arrangements if provided.

19.5.3 Specification

Make:
Model:
Serial No.:
Manufacturers name and address:

19.5.3.1 Overall Dimensions

	For operation	For transport
Length:	mm	mm
Width:	mm	mm
Height:	mm	mm

19.5.3.2	Weight:	kg
19.5.3.3	Power Source	
	Type:	
	Make:	
	Model:	
	Rated output:	kW
	Rated speed:	rev/min
19.5.3.4	Power transmission system	
19.5.3.5	Feeding Arrangements	
	Hopper size:	mm/mm
	Height of feeding above ground:	mm
	Feed rate(s):	kg/h
19.5.3.6	Shelling Unit	
	Type:	
	Sizes:	mm
	Rated speed(s):	rev/min
19.5.3.7	Concave	
	Type:	
	Range of clearance adjustment:	mm to mm
	Method of clearance adjustment:	
19.5.3.8	Sieve(s)	
	Type:	
	Sizes:	mm
	Slope:	°
19.5.3.9	Blower	
	No. of blades:	
	Dimensions:	mm
	Speed:	rev/mm
	Method of changing air volume:	
19.5.3.10	Maize Outlet	
	Type:	
	Dimensions:	mm
19.5.3.11	Transport system	
	Type:	
	Number and size of wheels:	
19.5.3.12	Safety devices:	
19.5.3.13	Output capacity (as specified by manufacturer):	kg/h

19.5.4 Results of Performance Tests

19.5.4.1 Crop

Maize variety:
Moisture content: %
Grains/spent cob ratio:
Cob and grain weight: g
Cob and grains sizes: mm/mm
Damage to grains: %

19.5.4.2 Summary of test results

Shelling drum speed or setting									
Cobs feed rate, kg/h									
Total maize grain input, kg									
Shelling efficiency, %									
Cleaning efficiency, %									
Increase in percentage of damaged grains %									
Percentage of blown grains %									
Output capacity kg/h									
Output capacity corrected to % moisture content kg/h									
Power requirement, kWh/tonne									
Labour requirement, man h/tonne									

19.5.4.3 Repairs or adjustments during tests

19.5.4.4 Comments and observations

APPENDIX 19A

1. Data sheet for crop samples

		Sample 1	Sample 2	Sample 3
Variety				
Moisture content	%			
Grain/spent cob ratio				
Cob weights	g			
Grain weights	g			
Size of cobs	mm x mm			
Size of grains	mm x mm			
Damage to grains				

2. Data sheet for analysis of test samples

Sample No	Feed rate kg/h	Sheller speed rev/min	Sample from	Total mass of sample, kg	Mass, kg			
					Clean grain	Broken grain	Un-shelled grain	Foreign material
			Main outlet					
			Sieve overflow					
			Blower outlet					

3. Test Data Sheet

Test No.	Date	Starting time h min	Stopping time h min	Duration of test h min	Drum speed rev/min	Feed rate, kg/h	Power requirements kW	Number of samples	Quantity of samples, kg		
									Main grain outlet	Sieve overflow	Cob outlet

4. Stoppages during test

Test Number:

Time			Reason for Stoppage
From	To	Total	

5. General observations

20 PROCEDURE FOR EVALUATION OF COMBINE HARVESTERS

CONTENTS

20.1 Scope 236

20.2 Definitions 236

20.2.1 Classification of Combine Harvesters 236
20.2.1.1 Self-propelled type 236
20.2.1.2 Trailed type 236
20.2.1.3 Specialised machines 236
20.2.2 Grain Output 237
20.2.3 Composition of Mixture 237
20.2.4 Percentage Damage and Impurities 237
20.2.5 Grain Losses 237
20.2.5.1 Pre-cut Loss 237
20.2.5.2 Cutter Bar/Header Loss 237
20.2.5.3 Threshing Loss 237
20.2.6 Moisture Content 238
20.2.7 Straw/Grain Ratio 238

20.3 Test Procedure 238

20.3.1 Machine for Test 238
20.3.2 Specification 239
20.3.3 Field and Crop Conditions 239
20.3.4 Tractors 239
20.3.5 Operators 240
20.3.6 Field Tests 240
20.3.6.1 Preliminary Running 240
20.3.6.2 Quality of Work 240
20.3.6.3 Rate of Work 244
20.3.6.4 Power Requirement 245
20.3.6.5 Fuel Consumption 246
20.3.6.6 Observations 246
20.3.6.7 Performance Tests on Slopes 247

20.4 Report 248

20.4.1 Diagram/Photograph 248
20.4.2 Brief Description 248
20.4.3 Specification 248
20.4.3.1 Overall dimensions 248
20.4.3.2 Weight (including full fuel tank but without driver) 248
20.4.3.3 Power Source 248
20.4.3.4 Range of speeds (self-propelled machines) 249
20.4.3.5 Wheels 249
20.4.3.6 Pick-up reel 249
20.4.3.7 Cutting Table 249
20.4.3.8 Corn Header 249
20.4.3.9 Cylinder Assembly 250
20.4.3.10 Separating mechanism 250
20.4.3.11 Grain Tank 251
20.4.3.12 Accessories provided with test machine 251
20.4.4 Test Conditions 252
20.4.5 Test Results 253
20.4.5.1 Quality of Work 253
20.4.5.2 Performance Rating Curve 253
20.4.5.3 Fuel Consumption 254
20.4.5.4 Power Requirement 254
20.4.5.5 Observations 254

20 PROCEDURE FOR EVALUATION OF COMBINE HARVESTERS

20.1 Scope

This procedure is applicable for the evaluation of self-propelled and trailed combine harvesters for cereals such as wheat, barley and oats.

The procedure also covers specialised machines for harvesting maize or rice or standard machines which have been modified.

The procedure gives explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and suitability for the task.

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance of the harvester.

20.2 Definitions

20.2.1 Classification of Combine Harvesters

20.2.1.1 Self-propelled type

A type of combine harvester where the engine is integral with the machine and provides power for all the threshing processes and for movement.

20.2.1.2 Trailed type

A type of combine harvester where the power for movement is supplied by a tractor. The threshing mechanism may be driven by an engine mounted on the harvester or from the tractor power take-off.

20.2.1.3 Specialised machines

Machines which are designed to harvest specialised crops or standard machines modified by attachments.

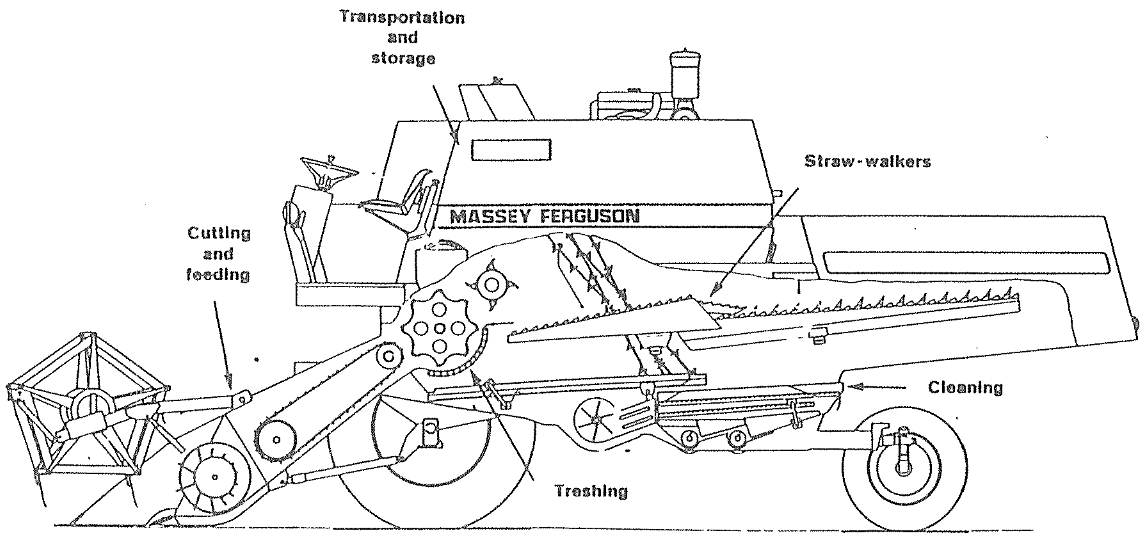


Figure 20.1 Direct cut combine harvester (Massey-Ferguson)

20.2.2 Grain Output

This is the weight of the mixture delivered by the machine per unit of time. (In all machines grain is cleaned at least once by a primary cleaning mechanism to remove impurities such as chaff. In some machines the mixture resulting from this primary cleaning is further graded. In this case the output from the two or more grades must be added together to give the total grain output).

20.2.3 Composition of Mixture

This is defined by the percentage of its weight at harvest moisture content accounted for by the following elements:

a) whole grain without apparent damage.
b) grain with apparent damage (broken, cracked or dehusked).
c) impurities (material other than grain - MOG).

20.2.4 Percentage Damage and Impurities

This will be expressed as a percentage by weight calculated as:

$$\text{Damaged grain or impurities, \%} = \frac{\text{Weight of damaged grain or impurities}}{\text{Total weight of sample including damaged grain and impurities}} \times 100$$

20.2.5 Grain Losses

Grain losses are expressed as a percentage of the machine's grain output as weight per unit area.

20.2.5.1 Pre-cut Loss

This is the grain shed on to the ground before any harvesting takes place. In laid crops, only those heads or grains actually in contact with the ground and with straw unattached to the root will be included with the pre-cut losses.

20.2.5.2 Cutter Bar/Header Loss

This is the grain and heads shed on to the ground as a result of the passage of the cutter bar, corn head and dividers.

20.2.5.3 Threshing Loss

This is the grain lost during the passage of the harvested material through the machine.

20.2.5.3.1 Drum Loss

This is the grain remaining in the ears or husks after passing over the shakers or top sieves.

20.2.5.3.2 Straw Shaker Loss

This is the loose grain passing from the combine with the straw.

20.2.5.3.3 Sieve Loss

This is the loose grain contained in the efflux from the sieves.

20.2.6 Moisture Content

The moisture content of grain samples may be obtained using a proprietary meter.

If this is not available or a more accurate result is required, the following method should be used.

Randomly obtained samples of approximately 500g each are placed into sealed containers and taken to the laboratory.

After weighing, the samples are dried at 110°C for at least 24 hours and then re-weighed.

The moisture content on a wet basis is calculated by the following formula:

$$M\ \% = \frac{\text{Weight of wet sample - weight of dry sample}}{\text{Weight of wet sample}} \times 100$$

20.2.7 Straw/Grain Ratio

This is the mean ratio between the calculated straw and grain yield expressed in weight per unit area.

The straw/grain ratio:

$$K = \frac{\text{Weight of straw per unit area}}{\text{Weight of grain per unit area}}$$

20.3 Test Procedure

The test will be carried out to assess the following features of the machine in a range of crops and harvest conditions which represent as far as possible the majority of conditions normally encountered in the country carrying out the tests.

a) Quality of work.

   (i) Rubbish content.
   (ii) Damage to grain.
   (iii) Losses of grain.
   (iv) Treatment of straw.

b) Rate of work.
c) Fuel consumption and power requirement.
d) Machine behaviour under all conditions.
e) Conditions and convenience for operator(s) including noise levels.
f) Ease of adjustment and routine maintenance.

20.3.1 Machine for Test

The manufacturer shall supply the machine complete and in working order together with specifications concerning construction, adjustment details and expected performance in various types of crop. Additional attachments required for specialised crops shall be supplied.

20.3.2 Specification

Prior to any field test work, the manufacturers specification shall be confirmed in respect to the following items:

a) Overall dimensions and weights.
b) Power source and transmission system.
c) Type and dimensions of pick-up reel, cutter table or corn header.
d) Details and settings of threshing drum assembly.
e) Details of separating mechanisms.
f) Details of fans and speeds.
g) Type(s) of elevator(s).
h) Position and size of grain tank.
i) Details and dimensions of delivery spout and auger.
j) Details of operator controls and driving position.
k) Arrangements for transport.
l) Safety arrangements.

A complete specification will be given in the report.

20.3.3 Field and Crop Conditions

The performance of combine harvesters will vary considerably according to the type and condition of the crop and the topography and soil condition of the field.

Harvesting should be carried out in at least five different fields. The aim will be to attempt to harvest crops under "average to good" conditions and in addition, to attempt work in each crop under bad conditions (laid and weedy crops).

It is important that the range and variety of crops covers those important to the country concerned.

For each field, the following conditions will be recorded and stated in the test report:

a) Atmospheric conditions.
b) Shape and size of plot.
c) State of ground
d) Slope of ground.
e) Type of crop.
f) Variety of crop.
g) Condition of crop.

Fields selected for the main performance and rating tests should be fairly flat and free from serious surface irregularities.

If the stability of the machine will allow, tests may be carried out in fields with slopes up to 20% to assess the handling characteristics and any influence on threshing losses. A crop in good condition for harvesting will be chosen for this work.

20.3.4 Tractors

If a tractor is required to power and/or pull the machine, it should have the weight and power output in accordance with the recommendations of the combine manufacturer.

If the manufacturer does not specify limits for the performance of the tractor, the officer in charge will choose a tractor which has ample power available and which is capable of getting the best out of the combine.

20.3.5 Operators

Operators of tractors or combines should be highly trained and be familiar with the operation of the types of machines undergoing tests.

20.3.6 Field Tests

20.3.6.1 Preliminary Running

With the machine set up in accordance with the manufacturer's instructions and the cutting and threshing mechanisms adjusted for the type of crop, runs will be made at various speeds.

These runs will enable operators and engineers to familiarise themselves with the operation of the machine and to check that settings are satisfactory.

20.3.6.2 Quality of Work

Quality of work done by the combine may be assessed by obtaining, by sampling, the amount of grain without damage and without rubbish for any given crop or field condition.

20.3.6.2.1 Drawing the Grain Sample

During a full day's work in one crop three 500g samples will be taken. Assuming approximately 5-8 hours elapse from the start of the operation to the finish, the samples will be taken periodically as follows:

Sample I, one hour after starting work,
Sample II, the middle of the working period,
Sample III, one hour before the end of work.

When a shorter period is worked, say 4 hours, Samples I and III will be sufficient, and, for a short afternoon period, Sample II will suffice.

The moisture content of the grain will be quoted as the mean of these samples unless a very great change in moisture content - affecting other results - occurs during the combining period in which event they will be recorded separately.

Each 500g sample will be drawn from a larger amount of grain collected normally during one complete round of the field. The observer will ride on the machine and repeatedly fill a sample bottle by placing it in the stream of grain which is entering the sacks or tank. Thus the bulk sample will be drawn continuously, except for the time required to empty the bottle into a sack or other container also carried by the observer. The observer should move the bottle about in the grain stream to avoid any bias which might otherwise result.

In crops where moisture content or rubbish are likely to be extremely variable it is advisable to continue to draw grain from the combine during a second round of the field.

When the bulk sample has been drawn it will be immediately reduced in proportions by means of a sample divider (Fig 4.41) until it can be sealed in a 500g sample bottle. The bottle will be labelled with the field index letter, the date and the time.

20.3.6.2.2 Determination of Moisture Content

The moisture content of the 500g samples will be obtained as outlined in paragraph 20.2.6

If a proprietary meter is used the required proportion of the 500g sample will be obtained and ground for moisture determination.

Moisture determinations will be made within 24 hours of the time when the sample was drawn. If in this time any condensation has occurred on the walls of the bottle, it should be shaken well to return the moisture to the grain.

The moisture content of the grain is measured as a step towards the definition of conditions, and in view of this it should be noted that the moisture content can be considerably increased by the operation of combining.

20.3.6.2.3 Rubbish Content and Grain Damage

Using a sample divider, the 500g sample will be divided into four parts. One quarter being retained for rubbish and damage analysis, the results being expressed on a weight basis. Any green material should be allowed to dry for 48 hours before it is weighed. Artificial drying is not required, the sample merely being allowed to dry in a warm room.

Damaged grains and rubbish are separated by hand in the laboratory.

20.3.6.2.4 Estimation of Grain Losses

The methods described below will be used when the Officer in Charge of the test is satisfied that the combine is operating at its best. Similar spot checks will be made in arriving at this setting, but for obvious reasons these results will not be reported. In all cases the points where sampling is to take place will be randomly chosen but will be located in representative regions of the field.

Method 1 - Continuous Collection

This method can only be used when a re-thresher unit is available.

The unit (Fig 4.45) enables the efflux from the straw shakers and the sieves of the test combine to be re-processed and any grain remaining in the ears or husks to be re-threshed.
Loose grain is collected within the machine and weighed to assess the percentage losses attributed to various parts of the combine being tested.

Many combines deliver the chaff and the straw in two separate streams at the rear of the machine, but if a particular machine does not separate the two streams, a simple deflector board should be fitted to effect the separation during the period of the test. This modification is necessary whichever method of loss determination is used.

In making a determination of the losses, two large sheets (3m x 4m approx, Fig 4.43) are held under the rear of the machine, as it is operating, in such a position that one sheet catches the sieve efflux and the other the straw shaker efflux. In order to spread the sheet fully, a wooden batten should be fixed to the front and rear of each sheet. A length of swath representing approximately 50 m^2 of combining will usually be a convenient amount to collect and such a length should be approximately marked out with sighting poles.

Loss determinations will only be attempted when the combine is operating steadily. The sheets should not be inserted shortly after a stop, when the threshing mechanism may not be fully loaded. It is probable that about 50 metres running is required to build up the load.

As the test plot is approached the combine driver will be instructed to drive well into the uncut crop so that a narrow band (say 25 cm) of the crop is left standing (see Fig 20.2). Missing the strip ensures that a full width swath is harvested. During routine field work the 25 cm strip will not be left uncut, and in this case the width cut will be determined by measuring across ten swaths, that is the distance from the centre of one swath to the centre of the tenth one from it. This distance will be measured at not less than ten points in different parts of the field.

A Calico sheet for straw walker efflux
B Calico sheet for sieve efflux
C Tripod and balance
D Distance representing 1/200 ha
E Swath
F Wire rectangles for cutter bar losses
G Second rectangle to locate "half width" rectangle at left of cut width
H Entry point
I Length of test run
J Straw walkers
K Sieve
L Deflector
X Stakes
W Width of cut
Y Uncut strip (25 cm approx)

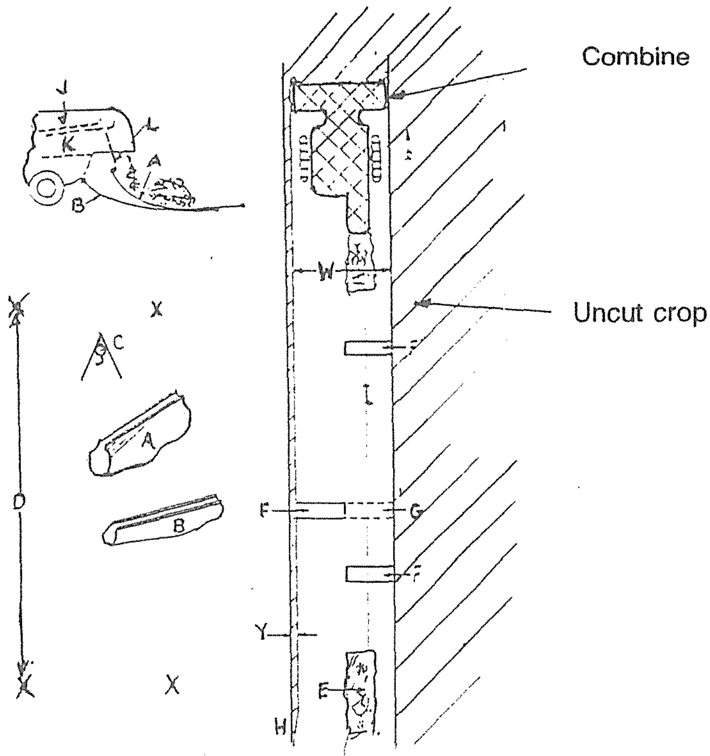


Figure 20.2 Continuous collection methods to determine combine losses
Source: Hebblethwaite, 1955

One of the observers carrying the sheets, will signal for their insertion at approximately the start of the 50 m^2 plot and at the same time start a stop-watch. When the end is approached, or when there is sufficient straw on the sheets, he will signal for their removal and stop the watch.

The length of the gap in the swath caused by removing the straw will be measured (it is regarded as the length of the plot). The width of the plot is the full width of the cut. The time taken will normally be recorded, although on certain occasions it may be more convenient to measure the speed of the machine in another part of the field. The weight of straw and chaff collected will be recorded.

To separate the individual grain losses, a re-threshing unit (a modified thresher) will be used as follows.

Straw sample The straw will be fed slowly on to the **straw walkers** of the re-threshing unit, and the loose grain which is shaken out will be retained in an envelope. This grain is the "Straw shaker loss" and is retained for subsequent final cleaning and weighing.

The straw will then be fed through the **drum** of the unit. The grain obtained is the "Drum loss" (unthreshed heads) and should be retained for weighing as before.

Chaff sample The chaff will be fed on to the **straw walkers** of the re-threshing unit. The grain separated will be recorded as "Sieve losses". Unthreshed heads passing over the rear of the re-threshing unit will be put through the **drum**, and the grains threshed out will be added to the "Drum loss" envelope. Replication of this sampling procedure is very desirable, but the exact number of replications will depend largely upon conditions and time available. In a crop having both laid and standing portions, each area will be sampled separately.

Method 2 - Determination on trays

This method will only be used when the continuous collection method cannot be used for practical reasons; the latter method is more reliable but requires more complicated equipment.

Two observers will normally remain with the combine, one primarily responsible for the time record, the other for the loss determinations. Replications should be numerous (at least 10 should be the aim in a normal field) and the location of the sampling points chosen should be representative of the whole field (if portions are laid the losses in the laid portions should be sampled separately).

As the combine passes the sampling point, the observer will place a tray (see Appendix Fig 20.3) on the stubble before the efflux from the rear of the combine reaches the ground at this point. In this case the deflector, previously mentioned, serves to direct the stream of sieve efflux to the tray before the straw shaker efflux; the classification of losses is based upon the assumption that there are two distinct layers of material which can subsequently be separated. After the passage of the combine, the swath will be separated so that the length on the tray represents the tray's exact width. This piece of swath will be lifted gently on to another tray and examined by hand for unthreshed heads. These heads will be placed in an envelope for subsequent threshing and weighing as "Drum losses (Fig 4.44)". Any grains remaining on the second tray after the careful removal of the straw will be retained as "Straw shaker losses". The material on the first tray will be sorted: the unthreshed heads will be placed with the drum losses; the grains will be placed in an envelope marked "Sieve losses".

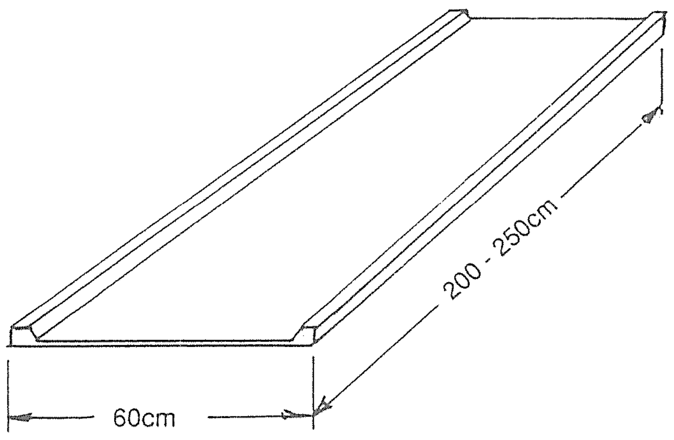


Figure 20.3 Straw collecting tray made from wood and hessian

The envelopes containing the impure grain will be cleaned and weighed in the laboratory; and the area which these represent will be calculated from the mean cutting width which will be determined as a matter of course in each field. No attempt should be made to separate individual grains in the field for this can be done much more rapidly in the laboratory.

20.3.6.2.5 Determination of cutter bar and pre-cut losses

Cutter bar loss is the grain and heads shed on the ground as a result of the passage of the cutter bar and dividers.

If the continuous collection method is used for threshing loss determination, the cutter bar loss will be determined on those portions of the ground which are protected from the combine efflux by the use of the sheets. A wire rectangle should be used to mark a piece of ground from which the grain will be collected by hand (Fig 4.42). The rectangle should measure 30 cm in the direction of travel of the combine and should represent either half the width, or the full width of the combine in the other direction (depending upon the size of the machine). At a sampling point, the rectangle will be located with its short side against the uncut crop and all grains and heads which lie in the stubble within this area will be placed in an envelope marked "Cutter bar + pre-cut loss". (If the half-width rectangle is used it should be located first at the right-hand, and then at the left-hand extremity of the width of cut: see Fig 20.2 for explanation).

If the tray method has been used for threshing loss determination, the rectangle is used in the same way except that in this case it is located where a tray has protected the stubble from combine efflux.

In collecting the grains from the ground it will be clear that shedding or pre-cut losses have been included, and because of this a similar number of determinations of pre-cut losses (using the same rectangle as before) must be made on the uncut crop (with the precautions previously mentioned being observed for partially laid or weedy crops). In laid crops, only those heads or grains actually in contact with the ground and with straw unattached to the root will be collected and included with the pre-cut losses.

From 10 to 15 replications in each field of both the pre-cut and cutter bar loss determinations are necessary to obtain a reasonable estimate.

20.3.6.2.6 Treatment of straw

In each of the crops harvested, note will be taken of the treatment and placing of the straw swath.

20.3.6.3 Rate of Work

During the field work, a continuous record will be kept of the operating time, turning time and idle time.

In addition to those factors required for the actual calculation of rates of work, certain items which define more closely the particular working conditions and the settings of the machine will be noted.

Upon entering each field any opening-out rounds which have to be done at reduced speed will be made, and the initial setting of the machine will be carried out. These operations will not be included in the time-recorded period, the recording starting only when the officer in charge is satisfied that the machine is operating satisfactorily, and finishing when the field is completed.

The mean speed of travel will be calculated for each field, using the area, the width of cut and the net time (already determined).

20.3.6.3.1 Estimate of crop yield

At a signal from the time recording observer, the bagging operator will start filling a new bag, and at the same time the observer will start following the combine with a distance measuring wheel. That particular bag will be labelled or marked, and each subsequent bag will be labelled until a complete round of the field has been made. The observer will then record the distance travelled, and will weigh the output of grain. This process will be repeated on three or four occasions during the combining of the field.

In the case of combines fitted with a grain tank, an observer will generally be able to ride in the tank and bag off the grain during the sampling rounds of the field.

20.3.6.3.2 Procedure for rating the combine

The following procedure may be used to determine a rate of working figure which can be directly compared with a similar figure for other machines.

It is important that the manufacturer's recommendations should be followed in order to obtain the optimum setting for each field.

When such a setting has been obtained, a number of 50 m^2 plots will be harvested in the way described in paragraph 20.3.6.2.4., 'Estimation of Grain Losses', with each run being made at a different speed.

The slowest run will be made at a little less than the estimated optimum speed, and subsequent runs made at speeds increased by steps of 0.5 km/h (or other convenient interval) until some limiting factor, e.g. drum blockage or excessive losses, indicates that the optimum speed has been passed. (In the case of a p.t.o.-driven machine the range of speed which can be used will be strictly limited and in this instance the adaptation of this part of the test must be left to the discretion of the Officer in Charge of the test).

During each run the following points will be recorded.

1. Weight of straw and chaff, i.e. throughput.
2. Time to complete plots.
3. Area of plot.
4. Throughput of grain-weight (the grain may be collected from the actual plot, or if more convenient when the combine next passes the measured run representing 50 m^2, i.e. distance "l" Fig 20.2). Care should be exercised to avoid an error due to the grain held back by the shutter of the bagging spout.
5. A sample of the grain will be drawn and analysed for:
   moisture content,
   rubbish content,
   damaged grain.
6. Grain losses including cutter bar and pre-cut loss (three cutter-bar loss determinations per plot are suggested).
7. Height of standing crop and of stubble.
8. Condition of the crop and weather conditions.
9. The exact nature of the limiting factor when it occurs.

From this information a curve (Fig 4.46) - straw throughput (kg/ha) against total threshing losses, kg/ha will be obtained. It is on this basis that machines can be compared in terms of rate of straw throughput at some arbitrarily chosen threshing loss (e.g. 100 kg/ha).

Replication of this work is desirable if time permits.

20.3.6.4 Power Requirement

In many cases, it is useful to establish the power requirement of the combine when working in various crops and conditions.

20.3.6.4.1 Engine Driven Machines

When the combine has its own engine, tests should be made as outlined in Section 4.3 to establish the engine power in relation to fuel consumption or exhaust temperature. These results may be used to estimate the power requirement of the machine during tests in the field.

20.3.6.4.2 Trailed Machines

For trailed machines, the draft will be measured at various speeds and field and crop conditions. A dynamometer shall be inserted between the tractor drawbar and the machine. Readings should be taken in opposite directions in the field to eliminate the influence of any slope.

The average pull will be reported.

20.3.6.4.3 Power take-off driven machines

If possible, a dynamometer should be placed in the power take-off drive line to enable torque and speed measurements to be made. These measurements should coincide with measurements of drawbar pull.

20.3.6.5 Fuel Consumption

When measuring fuel consumption as part of the power measurement in Section 20.3.6.4, a proprietary meter should be fitted into the fuel line between the tank and the engine.

For runs of greater duration, an auxiliary tank which can be switched into the combine's fuel system should be used. The tank should be so attached to the machine that it can be removed and weighed at the beginning and at the end of the time-recorded period and whenever it is refilled.

If the use of an auxiliary tank is impracticable, fuel consumption may be measured by filling the engine fuel tank completely at the start and finish of each time-recorded period and weighing the quantity of fuel added.

20.3.6.6 Observations

The following lists are designed to complement the recordings made during test runs proper in order to provide further information on the characteristics of the machine.

The items listed are only for guidance and actual observations reported will be the responsibility of the Officer in Charge.

20.3.6.6.1 Machine behaviour

(In general the more important behavioral characteristics will relate to the machine's ability to work under conditions which are in one or more respects difficult).

Cleanness of picking-up.
Occurrence of blockages.
If blockages of drum etc. occur - ease of clearing.
Emptying of moist or wet grain from grain tank.
Adequacy of engine's power and suitability of governor.
Abnormal losses or leakage of grain on sloping ground.
Stability and ease of control.
Adequacy of engine and cooling system air cleaners.
Speed of response (cutting table or header lift, etc.)
Any constructional features that limit performance such as "bottlenecks" and lack of adjustment.

20.3.6.6.2 Conditions and convenience for the operator(s)

Ease of access to driving position.
Accessibility and ease of operation of controls from driver's seat, e.g. steering wheel, gear lever, forward speed control, cutting table reel and header controls, drum speed adjustment, brakes.
Adequacy and visibility of instrumentation.
Visibility of cutter bar and dividers, grain circuits, contents of grain tank, both by daylight and at night by artificial lights on the machine.
Adequacy of road lighting.
Seating comfort, vibration, shade, exhaust heat, dust, provision of cab.

20.3.6.6.3 Ease of adjustment and routine maintenance

Observations under this heading should not be made until the operators are familiar with the work involved.

Adjustment, e.g. drum speed adjustment, drum/concave clearance checking and altering, speed and position of reel, changing sieves, fan speed and aperture, de-awner.
Changing from transport to field position.
Difficulties caused by superstructure when passing under bridges or through doorways, for example.
Cleaning out combine.

Cleaning grain circuits, for example when working on seed crops.
Cleaning stone trap.
Cleaning air filters.
Refuelling (including period of work possible on one tank full).
Time required for greasing and accessibility and number of grease points.
Number of different oils used.
Accessibility of engine for routine maintenance, dip stick, oil and water filling and draining holes, fan belt tension adjustment .
Accessibility of hydraulic master cylinder and reservoir.
Fitting auxiliary equipment, e.g. crop lifting fingers.
Adequacy of instruction book.

20.3.6.6.4 Labour requirement

The labour requirement can be sub-divided under two main headings:

(i) for the machine at work, which will be measured in terms of hectares per man hour, etc. and requires only that the observer notes the number of men employed on the machine, and
(ii) for the machine at rest, which requires a record of the number of men involved in all maintenance and adjustment, and, in addition, where they occur outside a time-recorded period, the timing of each operation. The observer will also note the extent of the skill and effort required to carry out these operations.

20.3.6.6.5 Repairs and modifications

Any repairs or modifications found to be necessary during the tests will be recorded together with any recommendations for changes in design or manufacture.

20.3.6.7 Performance Tests on Slopes

These tests will be carried out to investigate the influence of slopes on grain losses and handling characteristics.

Tests will be carried out on slopes up to 20% (1 in 5 or 11^{o}), however, steeper slopes may be used at the discretion of the officer in charge.

The work will be done after preliminary investigations to determine whether the machine is sufficiently safe from the point of view of stability, brakes, etc. The work will be carried out in one or more cereal crops selected by the station; one such will be a crop in good condition for harvesting. Four machine attitudes can be examined in the same crop:

1. Machine inclined to the right
2. Machine inclined to the left
3. Working downhill
4. Working uphill

The handling characteristics will first be examined briefly in all four attitudes and any grain leakage from the body of the machine will be noted. For many machines it will be possible to confine detailed loss measurements to two of the above four attitudes, after preliminary work has been carried out.

Runs 1 and 2 should be carried out alongside or close to each other and so should runs 3 and 4.

Clearly all runs cannot be carried out at a wide range of forward speeds, but they should at least be done at speeds close to the "optimum" (maximum throughput consistent with acceptable level of grain loss) for the flat areas of the field.

To ensure that the combine circuits are filled to equilibrium prior to entering the test run (length), the field should have a length such that a sufficient run-in can be arranged on land having a slope similar to that in the test run. In all other respects the test runs will be similar to those described in the procedure on flat land.

In addition, tests on undulating ground will be carried out.

Complete loss measurement runs cannot usually be carried out on undulating land, but the results of visual observations under such conditions should be included if possible.

20.4 Report

20.4.1 Diagram/Photograph

A line drawing and a photograph showing the principal details of the construction and layout of the machine shall be provided.

20.4.2 Brief Description

A brief description shall be provided to include the power unit and drives, cutter, header and drum feed, threshing and separating mechanisms and grain handling arrangements. Methods of transport and safety features will be included.

20.4.3 Specification

Make:
Model:
Serial No.:
Manufacturers' name and address:
Year of manufacture:

20.4.3.1 Overall dimensions

Overall width	- in work	m
	- transport	m
Overall length	- without dividers	m
	- with dividers	m
Overall height		m
Minimum ground clearance		mm

20.4.3.2 Weight (including full fuel tank but without driver)

Total	kg
- on left-hand wheel (traction if self-propelled)	kg
- on right-hand wheel (traction if self-propelled)	kg
- on steered wheels (self-propelled machines)	kg
- on drawbar (trailed machines)	kg

20.4.3.3 Power Source

Manufacturer	
Model	
Governed speed (nominal)	rev/min
Power (manufacturer's nominal figure)	kW

20.4.3.4 Range of speeds (self-propelled machines)

1st gear	km/h
2nd gear	km/h
3rd gear	km/h
Reverse	km/h

20.4.3.5 Wheels

Front wheels	- track width, centre to centre	mm
	- tyre size	
Rear wheels	- track width, centre to centre	mm
	- tyre size	
Wheel base		m
Brakes (type)		

20.4.3.6 Pick-up reel

Type		
Number of tine bars		
Diameter		mm
Range of speeds		rev/min
Range of adjustment	- fore and aft	mm
	- vertical	mm
Maximum distance above knife		mm

20.4.3.7 Cutting Table (Fig 20.4)

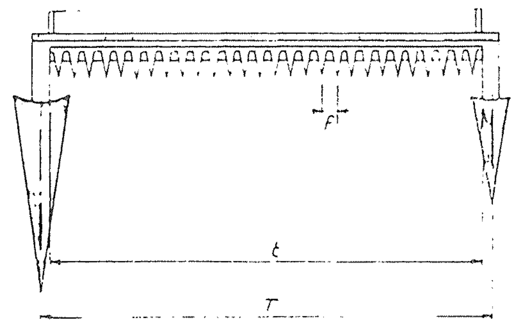


Figure 20.4 Cutter bar
Source: OECD, 1967

Distance from cutter bar to front end of feed auger drum	mm
Effective cutter bar width (t)	m
Working width (T)	m
Knife finger spacing (f)	mm
Knife stroke (amplitude)	mm
Cycles per minute	
Range of cutting heights	mm

20.4.3.8 Corn Header

Row spacing	mm
Range of cutting heights	mm
Speed of pick-up driver	mm/min

20.4.3.9 Cylinder Assembly (Fig 20.5)

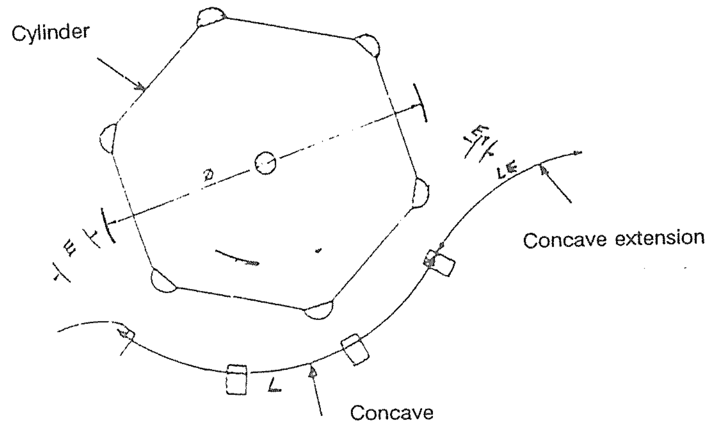


Figure 20.5 Cylinder and concave
Source: OECD, 1967

Cylinder	-	width	mm
	-	diameter (including bars) ϕ	mm
	-	speed range	rev/min
	-	number of bars	
Concave	-	range of clearance	
	-	(E)	mm
	-	(E_1)	mm
	-	number of bars	
	-	area	mm^2
	-	area of extension	mm^2

20.4.3.10 Separating mechanism

Straw shakers (Fig 20.6)

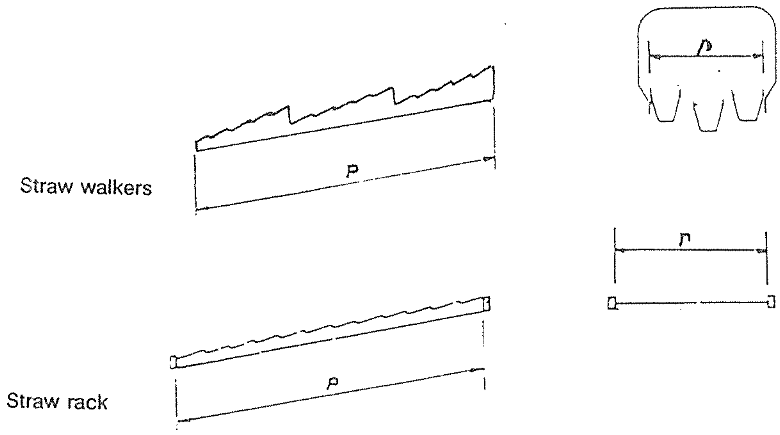


Figure 20.6 Straw walkers/rack
Source: OECD, 1967

number of walkers (or rack)	
length and width of one walker	mm
straw shaker area (s)	mm^2
oscillations per minute	
lift and throw	mm
type of extension	

Cleaning sieves (Fig 20.7)

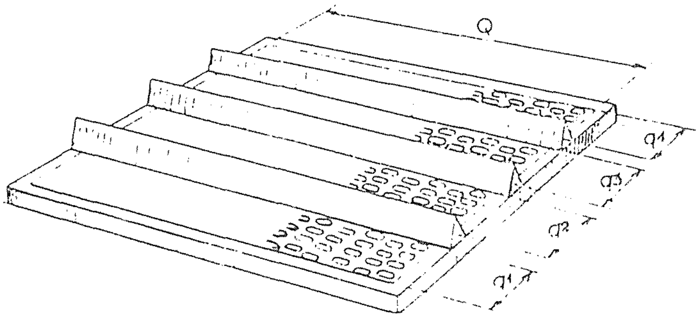


Figure 20.7 Sieve
Source: OECD, 1967

area of top sieve (s)	mm^2
sizes of top sieves	mm
additional area of extension	mm^2
area of bottom sieve (s)	mm^2
sizes of bottom sieve	mm
oscillations per minute	

20.4.3.11 Grain Tank

Capacity	m^3
Horizontal "reach" of emptying auger	m
Clearance beneath grain delivery spout	m

20.4.3.12 Accessories provided with test machine

20.4.4 Test Conditions

				Units		
Date						
Field No.						
Run No.					1	2
Atmospheric conditions	Temperature					
	Relative humidity			%		
Field conditions	Slope if greater than 3%			%		
	State of ground					
Crop conditions	Name and variety					
	Appearance (standing, bent, laid flat on the soil)					
	Type of weeds					
	Extent of weeds (sparse, average, dense)					
	Total length of straw from ground level (including ears)			mm		
	Threshed straw moisture content (wet basis)			%		
Adjustments	Clearance between drum and concave front/rear			mm		
	Drum speed			rev/min		
	1st Cleaning	Top sieve	Type			
			Size of holes ϕ	mm		
			Length of extension	mm		
			Perpendicular distance between lips (adjustable sieve only)	mm		
		Bottom sieve	Type			
			Size of holes ϕ	mm		
		Fan	Speed	rev/min		
			Position of shutters and deflectors			
	2nd Cleaning (if used)	Position of tailings return outlet				
		First screen	Size of holes ϕ	mm		
		Second screen	Size of holes ϕ	mm		

20.4.5 Test Results

20.4.5.1 Quality of Work

<table>
<tr><td colspan="3">Field No.</td><td>Units</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Run No.</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="3">Forward speed</td><td>km/h</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Length of stubble</td><td>cm</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Output per unit area</td><td colspan="2">Grain</td><td>kg/ha</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Straw</td><td>kg/ha</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Output per hour</td><td colspan="2">Grain</td><td>kg/h</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Straw</td><td>kg/h</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Straw/grain ratio</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Proportion of grain coming from principal outlet*</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Composition of mixture</td><td colspan="2">Whole grain</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Damaged grain</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impurities</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Moisture content of mixture (wet basis)</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Grain losses</td><td colspan="2">Drum losses</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Loose grain losses</td><td>Straw walker</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sieve</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total losses</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total losses per unit area</td><td>kg/ha</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Width of straw swath</td><td>m</td><td></td><td></td><td></td><td></td></tr>
</table>

* Machines with second cleaning only

20.4.5.2 Performance Rating Curve

The relationship between output of straw and chaff and the loss of grain will be shown graphically, the loss of grain being presented as a function of the output of straw and chaff. The individual point results from each test run will be shown on the graph together with any curve it may be possible to fit. (See Fig 4.46)

20.4.5.3 Fuel Consumption

Field	Run No.	Crop	Fuel consumption	
			Litres/hour	Litres/hectare

20.4.5.4 Power Requirement

Field	Run No.	Operating conditions	Power consumption, kW

20.4.5.5 Observations

20.4.5.5.1 Machine Behaviour

20.4.5.5.2 Conditions and Convenience for Operators

20.4.5.5.3 Ease of Adjustment and Routine Maintenance

20.4.5.5.4 Labour Requirement

20.4.5.5.5 Repairs and Adjustments During Tests

20.4.5.5.6 Performance on Slopes

Losses on sloping land.

Average slope	Speed, km/h	Net throughput, t/ha		Grain Losses, kg/ha			
		Straw	Grain	Drum	Shaker	Sieve	Total

21 PROCEDURE FOR EVALUATION OF ANIMAL CARTS

CONTENTS

21.1 Scope 256

21.2 Definitions 256

21.2.1 Examples of types of carts 256
21.2.2 Unladen mass 257
21.2.3 Laden mass and weight and rated load 257
21.2.4 Draft force 257
21.2.5 Pull force 257
21.2.6 Rolling resistance 258
21.2.7 Coefficient of rolling resistance 258
21.2.8 Maximum draft 258

21.3 Test Procedure 258

21.3.1 Preliminaries 258
21.3.1.1 Cart for test 258
21.3.1.2 Draft animals 259
21.3.1.3 Yokes 259
21.3.1.4 Tyres 259
21.3.2 Test procedure to establish the coefficient of rolling resistance on a hard surface . 259
21.3.3 Test procedure for strength/impact tests 259
21.3.4 Haulage tests 260
21.3.5 Trials on farms 261

21.4 Test Report 261

21.4.1 Diagram/Photograph 261
21.4.2 Specification 261
21.4.2.1 Brief description of cart: 261
21.4.2.2 Type and number of animals required 261
21.4.2.3 Manufacturer's recommended loading capacity: 261
21.4.2.4 Overall dimensions 261
21.4.2.5 Mass 261
21.4.2.6 Details of components 261
21.4.3 Results of tests 262
21.4.3.1 Track tests 262
21.4.3.2 Strength/Impact test 263
21.4.3.3 Haulage tests 263
21.4.3.4 Trials on farms 263

21 PROCEDURE FOR EVALUATION OF ANIMAL CARTS

21.1 Scope

This procedure is applicable for the evaluation of various types of animal carts. It includes explanations of definitions, terms and general testing procedures and prescribes the items to be measured and examined for evaluation of performance, working capacity and use in various conditions. Procedures are included for:

- assessment of draft and coefficient of rolling resistance on a standard test track
- quality of construction and vehicle strength
- field tests in on-farm conditions including: slope capability, handling and soft ground performance

It will be the responsibility of the Test Engineer to decide which measurements should be recorded to best judge the performance and suitability of the cart.

21.2 Definitions

21.2.1 Examples of types of carts

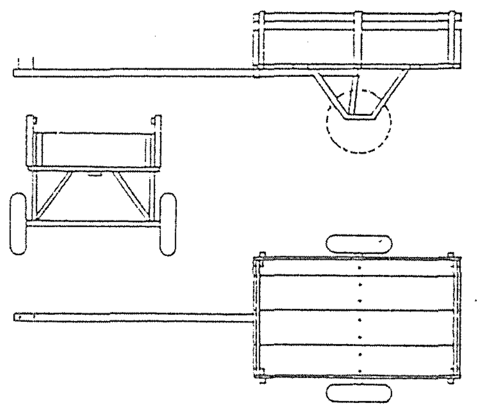


Figure 21.1 Pneumatic tyred cart for a pair of animals
Source: Starkey, 1989

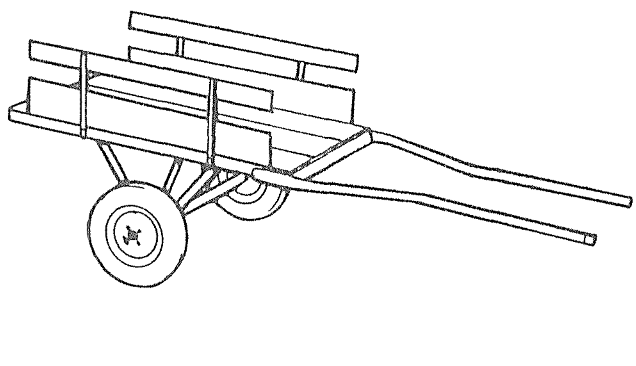


Figure 21.2 Twin shaft cart for single animals (Apicoma, Ouagadougou, Burkina Faso)
Source: Carruthers and Rodriguez, 1992

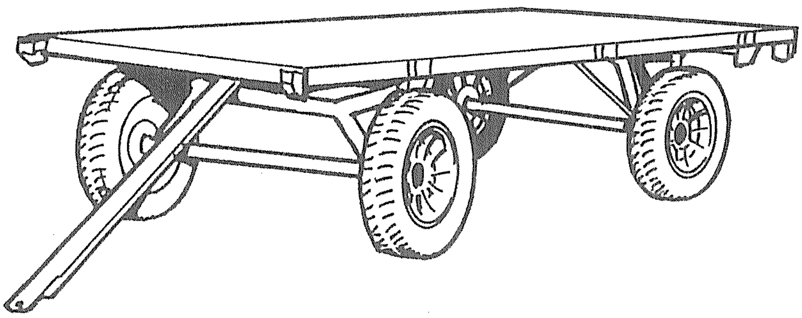


Figure 21.3 Four wheel cart (Coloso, S.A,, Santiago, Chile)
Source: Carruthers and Rodriguez, 1992

21.2.2 Unladen mass

The mass of the empty cart, without any load, operator or animal(s).

21.2.3 Laden mass and weight and rated load

Laden mass is the mass of the cart with loaded material including a mass of 75 kg for the operator but without the mass of the animal(s). The laden weight is the weight corresponding to laden mass.

Rated load is the manufacturer's recommended maximum load for the cart.

21.2.4 Draft force

The draft force is the force resisting motion when the cart is moving forward at a steady speed. It is horizontal on a level surface and parallel to the surface on a sloping one.

21.2.5 Pull force

The pull(ing) force is the total force exerted on the cart by the draft animals, specified by its magnitude and the angle which the line of pull makes with the ground surface.

The pull force is a combination (resultant) of the force needed to overcome the cart's draft force and the vertical force provided by the animals to support the cart's beam, pole or shafts. Because the vertical force is affected by the magnitude and distribution of the load in the cart, the magnitude and angle of the pull force will vary in consequence. The angle of pull does not necessarily correspond with the angular setting of the cart's beam, pole or shafts although it can be made to approximate it if the cart is carefully loaded to reduce the weight supported by the animals to near zero.

The preferred method of measuring the draft force is with a tractor and towing dolly (such as that described in Section 4.6.10), if these are not available then an approximation of the draft force can be measured by inserting a dynamometer in the line of pull using a telescopic pole (Section 2.2.3).

The draft can be calculated as follows (Fig 21.4):

Find Θ from: $\sin \Theta = (H-h) \div L$

Then: Draft force = Pull force x $\cos \Theta$

H working height of yoke (m)
h working height of axle (m)
L distance axle-hitch (m)
F_p pull force (N)
F_d draft force (N)
θ angle of draft (°)

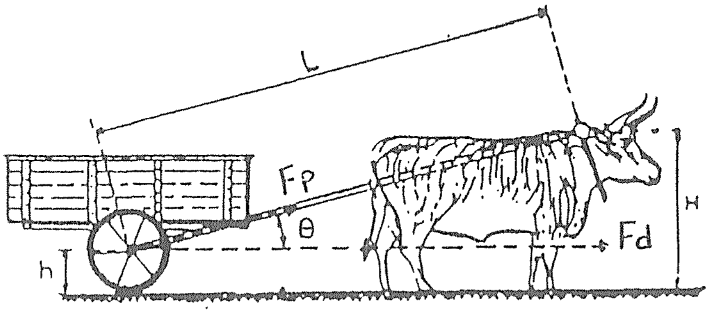


Figure 21.4 Calculation of draft force from measured pull force
Source: Zambian Bureau of Standards, 1990(b)

21.2.6 Rolling resistance

Rolling resistance is the force which resists motion of the wheels over a track or field surface. It is a function of the "coefficient of rolling resistance" of the wheels and the load carried by them.

21.2.7 Coefficient of rolling resistance

The coefficient of rolling resistance is defined as the total rolling resistance of the cart divided by the load carried by its wheels. Its value is a complex function of bearing friction, wheel type and dimensions and soil type and condition. It is usually determined experimentally.

21.2.8 Maximum draft

The maximum draft is limited by the pulling capacity of the animal(s) (approximately 10 per cent of body weight for continuous work). The load at which maximum draft occurs depends on the rolling resistance of the wheels, which is function of soil conditions.

21.3 Test Procedure

21.3.1 Preliminaries

21.3.1.1 Cart for test

Prior to any test work, the manufacturer shall supply the cart complete and in working order together with specifications concerning construction and materials and recommended load capacities. A complete specification will be given in the report.

The specification details given by the manufacturer shall be checked and confirmed. Items to be examined include:

a) General construction
b) Mass and loading capacity
c) Dimensions
d) Details of components
e) Details of attachments to the animal(s)

Other items are listed in the specification form.

21.3.1.2 Draft animals

Draft animals and their handlers should be trained for use with the type of cart under test. The animal(s) should be healthy and in good condition.

The number of animals required will depend on the design of cart under test. Details of the type, size and weight of the animals used for the tests will be included in the test report. If it is not possible to weigh the animals directly, it will be necessary to estimate body weight (see Section 4.5).

21.3.1.3 Yokes

The hitching attachment should be agreed between the cart manufacturer and the test engineer and details given in the test report.

21.3.1.4 Tyres

Where carts are fitted with pneumatic tyres, the inflation pressures should be consistent with the weight on the axle at maximum rated load and the tyre manufacturers recommendations.

21.3.2 Test procedure to establish the coefficient of rolling resistance on a hard surface

The track used for the tests should be level and have an even hard, clean and dry surface of concrete, asphalt or compacted earth. The length of the track should be sufficient for test conditions to become stabilised before measurements are taken.

The cart shall be towed by a tractor at a speed of 1 m/s (± 15%) using a towing dolly instrumented to measure the horizontal component of pull applied to the cart, i.e. the draft force. If a towing dolly is not available then the draft is measured as described in Section 21.2.5.

Test runs will be made with increasing loads corresponding to 50%, 75% and 100% of the manufacturer's rated load. Three runs will be made at each load to establish consistency of results.

The results are tabulated and a graph drawn of draft against laden weight to determine the overall coefficient of rolling resistance. The coefficient will be equal to the slope of the curve, i.e. draft, kN ÷ laden weight, kN.

Should the maximum available draft from the animals be reached before the manufacturer's rated load is applied to the cart, then the lower load becomes the rated capacity for the animals used and for subsequent tests.

This test may be repeated on tracks with different surface conditions.

Any repairs or adjustments made during the tests shall be reported together with any comments on performance.

21.3.3 Test procedure for strength/impact tests

A special track shall be constructed as shown in Fig 21.5 with obstacles 20 cm high set at the track width of the cart undergoing test.

The track shall be arranged so that, at the start of the test run, both wheels of the cart will drop simultaneously from obstacles of sufficient length to allow the normal forward speed to be attained. The next two obstacles will be taken by each wheel alternately and at the end of the run, the obstacles will be mounted by both wheels simultaneously.

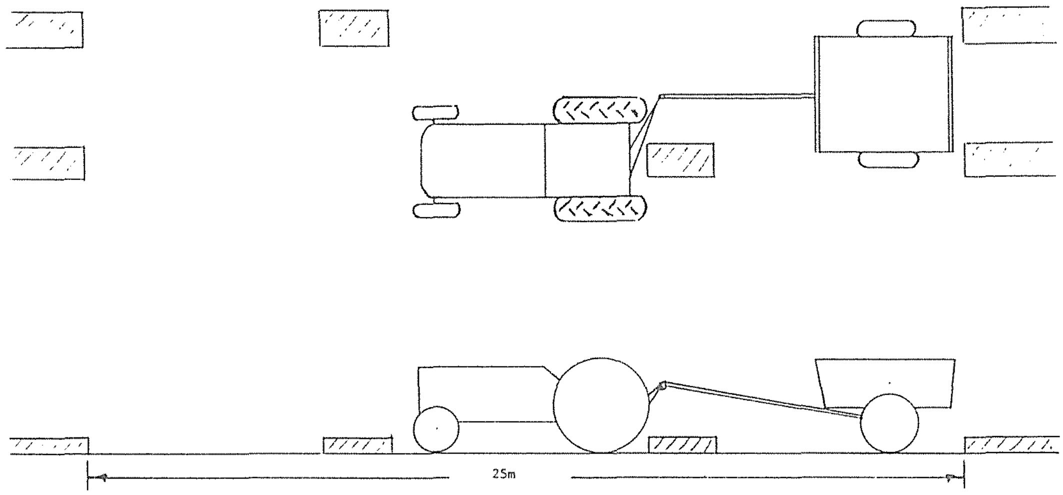


Figure 21.5 Layout of strength/impact track

To avoid excessive strain or harm to the animals, a motorised unit with an off-set towing hitch set to the nominal height of the yoke or harness should be used to tow the cart (Fig 21.5).

When the cart is fitted with pneumatic tyres their inflation pressure should be adjusted to that corresponding to the weight on the axle when loaded to full capacity, according to the tyre manufacturer's recommendations.

The cart shall be loaded to 50 per cent, 75 per cent and 100 per cent of maximum recommended load, evenly distributed. It shall then be attached to the towing unit and run along the track at a speed of 1 m/s (± 15%) for 30 minutes or until a failure occurs.

The cart shall be examined before and after each test to establish whether components have sustained strain or damage and full details of the test settings and observations shall be given in the test report.

21.3.4 Haulage tests

Tests shall be made for three hours duration on a hard-surfaced test circuit of about 1 km incorporating a longitudinal slope of approximately 12.5% (7°) for a minimum of 25 metres, to be taken in both directions, and a cross-slope of at least 12.5% for a minimum of 50 metres. The cart will be evenly loaded to the manufacturer's maximum rated load.

In addition tests of a similar nature will be conducted on a combination of road, track and field surfaces typical to the area of use.

During the tests the following measurements and observations shall be made:

a) Average speed
b) Failures, repairs or adjustments.
c) Stability and controllability of the cart.
d) Comfort of animals (see Section 8, Appendix 8A).
e) Comfort of operator.
f) Safety.

21.3.5 Trials on farms

A longer series of trials may be undertaken on farms to enable the cart to be evaluated under typical work conditions.

During the trials the following should be recorded:

a) Type and condition of road, track or field surfaces.
b) Types of animals used.
c) Number of days in use.
d) Distances covered.
e) Loads carried and weight of load.
f) Breakdowns and time lost for repairs.
g) Comments by users.

21.4 Test Report

21.4.1 Diagram/Photograph

A line drawing or photograph showing principle details of the construction of the cart and methods of attachment shall be provided.

21.4.2 Specification

21.4.2.1 Brief description of cart:

Make:
Model:
Serial No.:
Manufacturers name and address:

21.4.2.2 Type and number of animals required

21.4.2.3 Manufacturer's recommended loading capacity:

Mass:	kg
Volume:	m^3

21.4.2.4 Overall dimensions

Length:	cm
Width	cm
Height	cm

21.4.2.5 Mass

Total unladen:	kg
On hitch with maximum load evenly distributed:	kg

21.4.2.6 Details of components

21.4.2.6.1 Wheel equipment

a) Wheels

i) Type (e.g. wooden, pneumatic tyres)
ii) Number and size
iii) Recommended tyre inflation pressure, where applicable

b) Bearings

i) Type
ii) Method, type and recommended frequency of lubrication

c) Brake

i) Type
ii) Size and details of construction
iii) Method of operation

d) Track width: mm

21.4.2.6.2 Chassis and loading platform

a) Details of materials, construction and dimensions of chassis.

b) Details of materials, construction and dimensions of loading platform and supporting sides.

21.4.2.6.3 Hitching arrangements

Description of yoking or harnessing arrangement

21.4.3 Results of tests

21.4.3.1 Track tests

21.4.3.1.1 Animals used for tests

a) Type and breed
b) Measured mass of each animal: kg
c) Estimated mass of each animal: kg

21.4.3.1.2 Test track

a) Location
b) Type and condition of surface

21.4.3.1.3 Summary of test results

a) Table of results

Date of tests	Payload on cart, kg				
Draft force, kN					
Mean speed, m/s					

b) Performance curves of draft as a function of load on the cart.
c) Coefficient of rolling resistance.
d) Repairs and adjustments, comments.

21.4.3.2 Strength/Impact test

21.4.3.2.1 Test details

a) Location and date of test
b) Towing device
c) Mass of cart — kg
d) Mass of load — kg
e) Total mass — kg
f) Height of yoke — mm
g) Mean forward speed — m/s
h) Duration of test — min

21.4.3.2.2 Observations and remarks

21.4.3.3 Haulage tests

21.4.3.3.1 Animals used for tests

a) Type and breed
b) Mass of each animal: — kg

21.4.3.3.2 Test tracks

a) Location
b) Type and conditions of surfaces

21.4.3.3.3 Summary of test results

a) Date of tests
b) Duration of tests, — hours
c) Average speed, — m/s
d) Mass of payload, — kg

21.4.3.3.4 Observations

a) Failures, repairs and adjustments
b) Stability and controllability
c) Containment of load
d) Comfort of animals
e) Comfort of operators
f) Safety features

21.4.3.4 Trials on farms

21.4.3.4.1 Animals used in trials

21.4.3.4.2 Locations and details of road, track and field conditions

21.4.3.4.3 Results of trials

a) Dates and number of days in use
b) Distances covered
c) Type and mass of loads carried

21.4.3.4.4 Observations

a) Breakdowns and time lost for repairs
b) Comments by users

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ANNEX 1

INSTRUMENTATION AND EQUIPMENT

The following list of equipment available to carry out test procedures discussed in this document is generally concerned with that which is commercially available. No attempt has been made to include names of measuring equipment manufacturers as these vary from country to country but descriptions have been given.

The capacity and sophistication of the measuring equipment required will depend on the type and size of the machine tested and the complexity and style of test. However, it is surprising how much measuring equipment can be improvised, once the need for it is seen (Crossley and Kilgour, 1983).

i) General

Any testing group should be equipped with **basic measuring equipment** for use during test work and to enable calibration to be made on other instruments. This should comprise, measuring tapes, stop watches, fluid measuring cylinders, spring balances and standard weights of various sizes.

ii) Power Measurement

Rotative - for power measurement of engines and tractors complete **hydraulic or electric dynamometer** installations of varying size are available for measuring torque and speed. This equipment is ideally suited to laboratory installations where the need can be justified.

Complete **mobile dynamometers** can be used for tractor tests in the laboratory and on farms and test sites. These are also based on hydraulic pumps or electrical generators. Some generators can be used to provide power for other uses.

Watt meters are designed to measure the input electrical power of single and three phase electric motors.

Draft. Strain gauged **tensile links** are available in many sizes for measurement of tractor, machine or animal draft. Indicators for direct reading can be supplied with outputs for recorders if required. These units are protected for use in the field and are easily calibrated.

At lower levels of pull, **spring balances** may be used but need to be heavily damped.

Hydraulic. A **pressure gauge** and a suitable **flowmeter** can be used for hydraulic power measurements but complete **hydraulic test kits** are available which are portable and convenient for laboratory or farm use.

Fuel consumption. For laboratory use, **volume or mass measuring units** are available with manual or electric control for timing purposes. Simple versions may be constructed using clear tubing and valves and calibrated with the use of measuring cylinders.

For field measurement of fuel consumption, **mechanical/electronic meters** which can be fitted into the flow line enable total values of flow to be measured. With mechanical meters, electronic sensing heads can be fitted to enable **remote indicators** or **recorders** to be attached. This type of meter is equally suitable for short field tests or extended farm trials.

Field measurement. **Remote indicator** and **recording equipment** is available to take outputs from torque and speed transducers, strain gauged tensile links and flow meters. This type of equipment is ideal for vehicle mounting where in field trials the attaching of indicators to tractors or machines is difficult.

iii) Soils

When establishing and defining the properties of soils used in field trials, **methods of estimation** are possible for texture and moisture content without the use of sophisticated equipment. For accurate measurements required for final reporting the use of a **well equipped soils laboratory**, having the following facilities, is essential.

Texture	-	equipment for **particle size analysis.**
Moisture content	-	**machined cylinders** of various sizes for core and bulk density samples, **drying ovens** with at least 105°C capacity and accurate **weighing machines.**
Mean clod size	-	Sets of **sieves** with various sizes of mesh. The following instruments are intended for use in the field.
Soil hardness	-	a **cone penetrometer** measuring vertical resistance of cones of standard areas. The instrument has a direct force readout.
Shear resistance	-	a torsional direct reading vane type **shear meter** with ability to measure a range of soil textures at various depths.

iii) Cultivation

Equipment for the measurement of **width** and **depth** for furrows or ridges can be manufactured locally from details given in the test procedures. A light-weight **1m square frame** can also be made to enable random weed counts to be carried out. Attachments to the frame will enable evenness to the ground surface to be assessed.

iv) Seeding and Planting

The measurement of longitudinal **seed distribution** during laboratory tests requires an even level **track** with a **surface cover** to prevent seeds from bouncing. Satisfactory surfaces are clean sand, coconut matting, thick felt or paper coated with grease or heavy oil.

When seed distribution is assessed by plant emergence, the germination rate of the seed used for the trial has to be established. For this work a **laboratory** equipped to germinate seeds in controlled conditions is required.

v) Sprayers

Flow meters and **pressure gauges** are available designed especially for tests of knapsack and field sprayers in the laboratory and in the field.

Spray distribution from all sizes of machines can be measured using a **"Patternator" spray bench.** Light weight portable versions of this design are available comprising a series of grooves allowing liquid from the spray nozzle positioned overhead to run into graduated tubes, thereby creating a spray "pattern".

vi) Combines

Laboratory work for combine testing will require the use of **sample dividers** to reduce bulk grain samples in a random manner for further analysis. Proprietary **moisture meters** are available but if a more accurate result is required, a **laboratory** facility with accurate weighing facilities and drying oven capacity up to 110°C is required.

For measurement of grain losses in the field, equipment for collecting and sorting material from the efflux of the combine can be simply constructed from wood, canvas and strip metal.

If more accurate results are required the efflux will be required to be re-threshed to separate the grains. A **static threshing machine** may be used for this purpose but if large numbers of measurements are required, the use of a **mobile re-thresher** is an advantage.

This machine is basically a second combine harvester modified to pick up measured amounts of efflux from the test machine to be re-worked and allow grain present in the material to be counted. Designs and details of the construction of a re-thresher are available from several test authorities.

vii) Pumps

Tests of manual pumps will require only simple **volume** and **time** measuring equipment.

Motorised pumps will require **pressure gauges** for insertion into pipe lines for determination of suction and discharge head and instruments for measuring discharge. **Flow meters** of suitable size may be inserted in the discharge pipe line, alternatively various sizes of 'V'-notch or rectangular **weirs** are available. Weirs are especially useful when measuring flows in channels.

viii) Noise

Proprietary **portable meters** are available for measure of noise levels in dBA from engines or machines. Analysis and recording equipment can also be added.

ix) Smoke

Meters for measuring the **level of smoke** in engine exhausts are primarily designed for laboratory work. In the most widely used design, samples of the exhaust gas are compared with clean air resulting in a rating number.

x) Vibration

Accelerometer and **recording equipment** are available for the measurement of vibration of machine components. **Analysis** equipment is also provided.

xi) Anthropometric measurements

Specialised equipment is available for making anthropometric measurements. A **stadiometer** may be used for accurately determining stature and a **somatometer** used for measuring other body dimensions. However, simple equipment for measuring human size can easily be constructed and should be adequate if used with care. Simple personal **weighing scales** are suitable to measure weight.

xii) Physiological variables

As part of an evaluation of workload, **heart rate loggers** are available which measure and record heart rate over extended periods of work. Logged data is downloaded onto computer for analysis. Another (but more expensive) option for measuring the energy demands associated with work tasks is the use of a **portable oxygen consumption meter**. Body temperature can be taken using a simple **clinical thermometer**.

xiii) Climatic variable

If other environmental conditions are to be taken into account, **environmental variable data loggers** are available. They can be used in conjunction with **probes** for recording **air temperature**, **radiant temperature** and **relative humidity** and with an **anemometer** for recording air speed.

ANNEX 2 CONVERSION FACTORS TO SI UNITS

QUANTITY	UNIT	CONVERSION FACTOR
Length	1 in	0.0254 m
	1 ft	0.3048 m
	1 yd	0.9144 m
	1 mile	1609.344 m
Area	1 in^2	6.4516×10^{-4} m^2
	1 ft^2	0.092 903 m^2
	1 yd^2	0.836 127 m^2
	1 acre	4046.86 m^2 = 0.404 686 ha
	1 $mile^2$	$2.589\ 99 \times 10^6$ m^2 = 258.999 ha
Volume	1 in^3	$1.638\ 71 \times 10^{-5}$ m^3
	1 ft^3	0.028 316 8 m^3
	1 UK gal	0.004 546 092 m^3 = 4.546 092 l
	1 US gal	0.003 785 41 m^3 3.785 41 l
Mass	1 lb	0.453 592 37 kg
	1 UK ton	1016.05 kg = 1.016 05 tonne
	1 short ton	907.185 kg = 0.907 tonne
Velocity	1 ft/s	0.3048 m/s = 1.097 28 km/h
	1 mile/h	0.447 04 m/s = 1.609 34 km/h
Force	1 lbf	4.448 22 N
	1 kgf	9.806 65 N
Torque	1 lbf ft	1.355 82 Nm
Power	1 hp	745.700 W
	1 metric hp	735.499 W
Pressure	1 lbf/in^2	6894.76 N/m^2
	1 std atmos	101.325 kN/m^2
	1 bar	10^5 N/m^2
	1 in Hg	3386.39 N/m^2
	1 mm Hg	133.322 N/m^2
	1 in H_20	249.089 N/m^2
	1 mm H_20	9.806 65 N/m^2
Temperature	1°F	$^5/_9$ K or C

FAO TECHNICAL PAPERS

FAO AGRICULTURAL SERVICES BULLETINS

1 Farm planning in the early stages of development, 1968 (E Rep. 1982 – F S)
2 Planning for action in agricultural development, 1969 (E F S)
3 Karakul processing, 1969 (E)
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7 Technology for the production of protein foods from cottonseed flour, 1971 (E F S)
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9 Worldwide list of food technology institutions, 1971 (E/F/S*)
10 Technology of production of edible flours and protein products from groundnuts, 1971 (E F S)
11 Technology of production of edible flours and protein products from soybean, 1971 (E F S)
12 A guide for instructors in organizing and conducting agricultural engineering training courses, 1971 (E F S)
12 Sup. 1 Elements of agricultural machinery, Vol. 1, 1977 (E S)
12 Sup. 2 Elements of agricultural machinery, Vol. 2, 1977 (E S)
13 Fruit juice processing, 1973 (E S)
14 Environmental aspects of natural resource management – agriculture and soils, 1972 (E F S)
15 Manual on sericulture:
Vol. I – Mulberry cultivation, 1976 (E F)
Vol. 2 – Silkworm rearing, 1973 (E F)
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16 The use of aircraft in agriculture, 1972 (New edition, 1974, available in E, F and S in the FAO Agriculture Series, No. 2)
17 Airtight grain storage, 1973 (E F S)
18 Rice testing methods and equipment, 1973 (C E)
19 Cold storage – design and operation, 1973 (E F S)
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20 Processing of natural rubber, 1973 (E)
21 Rev. 1 Agricultural residues: world directory of institutions, 1978 (E/F/S)
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22 Rice milling equipment operation and maintenance, 1974 (C E)
23 Rice drying (E**)
24 Worldwide list of textile research institutes, 1974 (E/F/S)
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26 Tea processing, 1974 (E)
27 Some aspects of earth-moving machines as used in agriculture, 1975 (E)
28 Mechanization of irrigated crop production, 1977 (E)
29 Non-mulberry silks, 1979 (E)
30 Machinery servicing organizations, 1977 (E)
31 Rice-husk conversion to energy, 1978 (E)
32 Animal blood processing and utilization, 1982 (C E S)
33 Agricultural residues: compendium of technologies, 1978 (E/F/S)
33 Rev. 1 Agricultural residues: compendium of technologies, 1982 (E/F/S)
34 Farm management data collection and analysis, 1977 (E F S)
35 Bibliography of agricultural residues, 1978 (E/F/S)
36 China: rural processing technology, 1979 (E)
37 Illustrated glossary of rice-processing machines, 1979 (Multil)
38 Pesticide application equipment and techniques, 1979 (E)
39 Small-scale cane sugar processing and residue utilization, 1980 (E F S)
40 On-farm maize drying and storage in the humid tropics, 1980 (C E)
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