

**DEVELOPMENT OF AN EQUIPMENT FOR SOIL TILLAGE
DYNAMICS AND EVALUATION OF TILLAGE PARAMETERS**

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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirements of the Department of Agricultural Engineering, Federal University of Technology Akure for the award of Doctor of Philosophy in Farm Power and Machinery.



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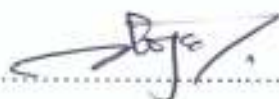


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DEDICATION

This work is dedicated to the Glory of God the son (Jesus Christ) in whom the fullness of the Almighty God dwells bodily and in whom we are complete, and to all men who have pioneered and /or encouraged soil tillage dynamics research.

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ABSTRACT

An equipment was developed and used to evaluate tillage parameters. The equipment consist of a soil bin, soil processing trolley, tool carriage and tool carriage subframes (adjustable and fixed types). The soil processing trolley was essentially a rectangular framework with a levelling board and compaction roller. The tool carriage and soil processing trolley were designed to move steel railings with Teflon wheels. This equipment enabled studies to be carried out on the draught requirement of model tillage tools (tines and blades) and the nature of soil disturbance as they were affected by tillage parameters, that is, soil implement and operational parameters. Also developed for this study was a soil-material friction measuring device (or apparatus). The apparatus enabled us to measure the angle of soil-interface friction.

The soils tested in this study were loamy sand, clay soil, sandy loam and sandy clay loam (bin soil). The physical properties of the soils showed that the mean bulk density of loamy sand was 1.56 Mg/m^3 with a standard deviation of 0.1 Mg/m^3 . Its clay ratio and saturated hydraulic conductivity were 13.6 and 5.3 mm/min respectively. The bulk densities of the clay soils were not significantly different at 5% level of significance. Similarly the bulk densities of the sandy loam soils were not significantly different at 5% level of significance. Neither were the bulk densities of the sandy clay loam soil (bin soil) significantly different at 5% level of significance. The mean saturated hydraulic conductivity of the sandy clay loam soils ranged from 0.85 to 1.22 mm/min. The cohesion of the soils ranged from 1.62 to 1.77 kPa for loamy sand, 10.0 to 15.6 kPa for sandy loam, 23.0 to 30.6 kPa for sandy clay loam and 35.2 to 44.2 kPa for clay. Mean values of cone index for the experimental soil ranged from 120 to 130 kPa for loamy sand, 870 to 1340 kPa for clay and 752 to 870 kPa for sandy loam.

Effect of moisture content and applied pressure on the compaction of the soils showed that loamy sand soil achieved higher bulk densities when the soil is approaching saturation. Clay soil are highly susceptible to compaction especially when their consistency changed from moist to wet. Compaction of sandy loam showed that increase in compaction are less dependent on moisture content but rather almost entirely due to applied pressure though these were not high neither. The sandy clay

loam soils were extremely sensitive to water content at the time of compaction. The percentage increase in soil compaction for the sandy clay loam is related more to changes in water content than to applied pressure.

The effect of applied pressure on bulk density of sandy clay loam could be described by a number of compaction behaviour equations. The equations were those of power, logarithmic, exponential and linear functions with very good R^2 value, while power fit seemed to be the best. The angle of internal friction of the soil ranged from 39.6 to 42.0 degrees for loamy sand; 25.3 to 30.1 degrees for clay; 29.6 to 32.9 degrees for sandy loam and 30.7 to 33.0 degrees for sandy clay loam. For the coefficient of soil-interface friction, it was highest for rubber followed by smooth steel and least with Teflon.

Effect of variation in soil parameters on soil disturbance and draught showed that draught of implement increased at a decreasing rate as the soil moisture content increased from 11.0 to 22.5% (db) in sandy clay loam soil. Polynomial equations best described the relationship with very good R^2 values. Also draught of implement increased at an increasing rate as the cone index increased by means of compaction.

Effect of variation in implement parameters on soil disturbance and draught showed that draught increased at a decreasing rate with tine width. The draught of blades increased in the order of magnitude; VEE blade (BVE); triangular blade (BTR); convex blade (BCV); semi circular blade (BSC); convave blade (BCC) and wide tine (TWT). In all the blades draught increased at an increasing rate. Draught was also found to be affected by surface finish. The draught force requirement was highest for rusted steel surface (SRS), followed by clean steel surface (SCS) while that of Teflon coated surface (STS) was least. Effect of cutting edge thickness showed that draught of implement increased at an increasing rate as the cutting edge thickness increased from 1 mm to 8 mm thickness. The increase in draught was typically 48 to 62%.

Effect of variation in operational parameters showed that draught increased with depth of operation at an increasing rate. An exponential curve best described the relationship. Also draught increase with forward speed at an increasing rate. Quadratic equation best described the relationship. Similarly, draught increased quadratically with increase in rake angle with minimum draught occurring at about 45° rake angle.

The parameters of soil disturbance are: ridge to ridge distance (RRD); width of crescent (WC); total disturbed width (TDW); after furrow depth (d_f); height of ridge (h_r) and rupture distance (f). Generally, the parameters of soil disturbance increased as the tillage parameters increased. However, it was observed that rupture distance decreased as the rake angle increased.

Keywords: *Development, equipment, soil tillage dynamics, draught, tine, blade, soil disturbance, equations*

NOTATION AND ABBREVIATION

- a. Cross sectional area, m^2
- c. Cohesion, kPa
- c_a . Soil – interface adhesion, kPa
- d. Depth of tool from soil surface, m
- d_f . After furrow depth, m
- e. Base of natural logarithm
- f. Rupture distance, m
- g. Acceleration due to gravity, m/s^2
- h_r . Height of ridge, m
- j. Deformation
- k. Deformation modulus
- m. Rupture ratio
- n. Number of tools
- r. Crescent radius, m
- v. Forward speed, m/s
- w. Width of tools, m
- CI. Cone index, kPa
- D. Draught force, kN
- H. Horizontal force component, kN
- L. Dimensional length, m
- MC. Moisture content
- RRD. Ridge-to-ridge distance, m
- R. Resistance (force), N
- TDW. Total disturbed width, m

V.	Vertical force component, kN
W.	Width, m
WC.	Width of crescent, m
WFS.	Width of furrow at surface, m
DT.	Draught of tine, N
DD.	Dry density, Mg/m ³

Greek symbols

α .	Rake angle, <i>degree</i>
α_c .	Critical rake angle, <i>degree</i>
γ .	Unit weight, kN/m ³
δ .	Angle of soil – interface friction, <i>degree</i>
ξ	Strain
$\dot{\xi}$	Strain rate, s ⁻¹
θ	Included angle between lower slip line and inter face, <i>degree</i>
μ .	Coefficient of friction
π .	Constant
ρ_b	Bulk density, Mg/m ³
ρ_d	Dry density, Mg/m ³
σ	Normal stress kN/m ²
τ	Shear stress, kN/m ²
Φ	Angle of internal friction, <i>degree</i>
Ψ	Soil – soil friction angle, <i>degree</i>

Other symbols and abbreviations are defined in the text where appropriate.

CHAPTER ONE

INTRODUCTION



1.1 Agricultural Background of Nigeria

Nigeria lies in the tropics. It is located between latitudes 4°N and 14°N and longitudes 2.5°E and 14.5°E in West Africa. It has a land area of 98.3×10^6 hectares out of which about 71.2×10^6 (that is, 72.4%) is considered agricultural land. Presently, only about 35×10^6 hectares (that is, 49.2%) of the cultivable land is being cropped.

Farmers constitute the single most important occupational group in Nigeria. According to the 1952/53 population census, 78% of the adult male population engaged in agriculture, forestry and fishing. The participation level was maintained in 1963/64. Out of the estimated economically active population of 25.1 million then, those engaged in agriculture accounted for 20.1 million, with perhaps 12.0 million males and 8.1 million females. In 1966/67 and 1970, there was a slight decline in the percentage of the population engaged in agriculture to 71.7% and 62.2% respectively (Agboola, 1979), in the late 1990's these figures further dropped.

1.1.1 Seasons of Nigeria

- (a) The seasonal pattern of Southern Nigeria is different from that of the North. In the South there are four seasons (Iloeje, 1981)

(i) The long wet season

This starts in mid-March and lasts till July. It is the season of heavy rains and high humidity.

This is the planting season.

(ii) The short dry season

This is the August break. It starts in July-August and lasts for about one month

(iii) **The short wet season**

This follows the August break and lasts from September to October. The rainfall is not usually as heavy as during the first wet season and the total amount is also usually less.

(iv) **The long dry or harmattan season**

This season follows and continues from November to mid-March. Harmattan mornings are cool and misty, but the mist disappears with the rising of the sun. Afternoons are full of haze because of the dust particles in the air. The air is so dry that wet washing dries almost as soon as it is put out. Grass dries off and lawns look patchy.

(b) **The seasons of Northern Nigeria.** In the North the long dry season starts earlier and ends later. The August-break does not exist and so the two wet seasons became one for the remaining five months.

1.1.2 Climatic Regions of Nigeria

The climatic regions of Nigeria are represented on the map of Nigeria shown in Appendix A.1. they are

- (i) The sub-equatorial south
- (ii) The tropical hinterland
- (iii) The tropical continental north and
- (iv) The high plateaux

The Sub-Equatorial South extends from the coast to roughly 130 to 160.km inland. It has over 150 cm of rainfall per annum; double maxima rainfall and no month has less than 2.5 cm of rain the total annual rainfall increase from 150 cm in the west to more than 300 cm in the Delta area.

The Tropical Hinterland. It comprises a strip of land approximately 240 km wider in the middle of Nigeria. It is bounded in the North by the double-maxima rainfall line. The total rainfall is between 100 and 150 cm and the region has up to four months of dry season.

The Tropical Continental North. It consists of the remainder of Northern Nigeria where the annual rainfall is between 50 and 100 cm. The region has between four and eight dry months.

The High Plateaux of Jos, Adamawa and Obudu. They belong to a class by themselves. The temperatures are lower and more equable than in the areas around. Their rainfall records show multiple peaks and the total is higher than in other places on the same latitudes. The mean monthly temperature for Jos. ($9^{\circ}52'N$) ranges from $20^{\circ}C$ in August to $25^{\circ}C$ in April and the rainfall is 140 cm per annum; while Yola ($9^{\circ}13'N$) has an annual total of only 100 cm

1.1.3 Vegetation of Nigeria

The main vegetation zones of Nigeria are shown in Appendix A2. Two broad-belts of plant groups can be found. Within each group it is possible to distinguish three-subtypes:

(1) Forests	(a) salt-water swamp (Mangrove)
	(b) fresh water swamp
	(c) high forest (forest regrowth)
(2) Savanna,	(a) guinea savannah
	(b) sudan savannah
	(c) sahel savannah

Salt-Water Swamp. It is restricted to a coastal strip 30 to 50 km wide, where the freshwater from the rivers meets and mixes with the salt water from the sea. The fresh water is thus polluted and rendered saline. As a result the soil is swampy and waterlogged and the water is brackish, that is, half salt, half fresh. The typical vegetation is made up of mangrove plants of different species.

Fresh Water Swamp. Further inland where the tide cannot reach, the land is free from the sea water. This belt of land about the width of fresh water swamp extends from Lagos to beyond Port Harcourt. Where the soil though not saline is still waterlogged. Here freshwater plants take the place of the mangrove plants. The most common species is the raffia palm (Iloeje, 1981).

The High Forest. This belt stretches from the western boundary of Nigeria South-eastwards through Ibadan and Benin, across the Niger to the Oban Hills. It is sometimes called the rainforest belt. Its average width is about 150 km, though it is considerably narrower in the vicinity of the Niger owing to the North-ward extension of the fresh-water swamps. The high annual rainfall ((130 to 150 cm in the west and over 200 cm in the east), the high humidity (generally over 80%) and the long wet season (8 to 10 months) ensure an adequate supply of water and the continuous presence of moisture in the air. These promote perennial tree growth. The actual vegetation shows a varied combination of different types of plant groups.

Derived Savanah. This is found on the northern fringes of the high forest belt. Here the vegetation is thinner and more deciduous in character as a result of low humidity and precipitation. The result is that when it is cleared, it is replaced by a type of parkland which represents an encroachment of the guinea savanna into the forest zone. It is made up of tall grasses and smaller trees which are diminutive survivals of the original plant species.

Guinea Savanah. This is the broadest vegetation zone in Nigeria, occupying nearly half its area. It is located in the middle of the country, extends southwards to southern Nigeria and pushes its head northwards beyond the latitude of Zaria. It covers the area which has 100 to 150 cm of annual rainfall and where the wet season lasts for 6 to 8 months.

Sudan Savanah This belt is found in the far north. It stretches from the Sokoto plains through the northern section of the high plains of Hausaland to the Chad Basin. It covers an area of just over a quarter of the whole country. It is typical of places where the total annual rainfall is between 65 and 100 cm. This zone holds the greatest density of population in northern Nigeria, produces important economic crops like groundnuts, cotton, millet and maize and has the highest concentration of cattle in the country (Iloeje, 1981). The actual vegetation is made up of short grasses and some stunted trees.

Sahel Savanah It is the last vegetation zone to be found in Nigeria as one approaches fringes. It is limited to a triangular piece of land in the north –

eastern corner of the country where the annual rainfall drops below 65 cm and the length of the dry season exceeds 8 months. The air here is perpetually dry except for one or two months in the middle of the very brief wet season. The grasses in this area are short and tussock. They are interspersed with sand dunes. As a rule this land is not cultivated without irrigation. The local people are nomadic herdsmen.

1.1.4 Major Soils of Nigeria

The soil zones of Nigeria are represented on the map shown in Appendix A3. Faniran and Areola (1978), Agboola (1979), combin and Fagbami (1994) described the characteristics of these major soils:

- (i) Entisols. These have no diagnostic horizons or profile development, alluvial soils; sands.
- (ii) Inceptisols. Soils that are usually moist, with pedogenic horizons of alteration of parent materials but not of accumulation. No clear cut diagnostic horizons, usually dark epidedons.
- (iii) Vertisols. Soils with high content of swelling clays and wide deep cracks at some season. They usually have dark top soil.
- (iv) Ultisols. Soils that are usually moist with horizon of clay accumulation and low basic cation supply; red or yellow argillic horizon; forest soils.
- (v) Oxisols. Oxic horizons with many free Sesqui oxides. Little horizon differentiation; deep soils; highly weathered.
- (vi) Alfisols. Soils with grey to brown surface horizons, medium to high base supply, and subsurface horizons of clay accumulation. Usually moist but may be dry during warm seasons; no pronounced colour changes vertically; forest soils.

1.1.5 Agricultural Production in Nigeria

A quick look at agricultural production in Nigeria is necessary as a background to this study.

- (i) Agricultural systems. These include shifting cultivation; rotational fallow agriculture, mixed agriculture, semi permanent or permanent agriculture.
- (ii) Major crops. These include
 - (a) Root crops such as yams, cassava, potatoes and cocoyams
 - (b) Grains such as cereals like rice, maize sorghum (guinea corn), millet, wheat and legumes such as soyabean, cowpea and groundnuts.
 - (c) Tree crops such as cocoa, kola, rubber and oil palm
 - (d) Fruits such as pineapple, pawpaw (papaya) citrus, plantains and bananas
 - (e) Industrial crops such as kenaf, sugar cane, tobacco.

The adoption of the above agricultural systems and the production of these major crops presupposes appropriate soil selection and adequate cultivation for maximum returns from the soil.

- (iii) Food demand and production. There has been continuous widening of gap between food demand and production. This is a significant and disturbing feature of Nigeria's agriculture although it is the largest single sector of the Nigeria's economy. Agriculture accounts for more than 50% of the gross domestic product (GDP) and until the 1970's, for about 80% of the total exports of the country (Oyenuga, 1967). The key to the nation's economic growth therefore should be to raise the productivity of the agricultural sector irrespective of how viable any other sectors of the economy may be in order to conserve foreign exchange. One way of boosting agricultural production in Nigeria is by appropriate and adequate mechanisation of tillage.

1.2 Status of Tillage Mechanisation in Nigeria

Mechanisation of tillage refers to the application of hand-tool technology, animal draught technology or mechanical power technology, singly or in combination, to execute any one of the tillage operations (Odigboh, 1991). It is therefore clear that all these technological mechanisation levels are weighted preponderantly in favour of the most primitive, that is, hand-tool technology.

1.2.1 Hand-Tool Mechanisation of Tillage

Odigboh (1991) reported that over 80% of the cultivated area in Nigeria is tilled and farmed using hand-tool technology. The only power available is from the farmer assisted by his wife. Unfortunately the assistance which he used to get from his children is no longer available in most cases since the introduction of free primary education in Nigeria. It should be noted that the farmer does not resent, in fact he is pleased with this loss of his children's assistance on the farm since the common most ardent ambition or hope of a Nigeria farmer is for his son to become anything but a farmer (Odigboh, 1976). His entire agricultural "machinery" for tillage consists of the hoe and its various forms, shapes and sizes, preserved as inherited from his ancestors (Odigboh, 1982; 1983). The area he can cultivate is inherently limited to about 2 hectares to produce what barely suffices to feed his family. He can do no better than that.

What has just been said above are bare facts. Some scientific and experimental basis for these facts include the following:

- (i) Humans are not efficient sources of power
- (ii) Human power output is limited by the thermal stress of high temperature and relative humidities prevalent in the tropics
- (iii) On the average human beings can work at a power out of 0.75kW
- (iv) While the work rate efficiency of humans is about 50% in temperate climates, the efficiency is less than 10% in humid tropical conditions such as we have in Nigeria (FAO, 1981).

- (v) Actual manual field rates for some tillage operations as reported by Anazodo (1976) include: ridging for cassava planting, 29.7 to 64.5 (with an average value of 43.8) man—day/hectare.

It is clear from this information that agricultural output of farmers using only hand-tool technology is too low.

The numerous attempts to redesign manual tillage tools, involving improvement on their durability and cutting edges and optimisation of their form and size and so on, have had no significant effects. In spite of all these attempts, the toilage, drudgery as well as the power constraint on timely tillage operations over a large enough area to increase production and earning capacity of the farmer has remained. Advocacy of hand-tool technology for agriculture amounts to virtual enslavement that condemns a large group of Nigerians to perpetual poverty (Odigboh, 1981).

1.2.2 Animal –Draught Mechanization of Tillage

Animal-draught power in the form of a pair or team of work bulls, oxen or even donkeys is used to some extent by farmers in the northern states of Nigeria. There it certainly provides some relief, albeit marginally, from the toilage inherent in field operations. It is claimed that animal-draught power is suitable to the low level of the small farmer's technical knowledge. That, coupled with the claimed low cost of the accompanying implements, they say, makes it an attractive agro-technology to promote in northern Nigeria where the farmers have the tradition of keeping large animals. However, it should be noted that as animal-draught power continues to be important in the north, its relative contribution to future farm power requirement is perforce progressively declining. Animal –draught technology is becoming increasingly unrealistic in Nigeria where it is faced with many serious limitations amongst which are:

- (i) It is limited to the tse-tse fly free northern states of Nigeria.
- (ii) With it, area cultivated and output per man are only marginally higher than possible with manual labour but barely enough to pay for the up-keep of the animals throughout the year.

- (iii) Its application is limited to a few light tillage and land preparation operations in already cleared land of very light soils.
- (iv) The draught animals suffer stresses from high temperature and high relative humidity conditions, diseases and malnutrition as do humans; thus their work rate efficiency is low.
- (v) The peak of the season's field operations requirements comes at the end of the dry season which is a period of food shortage for both human and livestock consumption. The animals are therefore not well fed at this time and so are ill-prepared for the heavy tillage work required of them. Yet during the wet season when the animals are well fed, there is little work for them. All told, the cost of keeping the draught animals is becoming prohibitive unattractive relative to the amount of season's work which they can give in return.
- (vi) The advantage of low cost commonly claimed for the animal-draught implements no longer holds. Whereas some years ago improved implements were generally within the reach of small-scale farmers, rapidly escalating manufacturing costs have caused these implements to be priced above the financial capacity of most peasant farmers. A pair of work bulls with matching implements now costs close to N70,000.00
- (vii) Animal-draught tillage mechanisation with its technical complexities of animal health care, upkeep, training and handling is in fact a very sophisticated technology that is extremely difficult to acquire particularly by farmers without draught animal husbandry tradition (Mrema, 1990).

I strongly believe that continued promotion of animal-draught technology for tillage mechanisation, like hand-tool technology amounts to a deliberate condemnation of the farmers to perpetual serfdom. The most ardent proponents will agree that animal-draught tillage mechanisation is becoming very uneconomical and is certainly not attractive enough to induce Nigerian youths into agriculture. Animal draught tillage mechanisation is not likely to play a significant role in the Nigerian agriculture of tomorrow.

1.2.3 Mechanical Power Mechanisation of Tillage

Considering all the factors involved mechanical power mechanisation of tillage will most likely be the appropriate technology package necessary for agricultural intensification programmes in Nigeria. All real stakeholders genuinely interested in the welfare of Nigeria and Nigerians must acknowledge that the war against hunger and scarcity of agro-industrial raw materials is too complex and too sophisticated for the armament of hoes and diggers in the hands of the army of aged and ageing peasant farmers or yoked behind malnourished mules, oxen and donkeys (Odigboh, 1990). Mechanical power mechanisation of tillage must be recognised as the missing input needed to accelerate agricultural production in Nigeria. Nigerian agricultural engineers must try to counter all contrary views from within Nigeria or from abroad, especially to remove the persistent bias and prejudice against mechanical power mechanisation of tillage of African farms.

Presented below are some brief comments on some of the important mechanical power tillage mechanisation issues and problems.

- (i) While fundamental physical and engineering principles governing the design and construction of farm machinery are the same everywhere, modification or adaptation of machinery from one area to fit the production environment and goals as well as the technical, economic and social conditions of another area is always necessary. But this adaptation activity does not take place in Nigeria.
- (ii) It is relevant to state that there is grossly inadequate agricultural mechanisation research especially in the area of tillage mechanisation going on in Nigeria today. Our agricultural research institutes, dominated by agronomists, soil scientists, economists and so on, are not interested and oftentimes impede and discourage young researchers interested in mechanisation research. Thus the various research projects in agronomy, farming systems and so on have no mechanisation component (Odigboh, 1991). In general, approach to agricultural mechanisation in Nigeria is laissez-faire of course, the inevitable result

is failure and then we turn round and blame MECHANISATION as though it has an animate personality.

1.3 Status of Soil and Tillage Research in Nigeria

When we talk about tillage research, force or force system is involved except we are talking about “no-till” which in actual sense is not tillage. The specialised area of soil and tillage research requires studies in the following areas amongst others:

(a) Soil Properties

- (i) Static state properties: position; structure; Density
 - (ii) Behaviour capacity properties: strength; transmission
 - (iii) Material properties: texture; mineral; chemical compare
 - (iv) Dynamic behaviour properties: Cohesion; friction and adhesion, cone index.
- (b) Soil dynamics in tillage and traction.
- (i) Soil – material interaction as it affects shape, orientation, depth, speed and so on.

In Nigeria most of the works that have been done in soil and tillage research to this present moment are in the areas of static state properties and material properties (Ojeniyi, 1988; Maurya et al; 1987; Olofintoye, 1987; Asoegwu, 1992; Haque and Mamman, 1992; IITA, 1980; Adeoye, 1982; Ike and Aremu, 1990) and many others.

However, only very few researchers have conducted studies into tillage research (Ademosun; 1990; Oni, 1991) It is not surprising therefore that we lack relevant data of parameters that are necessary for designing appropriate tillage tools and implements for our soils.

1.3.1 Tillage Machinery Laboratory

Tillage machinery laboratories are *sine-qua-non* in our tertiary institutions (especially where we run agricultural engineering programmes), if we are going to optimize design and mass- produce the most appropriate tillage tools and implements for Nigerian, soils. So far in Nigeria, efforts to develop tillage machinery laboratory was initiated and pioneered by Professor

O. C. Ademosun at the department of Agricultural Engineering of the Federal University of Technology, Akure (FUTA). Also at the University of Nigeria Nsukka (UNN), Professor U. G. N. Anazodo (of blessed memory) initiated and pioneered the development of tillage machinery laboratory in the department of Agricultural Engineering. At University of Ilorin, pioneering work was started there by Professor K. C. Oni. These efforts must be sustained and initiated in other institutions where Agricultural Engineering programme is being run.

The ultimate of this is to develop National Tillage Machinery Laboratories of contemporary status with the National Tillage Machinery Laboratory (NTML) Auburn, Alabama, U. S. A. These have large-scale out-door soil bins where full-size tillage machinery and equipment are tested and evaluated for their performances.

1.3.2 Optimisation of Tillage

By optimisation of tillage, we mean appropriate tillage operations for a particular soil and crop and with appropriate tools or implements. This concept also requires that the operations are performed with minimum energy to achieve the desired soil conditions. To optimize tillage therefore, studies must continue in soil dynamics in tillage and traction. Such studies will enable us to select and/or adapt tillage implements for appropriate tillage operations. Without adequate research and scientific knowledge in this area, we would not be able to optimise tillage (Aboaba 1976; Oni, 1988; Ademosun, 1990)

1.4 Justification and Relevance of this Research

- (a) There has been a dearth of information in the specialized area of soil implement dynamics in this country (Nigeria) but at the end of this study there shall be contribution to scientific knowledge in the area
- (b) Development of facilities and equipment for soil-implement dynamic research in Nigeria has been long overdue. This is the time to make progress in that direction

- (c) At the end of this work, there shall be relevant data on tillage parameters that are necessary to optimize tillage and to design the most appropriate tillage implements and equipment for Nigerian soils.
- (d) There is the need to establish or develop National Tillage Machinery Laboratory (NTML) where large scale full size tillage machines are tested and evaluated for their performances on Nigerian soils. This study is therefore a *sine-qua-non* to the establishment of NTML (perhaps at Akure, in Ondo State) in Nigeria.
- (e) FUTA is cited in an Agrarian State, where a large proportion of the adulthood depends on agriculture as a means of livelihood.
- (f) Agriculture has been the mainstay of the Nigerian economy until recently. Nevertheless, there is every indication now that we should "go back to the land".
- (g) There has been several calls by concerned agricultural engineering researchers (Aboaba, 1976) to intensify research in soil-implement dynamics.
- (h) Pioneering work has started at FUTA led by Professor O. C. Ademosun. This work must continue unabated.

1.5 Research Objectives

- (a) The general objective of this study is to develop equipment for soil tillage dynamics research and to evaluate the different tillage parameters.
- (b) The specific objectives include:
 - (i) To develop soil bin, equipment and apparatus for soil-implement dynamics in tillage research.
 - (ii) To evaluate tillage parameters, that is, soil, implement and operational parameters.
 - (iii) To study performance of simple tillage tools.

REVIEW OF LITERATURE

2.1 Soils

For engineering purposes, generally, soil is considered to be any loose sedimentary deposit, such as gravel, sand and clay or a mixture of these materials with air and / or water in the void spaces to form three-phase system (Smith,1975; Das, 1987). To a mining engineer, the soil is the debris covering the rocks or materials that he must quarry. It is a nuisance and must be removed. To the highway engineer, the soil may be the material on which a road bed is to be placed. If its properties are unsuitable, that particular soil must be removed and replaced with rock and gravel.

To an agricultural engineer, soil is a loose (unconsolidated) heterogeneous three-phase mineral or organic matter surface of the earth's crust that is capable of supporting growth of plant. Foth (1984) defines soil as unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects) micro and macro-organisms and topography, all acting over a period of time and producing a product-soil that differs from the -material from which it is derived in many physical, chemical and biological properties and characteristics.

Culpin (1986) defines agricultural soils to consist mainly of a heterogeneous collection of mineral particles existing either singly or as small 'crumbs' comprising several particles grouped together. Between soil particles are spaces which may be filled by air or by water.

Hillel (1980) describes soil as a heterogeneous, polyphasic, particulate, disperse and porous system, in which the interfacial area per unit volume can be very large. The disperse nature of the soil and its consequent interfacial activity give rise to such phenomena as adsorption of water and chemical ion exchange, adhesion, swelling and shrinking, dispersion and flocculation and capillary.

Systems in which at least one of the phases is subdivided into numerous minute particles, which together exhibit a very large interfacial area per unit volume are called disperse systems. Colloidal soils, gels, emulsions and aerosols are examples of disperse system.

The relative proportions of the three phases in the soil vary continuously and depend upon such variables as weather, vegetation and management.

2.1.1 The Development of Soils

Soils have been cultivated intensively for at least 5500 years. Yet these centuries of intensive crop production have contributed relatively little scientific knowledge about soils (Donahue et al., 1990). It is only in the past two centuries that appreciable scientific knowledge become known. Soil science, as we know it to day, embraces knowledge accumulated mostly in the last 60 to 80 years.

For Agricultural purposes, soils are the loose (unconsolidated) mineral or organic matter surface of the earth's crust that is capable of supporting plant growth.

2.1.1.1 Soil Formation

Soils are formed from hard (solid) rock masses, loose unconsolidated transported materials and organic residues. Originally, even the loose minerals were formed by the weathering of rock masses to stones, gravels, sands, silts, clays and soluble ions. Organic soils develop mostly from plants that have fallen into stagnant water where decomposition is slow (Donahue et al., 1990).

Soil formation comprises two different processes. First, the changes from a consolidated mass (rock) not capable of growing plants to the development of an unconsolidated (loose) layer of material that can support plants if climate is suitable and water is available. Second, the changes occurring within the loose material as time passes. This latter process is also called soil development. Actually, the change from a solid mass, to loose soil material and other changes within the soil profile occur simultaneously. Soil formation is used to mean both the production of unconsolidated material by

weathering processes and soil profile development, which are the changes involved in development of horizons.

Horizons tell much about the characteristics of a soil. They include information about hardpans, depth of organic matter accumulation, 'soil denseness' from clay deposition, and the extent of leaching.

The processes of weathering and of change within a soil mass is caused by many factors: Additions, losses, transformations occur constantly. Additions are made, among others, by water (rainfall, irrigation), nitrogen, from bacterial fixation, energy as sunlight sediment from wind and water, salts, organic residues, and fertilizers. Losses result from chemicals soluble in soil water, eroded small sized fractions, nutrients in grazed and harvested plants, water losses, carbon losses as carbon dioxide and denitrification loss of nitrogen (Donahue et al., 1990).

Transformations happen because of the many chemical and biological reactions that decompose organic matter, form insoluble materials from soluble substances and alter or dissolve some minerals. As water and organisms move within the soil, many substances are translocated to different depths – for example, clays to deeper layers and soluble salts into the groundwater or to the soil surface as water evaporates. Even localized sorting is active, such as forming deposits of carbonates or iron oxides in portions of the profile.

2.1.1.2 The Soil – Forming Factors

Even if soils were formed through the same weathering processes, they could still differ because of other influences. Studies of soils throughout the world have shown that the kinds of soil that develop are largely controlled by the major factors:-

- (a) Time
- (b) Climate
- (c) Biosphere
- (d) Parent Material
- (e) Topography

- (a) **Time as a soil-forming factor.** Consideration of time as a soil-forming factor assumes that the other soil-forming factors remain constant or nearly so.

A summary of soil formation rates by Buol et al(1980), indicates a range of 1.3 years per centimeter for young soil (Entisol) developed from volcanic ash to 750 years per centimeter for 1 – meter thick Oxisol in African. A given period of time may produce much change in one soil and little in another. For this reason, the maturity of soil is expressed in the degree of horizon development instead of the number of years. Conditions that hasten the rate of soil development are:

- (i) A warm humid climate.
- (ii) Forest vegetation
- (iii) Permeable, unconsolidated material low in lime content and
- (iv) Flat or depressional topography with good drainage

Factors that tend to retard development are:

- (i) a cold, dry climate
- (ii) grass vegetation
- (iii) impermeable, consolidated material, high in lime and
- (iv) a steeply slopping topography

- (b) **Soil development in relation to climate:-** Climate is an increasingly dominant factor in soil formation, with increased time, mainly because of the effects of precipitation and temperature (Brady, 1984; Foth, 1984 and Donahue, et.al., 1990).

Moisture is important in soil formation: A soil is said to be developed when it has detectable layers (horizons), such as accumulated clays, organic colloids, carbonates or soluble salts that have been moved downward by water. The extent of colloid movement and depth of deposition are determined partly by the amount and pattern of precipitation, which produces the leaching action. Surplus water is effective in the translocation of colloids and the removal of soluble weathering products from the solum.

Indirectly, precipitation has another influence if leaching cause the pH of the surface layers to become about 4.5 or less. Under these conditions, microbial decomposition of organic matter may become so restricted that the litter added to the surface of the soil accumulates instead of decomposes. This accounts for the existence of prominent O horizons in some forest soils.

Every increase in temperature of 10°C increases the rate of chemical reactions two to three times. Increased weathering and clay content occur with an average increase in soil temperature.

Climate also in influences soil formation indirectly through its action on vegetation. Semiarid climates encourage only scattered shrubs and grasses (Tedrow et al., 1967). Arid climates supply only enough moisture for sparse, short grasses or shrubs which may not be dense enough to protect the soil against wind and water erosion. Many arid soils exhibit only slight organic matter accumulation and small amounts of profile development. This is contrasted with the deep-weathered profiles of the humid tropics.

(c) **Biosphere and soil formation:**

The major role of biotic activity in profile differentiation cannot be over emphasized. Organic matter accumulation, profile mixing, nutrient cycling, and structural stability are all enhanced by the activities of organisms in the soil. Also, nitrogen is added to the soil system by micro organisms alone or in association with plants.

Burrowing animals, such as moles, gophers, prairie dogs, rabbits, earthworms, ants, and termites are highly important in soil formation when they exist in large numbers. Soils that harbour many burrowing animals have fewer but deeper horizons because of the constant mixing within the profile, which nullifies the organic colloid and clay movements downward.

Micro organisms help soil development by slowly decomposing organic matter and forming weak acids that dissolve minerals faster than pure water.

The most striking evidence of the effect of vegetation on soil formation is seen in comparing properties of grassland and forest soils. Grassland soils

have several characteristics that are of considerable agricultural significance. For example, the organic matter content so the grassland soils, is generally much higher, especially in the subsurface horizons. This gives the soil darker colour and higher moisture- and cation-holding capacity as compared to the "forest" soil. Also, structural stability tends to be encouraged by the grassland vegetation.

Plants absorb nutrients from the soil and transport these nutrients to the tops of the plants. When the tops die and fall onto the soil surface, decomposition of organic matter releases the nutrients in a self fertilizing "do-it-yourself manner".

Human activities should not be over looked as factors influencing soil formation. The removal of natural vegetation by cutting trees or by cultivating the soil abruptly modifies the soil- forming factors. Likewise, irrigation of a soil in an arid area drastically influences the soil-forming factors as does adding fertilizer and lime to soil of low fertility.

(d) Parent Material

Parent materials influence soil formation by their different rates of weathering, the nutrients they contain for plant use, and particles sizes they contain (for example sandstones = sandy; conglomerates = rocky; shales = clayey). The less developed a soil is the greater will be the effect of parent material on the properties of the soil. However, even the properties of well developed soils will be greatly influence by the parent material.

(e) Topography And Soil Formation

Topography modifies soil profile development in three ways

- (i) By influencing the quantity of precipitation absorbed and retained in soil, thus affecting moisture relations.
- (ii) By influencing the rate of removal of soil by erosion and
- (iii) By directing movement of materials in suspension or solution from one area to another

As the steeples of slope increases there is greater run off and erosion, soil creep, less water infiltration and less water available for chemical and

biological activity. The net effect is a retardation in soil genesis. Generally an increase in percent slopes is associated with a reduction in (a) leaching (b) organic matter content (c) clay translocation (d) mineral weathering (e) horizontal differentiation (f) solum thickness.

Erosion on steep slopes commonly results in thin soils, especially where soils are underlain by bedrock.

2.1.2 Soil Physical Properties

The physical properties of a soil have much to do with its suitability for the many uses to which it is put. The rigidity and supporting power, drainage and moisture storage capacity, plasticity, ease of penetration by roots, aeration, and retention of plant nutrients are all intimately connected with the physical condition of the soil. It is pertinent, therefore, that persons dealing with soils know to what extent and by what means those properties can be altered. This is true whether the soils is to be used as a medium for plant growth or as a structural material in the making of highways, dams, and foundation for buildings or for waste disposal systems.

Tillage operations alter the soil physical properties, and hence the operations selected should affect the soil physical properties in the desired manner.

Soil physical properties of greatest importance to crop growth function (seed germination, root and shoot development) include water, strength and porosity characteristics and aeration and temperature regimes. None of these properties are independent variables since a change in one may produce a change in the others. For example, soil water content plays a dominant role in determining the nature and extent of variations in the other physical properties.

The physical properties of soil and their various interactions are influenced largely by soil structure (as characterized by the size, shape, and strength of aggregates or the size, shape and stability of pores), and crop residues or organic amendments (placement, quantity and type of organic materials) (Godwin, 1990).

The objective of this section is to discuss fundamental principles underlying soil physical properties and practical aspects of tillage-induced effects on soil properties for the purpose of creating a structurally favourable seedbed environment, increasing water infiltration and retention (evaporation control) and protecting soil from erosion.

2.1.2.1 Soil texture

Soil texture refers to the coarseness or fineness of the soil. Specifically, texture is the relative proportions of **sand, silt and clay** or the particle-sized groups smaller than gravel (less than 2 millimeters in diameter).

Bouyoucos (1962) devised the hydrometer method for determining the content of sand, silt and clay without separating them. The proportions of the separates in classes commonly used in describing soils are given in the textural triangle shown in Appendix A4. The following classification has been devised for grouping soils texturally (Figure1).

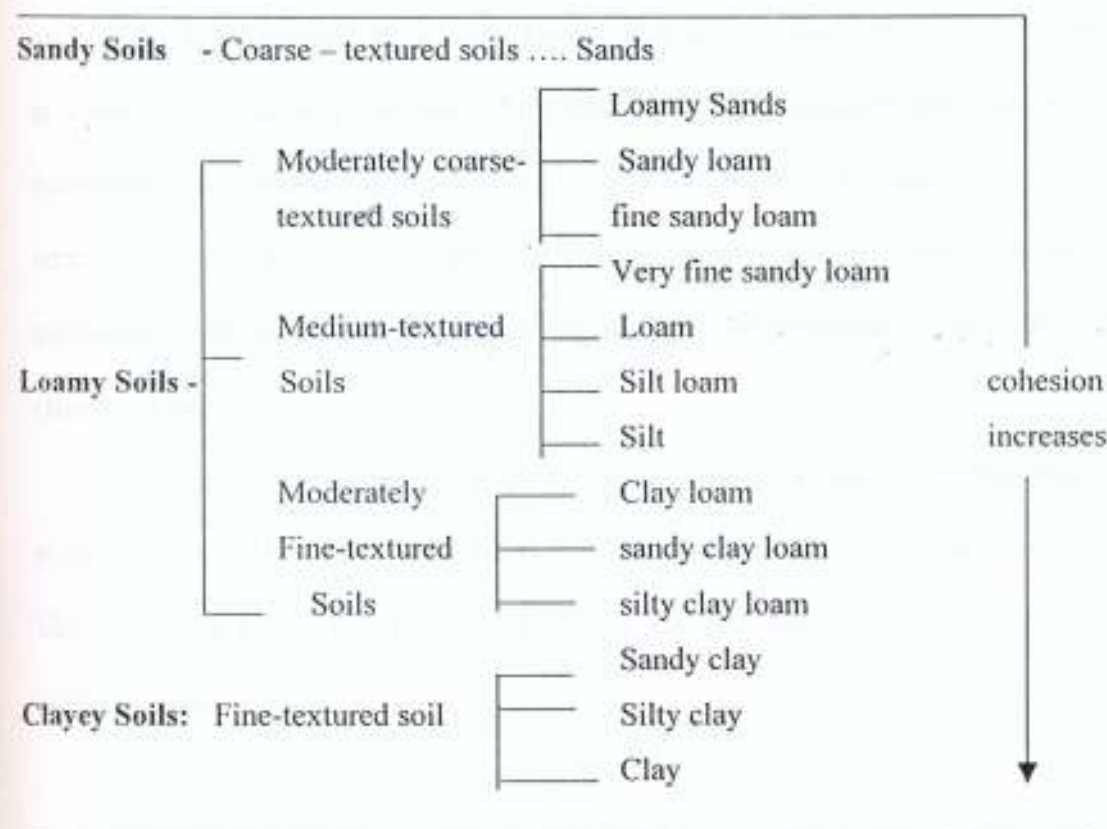


Figure.1 Soil Textural Classification (USDA).

Plasticity, rigidity, permeability, ease of tillage, droughtiness, fertility and productivity may be closely related to the textural classes in a given geographical region, but because of the great variation that exists in the mineralogical composition of the separates no broad generalizations of the world's soils can be made.

The ability of the soil to support machinery and hooves of grazing cattle is related to both texture and water content. Soils with high contents of organic matter and clay have a low load-bearing capacity when wet (Brady, 1984)

2.1.2.2 Soil Structure and Aggregation

The term structure relates to the grouping or arrangement of soil particles. It is strictly a field term that describes the gross, overall combination or arrangement of the primary soil separates into secondary groupings called aggregates or peds. A profile may be dominated by a single type of aggregate. More often several types are encountered in different horizons. Soil conditions and characteristics such as water movement, heat transfer, aeration, bulk density and porosity are much influenced by structure. Infact, the important physical changes imposed by the farmer in ploughing, cultivating, draining, liming and manuring his land are structural rather than textural (Brady, 1984).

The dominant shape of peds or aggregates in a horizon determines their structural type. The four principal types of soil structure are spheroidal, platy, prism-like and block-like. The spheroidal, prison-like and block – like types have two subtypes each.

A brief description of each of the structural types with schematic drawings is given in **Figure 2**

In tilled soils, aggregates are formed and fragmented by the physical process of tillage. Differences between aggregate size ranges may not be large due to the fact that some are formed by the breakdown of larger aggregates, while others are formed by the compression of smaller aggregates into larger ones. Aggregation under various cropping systems is associated with the activity of both plant roots and soil microbes (Oades, 1984).

Plate-like

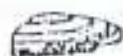


Plate - leafy and
flaky also found

May occur in any part of profile. At times
inherited from the soil material.

Prism-like



Prismatic
(Level tops)



Columnar
(Rounded tops)

Both usually subsoil manifestations.
Common in soils of arid and semi-arid
regions.

Block-like



Blocky
(Cube-like)



Blocky
(Subangular)

Common in heavy subsoils, particularly
those of humid regions.

Spherical



Granular
(Porous)



Crumb
(Very porous)

Characteristic of the furrow slice.
Subject to wide and rapid changes.

2: Structural Types Found in Mineral Soils (Brady, 1984)

Researchers have examined the physical and mechanical properties of individual aggregates and beds of aggregates in an effort to define the basic properties of aggregates that influence seedbed condition in relation to the germination and emergence of crops. Particle size distribution affects nutrient and water availability while bulk density affect shoot and root growth through porosity and water relations (Braunack and Dexter, 1989).

Strength of aggregates influences the load that soils can bear without undue structural damage from the passage of vehicles. It also affects the detachment of particles under raindrop impact (Francis and Cruse, 1983) and hence surface crusting. Root proliferation is also influenced by aggregate strength (Voorhees et al., 1971; Whiteley and Dexter, 1984). Dexter and Kroesbergen (1985) have described some simple methods for the determination of the tensile strength of aggregates. A sophisticated technique which enables the energy to crush individual aggregates to be measured has been developed by Boyd et al. (1983)

Aggregate size has effect on the germination and growth of crops. It has been suggested that ideal conditions for a seedbed are produced by aggregates not less than 0.5-1 mm and not coarser than 5-6 mm (Russell, 1973). To maximise seed-soil contact, Hadas and Russo (1974) suggest that aggregates should be one-fifth to one-tenth the size of the seed. This, however, depends on soil water suction. For small-seed crops this would result in dust particle sizes which are highly erodible (Braunack and Dexter, 1989).

2.1.2.3 Particle density and bulk density

(a) **Particle density:-** One means of expressing soil weight is in terms of the density of the solid particles making up the soil. It is usually defined as the mass (or weight) of a unit volume of soil solids and is called particle density (ρ_s). For many mineral soils, the particle density will average about 2.60 grams per cubic centimeter (gm/cm^3). It does not vary a great deal for different soils unless there is a considerable variation in content of organic matter or mineralogical composition. When unusual amounts of minerals with high particle density such as magnetite, garnet, epidote, zircon, tourmaline and hornblende are present, the particle density may exceed 2.75 Mg/m^3 or $2.75 (\text{gm/cm}^3)$ Brady (1984)

Organic matter weighs much less than an equal volume of mineral solids, having a particle density of $1.1 - 1.4 \text{ gm/cm}^3$. Consequently, the amount of this constituent in a soil markedly affects the particle density. This accounts for the fact that mineral surface soils (which almost always have higher organic matter content than the subsoils) usually possess lower particle densities than do subsoils.

(b) Bulk density:- A second important weight measurement of soils is bulk density (ρ_b). It is defined as the mass (weight) of a unit volume of dry soil. This volume includes both solids and pores.

$$\text{Bulk density, } = \frac{\text{mass of oven dry soil} \quad \text{gm}}{\text{Volume of oven dry soil} \quad \text{cm}^3} \quad (1)$$

Obviously bulk density is always smaller than particle density. The bulk densities of clay, clay loam and silt loam surface soils normally may range from 1.00 to as high as 1.60 gm/cm^3 depending on their condition. A variation from 1.20 to 1.80 gm/cm^3 may be found in sands and sandy loams. The bulk density is affected by the structure of the soil, that is, its looseness or degree of compaction as well as by its swelling and shrinkage characteristics, which are dependent upon clay content and wetness (Hillel, 1980b). Even in extremely compacted soil, however, the bulk density remains appreciably lower than the particle density, since the particles can never interlock perfectly and the soil remains a porous body, never completely impervious. The average soil bulk density of cultivated loam is approximately $1.1-1.4 \text{ gm/cm}^3$. For good plant growth, bulk densities should be below about 1.4 gm/cm^3 for clays and 1.6 gm/cm^3 for sands (Brady, 1984).

The system of crop and soil management employed on a given soil influences its bulk density, especially of the surface layers. Ojeniyi (1988) reported that the soil under bare fallow and cowpea respectively had lower mean dispersion index, bulk density and higher porosity than the soil under maize. Also, that the soils under maize followed by cowpea, and under maize both had higher bulk density, dispersion index and lower porosity than the soil under fallow and cowpea.

Maurya et al. (1987) reported that soil bulk density was affected by the ploughing method: at 5 cm depth bulk density was higher in chisel ploughing

treatment than conventional ploughing. At 25 cm depth, chiseling significantly decreased bulk density than conventional ploughing. This result is in line with that of Weatherly and Dane (1979). Below 30, cm bulk density was more or less the same in the two ploughing treatments.

Bulk density of soil is measured by taking an undisturbed block of soil (clod or soil core) determining its volume, drying it and weighing it. Clods can be coated with paraffin or liquid plastic and dipped into water to measure water displacement and hence to calculate volume.

2.1.2.4 Pore space and porosity

Pore space- The pore space of a soil is that portion of the soil volume occupied by air and water. The amount of this pore space is determined largely by the arrangement of the solid particles. "Tortuous Pathways" best describe soil pores. Sands have large and continuous pores. In contrast, clays, although containing more total pore space because of the minute size of each clay particle, have very small pores which transmit water slowly.

Two types of individual pore space occur in soils – macro and micro. Pores less than about 0.06 mm in diameter are considered as micropores and those larger as macropores. The macropores characteristically allow the ready movement of air and percolating water. In contrast, the micropores are mostly filled with water in a normal field soil and do not permit much air movement into or out of the soil.

Past cropping exerts a decided influence upon pore space of the furrow slice. Tiessen et al. (1982) reported that the continuous blue grass sod of the Hagerstown loam of Pennsylvania had a total porosity of 57.2% whereas the comparable rotation plot (cropped soil) showed only 50%. This is in agreement with report of Ojeniyi (1988) and Brady (1984) that cropping tends to lower the total pore space to less than that of the virgin or uncropped soils.

Porosity:- Porosity (n) is the volume percentage of the total pore space, that is, the ratio of the volume of voids to the total volume. Its value generally lies in the range 30-60%

2.1.2.5 Soil Consistency

Soil consistency is a term used to describe the resistance of a soil at various moisture contents to mechanical stresses or manipulations. It is a composite expression of those cohesive and adhesive forces that determine the ease with which a soil can be reshaped or ruptured. It is commonly measured by feeling and manipulating the soil by hand, or by pulling a tillage tool or instrument through it. The consistency of soils is generally described at three soil moisture levels: wet, moist, and dry.

In a progressive transition from a dry state to a moist, then to a wet, then saturated, and finally to a super-saturated state, the soil by turns undergoes a rather dramatic series of changes in consistency, from a hard and brittle solid, to a soft and friable solid, to a moldable plastic Semi solid, and then to a sticky and viscous liquid (Hillel, 1980). These transition were codified by a Swedish soil scientist named Atterberg, who devised simple empirical criteria or testing procedures, known universally as the Atterberg Limits. Bowles (1986) stated the five limits proposed

- (i) Cohesion Limit- that moisture content at which soil crumbs just stick to gather.
- (ii) Sticky Limit- that moisture content at which soil just sticks to a metal surface some. This has some significance to the agricultural engineer, since it is related to soil sticking to the moldboard of a plough or disc in cultivating soil.
- (iii) Shrinkage Limit- the moisture content below which no further soil volume reduction (or shrinkage) occurs.
- (iv) Plastic Limit- moisture content below which the soil is non-plastic. It is the moisture content of which the soil begins to break apart and crumble when rolled by hand into threads 3mm ($\frac{1}{8}$ in) in diameter
- (v) Liquid Limit- moisture content below which the soil behaves a plastic material. At this moisture content, the soil is on the verge of becoming a viscous fluid.

2.1.2.6 Soil Colour

Dark soils absorb more heat than do light-coloured ones. When these temperatures reach up to between $65.5 - 70^{\circ}\text{C}$, they become lethal to many plants that could be grown on those soils (Donahue et al., 1990). Although black soils having high humus content absorb more heat than light – coloured soils, they also frequently hold more water. However, water has greater heat capacity than the soil minerals. Water also has high heat of evaporation. The net result is that many dark soils are not warmer than adjacent light-coloured soils because of the temperature-modifying effects of soil moisture.

Soil colour indicates many soil features. A change in soil colour from the adjacent soils indicates a difference in the soil's mineral origin (parent material) or in soil development. White colours are common when salts of carbonate (lime) deposits exist in the soil. Spots of different colours (mottles), usually rust colour indicate a soil that has a period of inadequate aeration each year. Bluish, grayish and greenish subsoils (gleying) with or without mottles, indicate longer periods each year of waterlogged conditions and inadequate aeration. Within small geographic regions, darker colour usually indicate higher organic matter contents. However, between contrasting climatic conditions colour is not a good indicator of organic matter content.

Soil colour determination is standardized and determined by the comparison of the soil colour to Munsell colour charts.

2.1.2.7 Soil Temperature

The temperature of a soil greatly affects the physical, biological and chemical processes occurring in that soil. In cold soils, chemical and biological rates are slow. Biological decomposition is at near a stand still, thereby limiting the rate at which nutrients such as nitrogen, phosphorus, sulphur and calcium are made available. For example the oxidation of nitrogen to the nitrate form

(nitrification) does not begin until the soil reaches about 5°C , the most favourable limits being 27 to 32°C (Brady, 1984).

The effect of tillage on soil temperature depends mainly on the type of tillage, crop residue and cultural practices. During daylight hours when soil temperatures increase, soils near the surface are warmer when tilled and cooler when untilled. During the right time, the opposite occurs. Conversely, subsoil temperatures remain higher during the daytime in untilled soils at any given depth (Godwin, 1990).

2.1.3 Chemical and Colloidal Properties

A knowledge of soil chemistry is used to improve the availability of nutrient to plants, to utilize soil microbial populations, to improve the physical condition of the soil, to improve soil stability under loads, to stabilize soil, to diminish corrosion of pipes (buried metals) and so on. Soil colloids are the most chemically active portion of the soil (Brady, 1984)

2.1.3.1 Soil Clays

Clays, the active mineral portion of soils are dominantly colloidal and crystalline. The term 'clay' has three meanings in soil usage:

- (i) It is a particle fraction composed of any particles less than 2 micrometers ($2/\mu\text{m}$) in effective diameter
- (ii) It is a soil textural class. Clay as discussed here in this study includes only clay minerals of specific crystalline or amorphous composition and of any size up to several micrometers.

For various reasons, clays have a net negative charge, which will attract and positively charged cations such as potassium (K^+), sodium (Na^+), ammonium (NH_4^+), calcium (Ca^{2+}), Magnesium (Mg^{2+}) and hydrogen (H^+). The amount of these positive cations held by clays vary with the kind of clay. Plant roots can use these firmly held cations as nutrients.

2.1.3.2 Organic Colloids (Humus)

Humus is a temporary intermediate product left after considerable decomposition of plant and animal remains-temporary because the organic substances remaining continue to decompose slowly. Humus is generally dark-coloured material found mostly in the surface zone (A horizon) of soils. Humus is a morpous, nearly insoluble in water but mostly soluble in dilute alkali (NaOH or KOH) solutions.

Humus often coagulates in association with clay and serves as a cementing agent, building and stabilizing soil aggregates (Hillel, 1980).

2.1.3.3 Cation Exchange

Cation exchange takes place on the surfaces of clay and humus colloids as well as on the surface of plant roots. The cations most numerous on exchange sites in soils are calcium (Ca^{2+}) Magnesium (Mg^{2+}), hydrogen (H^+), sodium (Na^+), potassium (K^+) and aluminium (Al^{3+}). Cation exchange is an important reaction in soil fertility, in correcting soil acidity and basicity in changes altering soil physical properties, and as a mechanism in purifying or altering percolating waters.

2.1.4 Soil Organic Matter

2.1.4.1 Significance of organic matter

Organic matter, living or dead plant and animal residue, is a very active and important portion of the soil. Researchers (Donalhue et al 1990; Foth, 1984; Brady, 1984; Ayanaba and Sander, 1981; Godwin, 1990) summarized some benefits of organic matter to agricultural soils in the following terms:

- (1) Organic matter is the source of 90 – 95 percent of the nitrogen in unfertilized soils.
- (2) Organic matter can be the major source of both available phosphorus and sulphur when soil humus is present in appreciable amount (about 2 percent or more).

- (3) Organic matter supplies directly or indirectly through microbial action, the major soil aggregate- forming cements, particularly the long, sugar chains called polysaccharides.
- (4) Organic matter contributes to the cation exchange capacity often furnishing 30 – 70 percent of the total amount. The large available surface of humus have many cation exchange sites that adsorb nutrients for eventual plant use and temporarily adsorb heavy metal pollutants (lead, cadmium etc) which are usually derived from applied waste waters. Adsorption of pollutants helps clean contaminated water.
- (5) Organic matter facilitates soil aggregation and provides structural stability which helps to improve air and water relationships and root growth and protect soils from wind and water erosion.
- (6) Organic matter imparts a dark colour to most soils which increases their capacity to absorb heat and warm up rapidly in hot weather.
- (7) Organic matter is a carbon supply for many microbes that perform other beneficial functions in soil (e. g. free nitrogen fixers, denitrifiers)

It was reported (Iremiren, 1992) that organic matter content largely determines the inherent fertility of a soil and that it consisted of very thin layers concentrated within the first 15 cm of the top soil in tropical soils. In contrast the layer could be about 50 cm thick in temperate soils.

He further, reported that organic matter content of the soils in Nigeria decreases from the forest to the savanna in the order:

Forest, $1.3^+ - 0.08\%$ > Derived savanna, $0.98^+ - 0.07\%$ > Guinea savanna, $0.7^+ - 0.06\%$

2.1.5 Soil Taxonomy

Soil taxonomy is a classification of soil according to natural relationships among the soil characteristics. Taxonomy is concerned with classifying and arranging

such natural and individual characteristics as horizons, soil moisture regime, soil texture, soil mineralogy, soil structure and colour.

The six categories of the United States system of soil taxonomy are in decreasing rank: ORDER, SUBORDER, GREAT GROUP, SUB-GROUP, FAMILY AND SERIES. The New American soil classification system (Summary of the global soil orders) is shown in Appendix A5

2.1.5.1 Major Soil Types in Nigeria

The major soil types found in Nigeria are as shown in Appendix A3. They include.

- (i) alluvials (ii) Ferro soils (iii) Ferruginous tropical soils (iv) lithosols (v) vertisols (vi) regosols and (vii) semi-arid brown and reddish brown soils (Agboola, 1979).

About one-third of Nigerian soils are of only medium productivity (Agboola, 1979). The ferruginous tropical soils mainly constitute this class. The main weakness is that under cultivation, the soil surface forms a hard crust when exposed to heavy rainfall, and causing low infiltration rates and high run-off. Most of the other soil types including the vertisols, lithosols, regosols and semi-arid brown and reddish-brown and ferralitic soil are considered to be of low or very low productivity are inadequate moisture and low organic matter content.

2.1.5.2 Soil Map of the World

The soil map of the world is presented in appendix A6. The information therein enables us to observe soil types of countries with respect to climate across the world.

2.2 Soil Failure Analysis

Soil failure has been defined as the alteration or destruction of a soil structural condition by mechanical forces such as shearing, compression or tearing (ASAE

standards, 1989). As a time moves, it causes permanent deformation of the soil, which is referred to as soil failure (Stafford, 1984).

2.2.1 Nature of Soil Failure

Soil is extremely weak in tension, very strong in compression and in practice fails mainly in shear (Spoor, 1969). Whenever a body of soil is subjected to stress, some strain will take place. If the magnitude and duration of the stress application are small, strain may be practically unnoticeable and disappear after removal of the stress. If however magnitude of the stress is large, considerable strain may result with only partial recovery or non at all, so that permanent deformation results. In soil, strain is often very large. For example, an increase in bulk density from 1.1 to 1.4 gm/cm³ represents a volume change of 27% (Hillel 1980). In small and confined test samples of soil, strain may be fairly uniform. However, under natural soil conditions, deformation can take place in a very complicated geometric pattern (Hillel, 1980).

There is as yet no way to predict the amount and type of strain from a given form and magnitude of stress (Gill and Vanden Berg, 1968). Hence the stress-strain relations of a soil must in each case be determined experimentally. Soil deformation is often time dependent in a manner that does not conform to either elastic or plastic theories. More complex models are therefore needed to describe soil behaviour. McMurdie (1963) applied the theory of visco elasticity to soil in a study of creep phenomena. On the whole, progress in developing stress- strain- time relations which adequately characterize soil behaviour has been slow, apparently owing to the inherent difficulty of the subject as well as to soil variability in space and time as regards composition, moisture, compaction, and aggregation. The concept of soil failure under stress underlies the very important concept of strength which shall be discussed in section 2.6.

"Failure" is sometimes used interchangeable with "yield", but this can be misleading. The concept of yield originally served to characterize the behaviour of ductile metal. Usually, when a rod of ductile metal is stressed by tension, the strain is

at first elastic. As the stress is increased, a point is eventually reached, called the yield point, beyond which plastic behaviour is observed. In common engineering usage, the yield stress is taken to be the highest stress which can be borne by the metal member of a structure. In actual fact, there may be a considerable difference between the yield stress and what is known as the ultimate stress, or failure stress at which fracture or separation actually occurs. Failure in soil is more complex than in most ductile or brittle materials. Depending on such variables as moisture and clay contents, soils can vary their properties from those resembling a viscous liquid to those resembling a brittle solid (Hillel, 1980).

2.2.1.1 Types of Soil Failure

Gill and Vanden Berg (1968) reported four types of soil failure in terms of stress-strain behaviour namely shear, compression, tension, and plastic flow. Koolen and Kuipers (1983) report two types of soil failure: shear failure and tensile (Brittle) failure. Selig and Nelson (1964) report two principal failure mechanisms, namely passive shear failure and tensile failure. Hillel (1980) also report two types of soil failure: tensile failure and shear failure. According to him, soil failure occurs for example when a cylinder of soil is subjected to axial stress if it is a rigid soil, failure is by fracture and if it is soft soil, failure is by plastic flow. Elijah and Weber (1971) identified four distinct types of soil failure namely shear planes, flow, bending and tensile. They reported that two or more of the four types of failure were often observed in the same test run. Payne (1956) and Selig and Nelson (1964) observed that a blade working in a soil creates a series of compression and shear failure and that the failed mass in front of the soil moved up until it collapsed under its own weight. Stafford (1981) explained soil failure caused by a rigid tine and associated draught force characteristics on the basis of critical state model of soil mechanics. Two general modes of failure, termed brittle and flow, were identified with two regions of critical state model (Atkinson and Bransby, 1978). Olson and Weber (1965) and Stafford (1981) observed that the type of failure can change from "shear" to "flow" as the implement speed is increased.

2.2.1.2 Soil Failure in Confined Spaces

It was reported by spoor (1969) that a much greater force will be required to move a plate or tool working in soil in a confined space than in the open soil.

Godwin and Spoor (1977) carried out studies using a glass-sided box to observe the soil failure pattern in the vertical plane containing the centre line of the tine. The distance ahead of the tine at which the district shear plane broke the surface was defined as the forward rupture distance. f. A. compacted soil-wedge was observed on the front of each tine at all tine widths and rake angles tested (Figure 3)

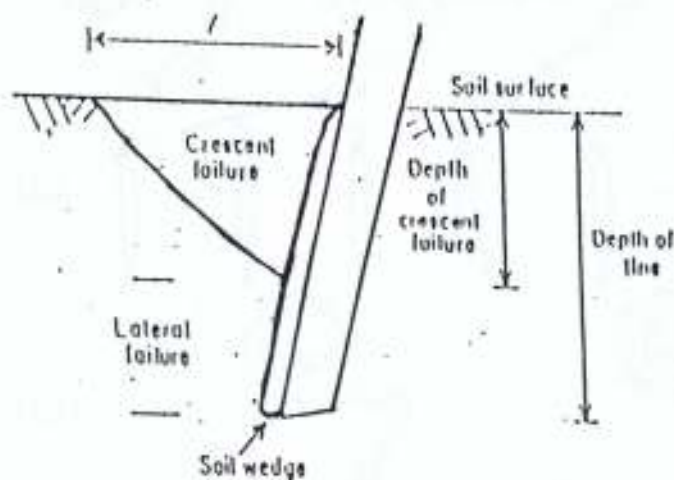


Fig. 3: Soil Failure Pattern (Godwin and Spoor, 1997)

2.2.2 Soil failure with Narrow Tines

When a soil has to be loosened, a body (operating tool) can be move through the soil. Such a body will be labelled a tine if the loosening effect reaches considerably further than the width of the body (Koolen and Kuipers, 1983). In his analysis Payne (1959) defines narrow tines as those haivng a depth/width ratio greater than 1.0. Spoor (1969) defines narrow tine as one where the depth of working is large compared with the width and where the end effects cannot be neglected. Tines occur in chisel ploughs, spike-tooth harrows, cultivators, p.t.o driven implements for seedbed preparation, weeders and subsoilers (Krause and Lorenz, 1979; Davis et al, 1992; Bernacki and Haman, 1973).



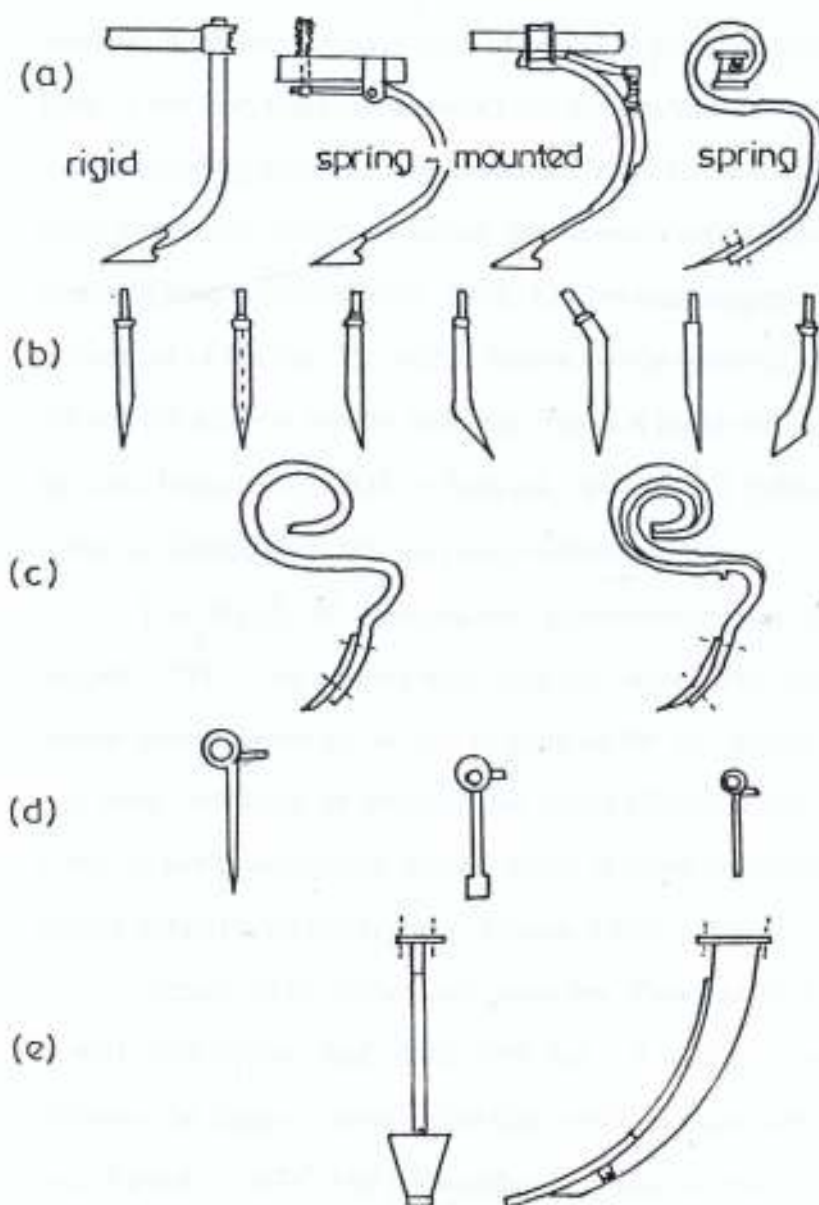


Fig.4 : Major common types of tines (Koolen and Kuipers, 1983)

2.2.2.1 Patterns of Soil Cleavage

Three movement patterns typical of soil influenced by a tine has been distinguished; the shear type, the flow type and the type with open crack formation (Koolen and Kuipers, 1983). The shear type is by far the most important and has been investigated most thoroughly. This type is described extensively for a straight vertical tine without profile (Koolen, 1977). The following patterns of soil cleavage and the accompanying process have been observed as the tine moves through a soil block. In front of the tine, there is a compact soil mass which can clearly be distinguished from the surrounding soil. This soil mass is usually called soil-wedge. The loose soil in front beside the aredge is called the crescent soil. There always remains a small trench behind the tine (Payne, 1956; Koolen and Kuipers, 1983). During the forward movement of the tine, the wedge moves slowly upwards, the upper part being broken off and left aside at regular intervals. There is loose soil in front of and to the sides of the tine being transported in forward, upward and sideways directions, as well as loose soil falling back into the furrow behind the tine.

The degree of crescent soil pulverization can vary strongly (Koolen and Kuipers, 1983). An extreme case happens, when after shearing, there is little or no further pulverization of the soil in front of the soil wedge. Then the freshly formed soil lump will keep its crescent like shape (Payne, 1956). However, in most cases some further pulverization occurs, which is more pronounced at higher speeds and at greater natural soil heterogeneity. (Payne, 1956).

Furrow width values are given by Payne (1956), O'callaghan and Farrelly (1964), and Willatt and Willis (1965a). A unique relationship appears to exist between the ratios; furrow width/tine width and tine depth/tine width (O'Callaghan and Farrelly, 1964). The relationship between the ratios, distance from tine to tip of crescent/width of tine and tine depth /tine width is also unique (Payne, 1956). These relationships apply to different tine widths and working depths, but are slightly dependent on soil type (Payne, 1956) and on travelling speed (Willat and Willis, 1965a). The furrow walls and bottom

can exhibit fissures. The longer axes of these fissures are perpendicular to the travelling direction of the tine (O' Callaghan and Farrelly, 1964)

The loose soil pushed away by the tine partly falls back into the furrow, and partly comes to rest outside the furrow on top of the still firm soil surface. Usually, a small trench is left in the middle of the furrows, with a small ridge on either side. If there is not much crescent soil pulverization, the soil clods that have come to rest can have equal shapes and positions and exhibit a very regular pattern (Payne, 1956). In the loose soil left behind mixing and sorting occur often.

2.2.2.2 Vertical Wedge Formation

Soil wedge formation has been described extensively (Gill and Vanden Berg, 1968; Koolen and Kuipers, 1983; Koolen, 1977). O'Callaghan and Farrelly (1964), Godwin and Spoor (1977) showed that soil wedges develop on the face of plane tines and that the nature of the general soil disturbance depends upon soil conditions, tine rake angle and working depth. The soil wedge that moves upwards will be refilled from beneath with soil from the lower part of the tilled layer (Willat and Willis, 1965b). The upward wedge speed fluctuates. Sometimes the wedge or part of it tends to adhere to the tine (Koolen and Kuipers, 1983). Harrison (1982) observed that soil wedge is not only a function of rake angle and external friction but is also a function of blade sharpness.

2.2.2.3 Critical Depth

Critical depth has been described as the depth below which the amount of upward soil loosening generated by the tine is minimal and the lateral extent of the major soil failure planes to the side of the tine changes little with increasing depth (Spoor and Fry, 1983). However, in their study Spoor and Fry (1983) defined critical depth as the depth at which the horizontal distance between the failure planes approaches 1.5 times the tine width. Critical depth also represent the depth below which lateral deformation beyond the failure plane become significant. Spoor and Godwin (1978) reported that there is a critical working depth for all rigid tines below which compaction occurs rather than effective soil loosening. The work of Godwin and spoor (1977) suggest

that below critical depths, soil movement changes from a predominantly forward and upward form (crescent failure) to a mainly forward and side ways one (lateral failure). Spoor and Fry (1983) concluded that

- (i) Critical depth increases with increasing tine width and curved low rake angle tines tend to have deeper critical depths than steeply raking tines
- (ii) Critical depth tends to increase with increasing soil moisture content and increasing bulk density.
- (iii) The lower the vertical confining stress imposed on soil at depth by the surface layers, the greater the critical depth. The critical depth is smaller as the soil is looser. It increases with increasing angle of internal friction of the soil, increasing tine width and increasing forward rake angle of tine (Godwin and Spoor, 1977, Spoor and Godwin, 1978). For example, for a 25.4mm wide vertical tine without profile, the critical depth in a dense soil appeared to be about 120mm (Koolen and Kuipers, 1983)

2.2.2.4 Narrow Tine Theory by Payne

Payne (1956) studied simple tillage tools in detail and their interaction with soil under various conditions. He observed soil reactions and failure section qualitatively. With narrow tools Payne further reasoned that the vertical shear surfaces would intersect each other as well as the bottom curved surface. Thus a wedge of soil immediately adjacent to the tool would be isolated from the rest of the soil mass. With wide tools, the vertical shear surfaces would not intersect each other so that the wedge would never be formed.

As the narrow tool advances, it pushes forward and upward two blocks of soil on each side of the center line of the tool in the direction of travel. He termed the soil broken loose but not part of the wedge as the crescent. The knife-like action of the wedge causes the symmetrical formation of four blocks of soil adjacent to the wedge in the crescent

2.2.2.5 Narrow Tine Theory Proposed by J.R.O' Callaghan

The theory distinguishes between tines working at shallow depths and those working at large depths

- (a) Shallow tines.

The theory considers that tine acts like a retaining wall so that at the point of failure, a prism of soil is about to move upwards in a vertical plane. The slip surface takes the form of a logarithmic spiral. The passive earth pressure per unit width of tine can be calculated using Ollide's logarithmic spiral construction or other approximated methods, and the draught force of the tine determined.

(b) Deep Tines

The theory considers that tine behave like a footing so that at the point of soil failure the soil is just about to move in a horizontal plane. it is proposed that Prandtl's analysis for a punched indentation problem applies.

2.2.2.6 Narrow Tine Theory by Hettiaratchi D.R.P. and Reece A. R

This theory attempts to provide a semi empirical solution which will allow the rapid analysis of tine failure problems. The soil failure pattern assumed is based on that described by Payne and use is made of retaining wall and bearing capacity theory in the analysis. It is assumed that soil failure takes place in two ways simultaneously.

(a) Forward vertical failure

This failure takes place directly in front of the tine and the tine is considered to behave like a retaining. The soil force on the tine due to this type of failure can be determined by using the general soil mechanics equation and the n-factors appropriate to a retaining wall type of failure.

(b) Sideways horizontal failure

The soil at the side of tine undergoes a bearing capacity failure. In this analysis, unlike that of O'callaghan, the soil is considered to have weight and the vertical plane containing the tine does offer some resistance to the soil displaced by the soil wedge.

2.2.2.7 Current Narrow Tine Theories

It can be concluded from previous work that changes in the nature of soil failure occur with changing tine working depth and soil conditions. Spoor and Fry (1983) noted that no detailed investigations have been made to determine the exact three-dimensional nature of soil disturbance generated by

low rake angle narrow tines or the factors controlling it. They therefore examined this disturbance and the major determining factors.

Soil Deformation mechanisms:- The experimental results of Spoor and Fry (1983) suggest that two, forms of soil deformation occur simultaneously.

- (a) An intermittent form, relatively close to the tine where soil is brought to complete failure and slips towards the soil surface along well defined failure planes –upward failure
- (b) A continuous, more general form of disturbance, more closely associate with horizontal planes, where the failure state may not be reached-lateral deformation

Upward failure- Glass sided tank studies by Hettiaratchi and Reece (1975) and Tanner (1960) examining soil deformation ahead of tines in vertical elevation, clearly showed the regular generation of curved failure planers extending from the tine base to the soil surface. The forward extent of these failure planes ahead of the fines decreases rapidly at depth will in creasing working depth until they approach, in the limit, the soil wedges on the tine face. The side failure planes observed on excavation are the final as the tine moves forward.

Lateral Failure – Godwin and Spoor (1977) shows the trajectory of soil particles when forced to move in a horizontal plane ahead of a vertical tine called pure lateral deformation. The extent of the movement is considerable, deformation occurring along many planes, with the soil moving towards undisturbed soil ahead and to the sides of the tine. This type of movement many cause either compaction or loosening depending upon soil compatibility confining stress and particle trajectory. Within compactable soils compaction must occur with initial strains in situations where no upward component of movement exists. Compaction needs not occur if the soil is free to move upwards. Other situation may arise where, although compaction does occur initially, the final net density may still be zero. In these cases, the froward limit of the disturbed zone continuously advances as the tine moves forward, and hence compaction caused by soil movement towards the undisturbed soil may be alleviated almost immediately as the “undisturbed” soil itself is moved away.

The limit of soil disturbance to the side of the tine will for a given potential strain, be dependent upon soil compatibility and the shear stress/strain relationship for the particular soil. Providing the vertical component of movement is sufficiently greater than the lateral component, no compaction will occur. With increasing sideways movement an ever greater upward component will be required if compaction is not to occur

Soil Deformation Process

Spoor and Fry (1983a) summarized the deformation process as follows: soil deforms continually ahead of the tine in a form of lateral deformation, although not necessarily solely in a horizontal plane. Larger compressive stresses and strains are generated close to the tine and these increase until the boundary conditions for upward failure are satisfied. Upward failure then occurs with the failure planes, either at the limit or within the area already strained in a lateral manner. These failure planes are more likely to be at the limit of lateral deformation when tines are working above critical depth and well within the disturbance limits when below critical depth. After upward failure, the stress level immediately ahead of the tine will fall, lateral deformation will continue, with stress and strain levels building up for the next upward failure

Controlling Factors.

In their studies Spoor and Fry (1983b) report the following controlling factors. According to the report upward failure will continue from the tine working depth so long as the boundary stress and strain conditions are met. The greater the working depth, and the more compressible the soil, the greater the upward strain required for complete failure. Below a certain working depth tines with a limited lift height on the leading edge may be unable to generate sufficient vertical strain for failure. This has been shown to be the case with mole ploughs (Godwin et al., 1981), where below certain depth upward failure ceases and stable mole channel formation becomes possible.

Whether a net increase in density occurs in the disturbed zone beyond the main failure planes is dependent upon the relative values of the upward and sideways components of movement. For compaction to be avoided,

the vertical component of movement must always exceed the lateral component and the greater the latter, the greater the difference between the two must be. For a given soil condition, the greater the vertical continuing stress, the smaller the vertical component of movement is likely to be, and hence the greater the risk of lateral compaction occurring. Vertical confining stresses increase with increasing working depth, larger tine rake angles, and with increasing shear strength in the upper soil layers.

2.2.3 Soil Failure with Wide Tines

Payne (1956) classified tines operating below an extended horizontal surface as being wide if the depth/width ratio (aspect ratio) less than 0.5. the ratio designates the portion of the tool that is incontact with the soil rather than the absolute dimensions of the tool (Gill and Van den Berg,1968). Wide time failure is common in situations where the width of cut is very large compared with the working depth (Spoor, 1969). According to Spoor (1969), soil failure in front of very wide tines or blades can be reduced to a 2-dimensional problem by neglecting the end effects at the edge of the blade. A very long blade can be likened to an infinitely long retaining wall and retaining wall failure theory can be used in the analysis.

In the failure pattern of a straight blade, a prison of soil is separated in front of the implement and slides forward and upward along the failure surface as the implement moves forward. The actual failure surface is composed of a curved portion leading into a straight portion, the latter intersecting the soil surface at an angle of $(45-\phi/2)$ to the horizontal. Due to the regular nature of the failure surface, it is possible to predict the distance in front of the implement where the failure plane is likely to break the surface-rupture distance.

The rupture distance is a function of α , ϕ and the working depth of the implement (Spoor, 1969). With continued tine movement, a series of failures develop and the failed soil builds up in front of the implement producing a surcharging effect on the failure surface. With backward raked blades (large rake angle), the failure pattern is more complex but the general analysis is the same.

2.2.3.1 Logarithmic Spiral (Ohde's) Analysis

The failure pattern in front of a wall in the passive case is made up of two zones

- (a) One of radial shear
- (b) A pure passive Rankine zone (Figure 5)
(Terzaghi and Peck, 1967; Craig, 1979)

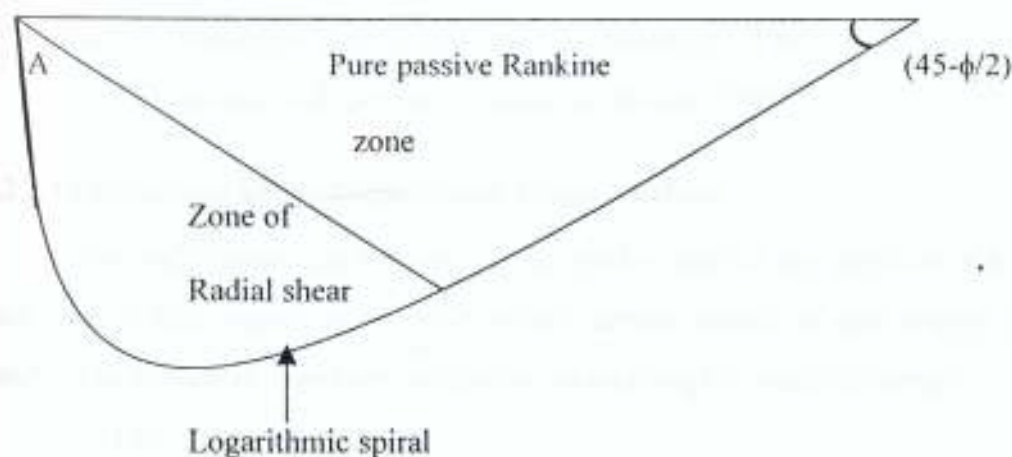


Figure 5 Failure Pattern in Front of a "Wall" (Passive Case)

The zone of radial shear is bounded by a failure surface whose shape approximates to a logarithmic spiral. The center or pole of the spiral lies on a line that makes an angle of $(45-\phi/2)$ to the horizontal. In the analysis, the position of the pole can be located by two methods:

- (i) Using a minimizing technique,
- (ii) From the geometry of the slip planes.

2.2.3.2 Calculation of Passive Earth Pressure

In the broadest sense, the term passive earth pressure indicates the resistance of a mass of soil against displacement by lateral pressure. The object that exerts the lateral pressure may consist of the foundation of a retaining wall, the outer face of the buried part of a sheet pile bulkhead, or a block of masonry such as the abutment of a loaded arch. It may also consist of a mass of soil that exerts a horizontal pressure because it supports a vertical load (Terzaghi and Peck, 1967). The soil beneath a loaded footing acts in this manner.

Since the stability of almost any lateral earth support and the bearing capacity of every shallow foundation depend to some extent on the passive earth pressure, the problem of computing this pressure is of outstanding practical importance (Terzaghi and Peck, 1967).

Having determined the position of the pole of the spiral, the passive pressure can then be calculated in a number of ways:

- (i) Graphically (Terzaghi, 1943)
- (ii) Semi rigorous method (Osman, 1964)
- (iii) Numerical step by step solution (Sokoloski, 1960)
- (iv) General soil mechanics equation (Reece, 1965).

2.2.3.3 Limitations of the Logarithmic Spiral Analysis

The logarithmic spiral theory can be used to predict the force on wide blades with quite a high degree of accuracy within certain ranges of rake angles (Spoort, 1969). The N-factors have been computed for rake angles within the range.

$$\alpha = (45 - \phi/2) \text{ to } \alpha = (180 - \phi)$$

With rake angle less than $(45 - \phi/2)$, a modified form of failure is required because the soil-metal interface would then lie completely within the passive Rankine zone.

With backward rake angles, there is again a change in the failure surface with a soil wedge being formed adjacent to the interface.

2.2.3.4 Current Wide Tine Theories

- (a) Slip-line field and passive failure. Hettiaratchi and Reece (1974) show that the geometry of the rupture surface depends on the magnitudes of the two non-dimensional groups $c/\gamma z$ and $q/\gamma c$ referred to as soil numbers and representing the ratio of cohesive and surcharge forces respectively. When the magnitudes of these soil numbers are very large, the curvilinear slip-line fields decompose into logarithmic spirals and straight lines. The main slip-line fields are built up from a small number of basic zones each of which has simple mathematical properties. The passive resistance is calculated from the equilibrium of these component zones and of the field as a whole.

Reece and Hettiaratchi (1969) reported four distinct types of slip-line fields which depend on the failure geometry controlled by the interface rake angle, α , the direction of translation, B, the soil internal friction angle, ϕ and the soil interface friction angle, δ (Figure 6)

- (b) Basic passive slip-line fields. The basic slip -line appropriate to passive failure in front of an interface with large rake angle is shown in Figure 7 (a) consisting of three distinct zones. The zone OCD is the passive rankine zone (R) in which the direction of the slip-line is controlled by gravitational field, the slope of the soil surface and the nature and direction of action of the surcharge pressure. Adjacent to the interface is zone OAB labelled (I) also composed of straight slip - lines whose inclination with the interface is governed by the values of δ and ϕ . Its geometry is controlled by the angle $OAB = \theta^*$. The transition zone OBC {labelled T} simply fills up the slip-line field, if any between the interface and the Rankine zones. This zone is composed of curved slip-lines which are logarithmic spirals and straight radii and the slip-line field merges smoothly into the adjacent two zones.

Analysing the geometry of triangle GHS in Figure 7 (b) leads to the followings.

$$\nabla = \sin^{-1} (\sin \delta / \sin \phi) \dots \quad (2)$$

$$\theta^* = 45^\circ + \frac{1}{2} \phi + \frac{1}{2} (\delta + \nabla) \dots \quad (3)$$

- (c) Small rake angles

As the rake angle is made smaller from the situation shown in figure 6 the transition zone decreases in size until it finally disappears at a limiting value α_d given by

$$\alpha_d = 90 - \frac{1}{2} (\delta + \nabla) \dots \quad (4)$$

For values of α less than α_d , there is no transition zone to provide a smooth transition between the slip-lines and the stress conditions in the interface and Rankine zones as shown in Figure 8.

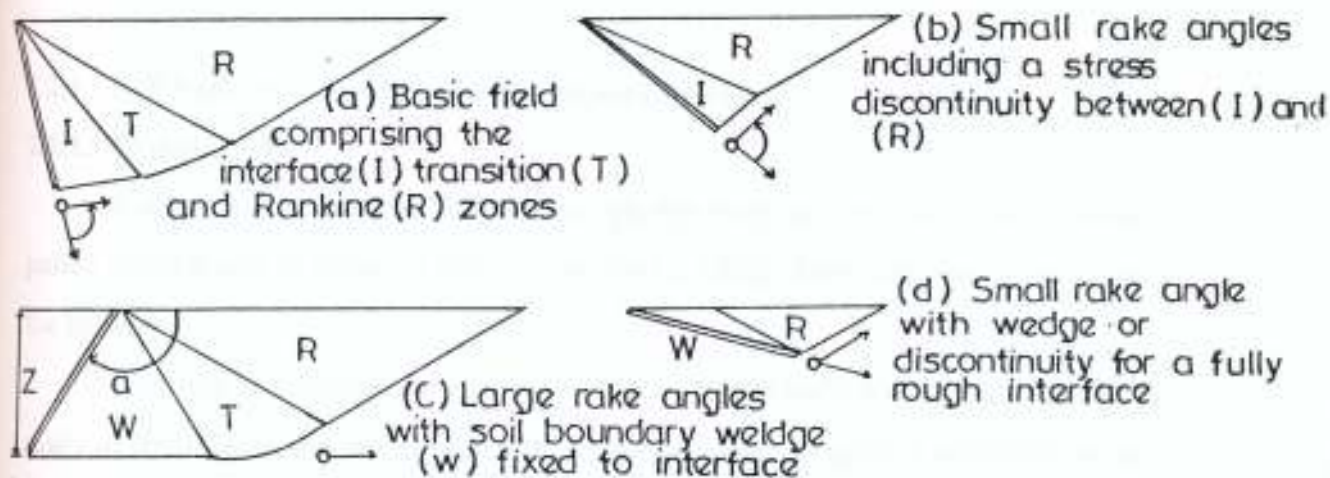


Fig-6 :Main types of slip-line fields which result from various combinations of rake angle α , soil interface friction δ and direction of translation β for which they are valid

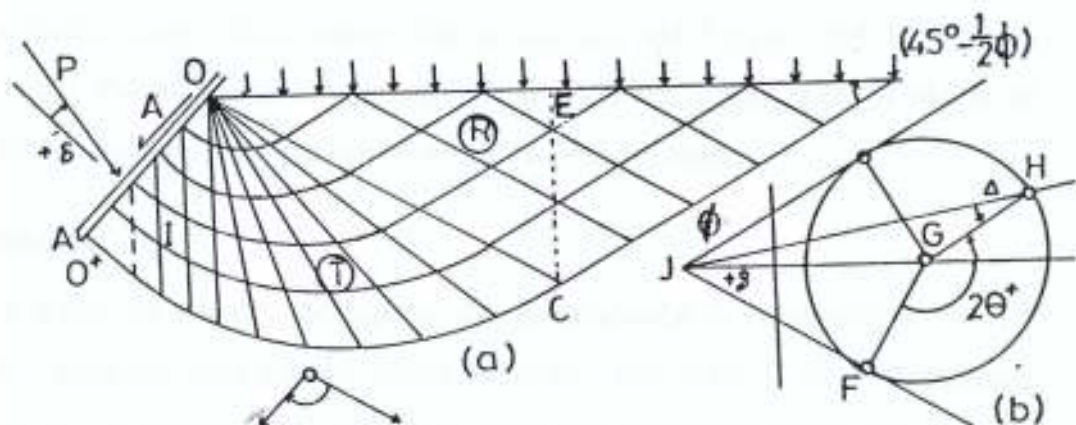


Fig-7 : (a) Basic slip-line field and rupture zone (b) Mohr's diagram for angle θ^*

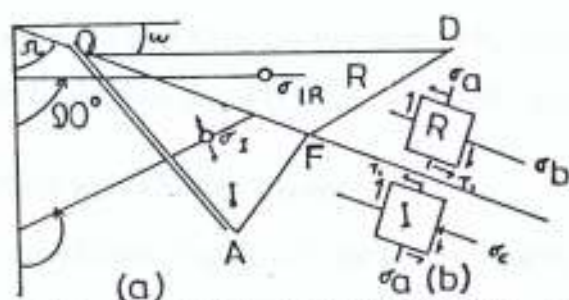


Fig-8 :The slip line field for small rake angles (a) The plane of discontinuity OF separates the interface and Rankine zones (b) The stress conditions on either side of the discontinuity
Source : Reece and Hettiaratchi (1989)

2.2.4 Soil Failure with other Soil-Engaging Implements

2.2.4.1 Plough Bodies

Koolen and Kuipers (1983) defines plough body as that body that is being pulled through soil to loosen it and does so over a width about equal to the width of the body.

Krauze and Lorenz (1979) gave a survey of tillage tools, the operating parts of many of these tools can be considered as plough bodies. Figure 9 represents some plough bodies. The plough bodies in (a) to (h) can be described as blades. The others are mouldboard plough (i), a rotatiller blade (j), a sweep (k), and a potato harvester lifting blade (l). Other agricultural machines with plough bodies are root-crop harvesters, soil fumigators, manure injectors, vertical augers for making boreholes and non-vertical augers for cleaning ditches (Koolen and Kuipers, 1983). Plough bodies occur also in earth moving equipment (Nichols, 1976) Such as blades of bulldozers and graders, shares of scrapers and buckets and augers.

2.2.4.2 Blades

A blade has a horizontal cutting edge perpendicular to the direction of travel and with a shape that does not vary across the width. The action of the blade depends especially on the cutting angle, the blade shape, the inclination of the rear end, the blade size and the operating depth.

Payne (1956) defines blades as tools having a depth/width ratio less than 0.5. Following the definition of Mckyes (1978), a blade is said to be wide if its length to working depth ratio is equal to or greater than 10.0, that is $L/d \geq 10$, where L is the length of soil cut by the tool and d is the depth of soil cutting.

2.2.4.3 Soil Failure with Curved Blades

With curved blades (Figure 10) the failure pattern is similar to those of wide tines but the surcharging pattern can vary depending on whether soil moves along the blade or not, that is, whether scouring occurs or not. With scouring, a triangular shaped surcharging wedge is formed. When the blade does not scour, the curved portion of the blade fills with soil and a more

tool behave as a straight blade(Spoor, 1969)

The mode of soil failure at the surface depends on the blade curvature at a given rake angle. With slightly curved blade (large radius of curvature) the soil rises up the blade and emerges straight upwards from it. As the blade curvature increases, the soil tends to roll until it almost rolls over completely. With further curvature, the curved blade behaves exactly like a straight blade (Spoor, 1969).

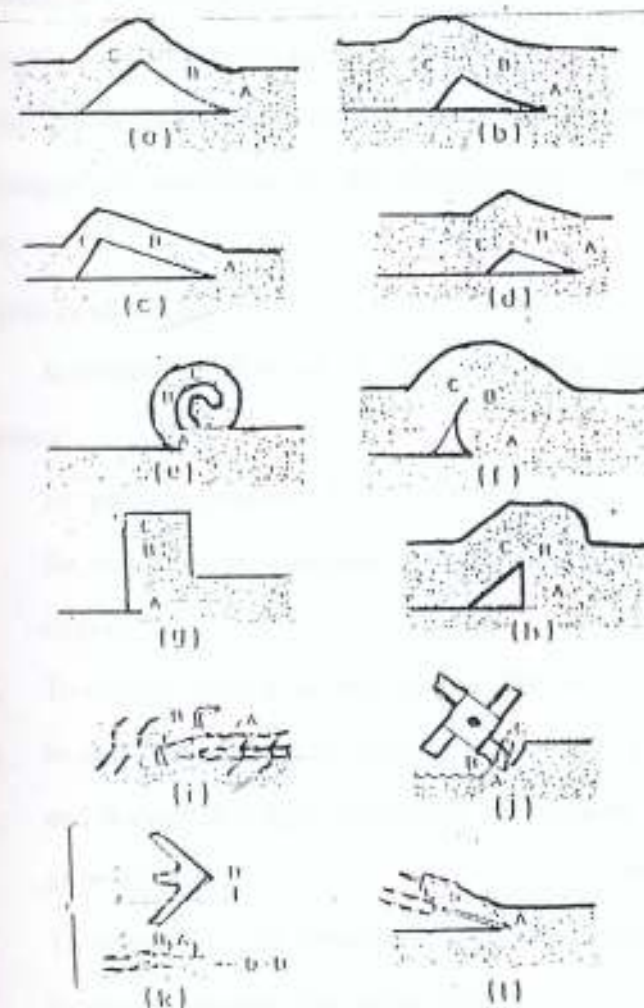


Fig.9: Typical Plough Bodies(Koolen and Kuipers,1983)

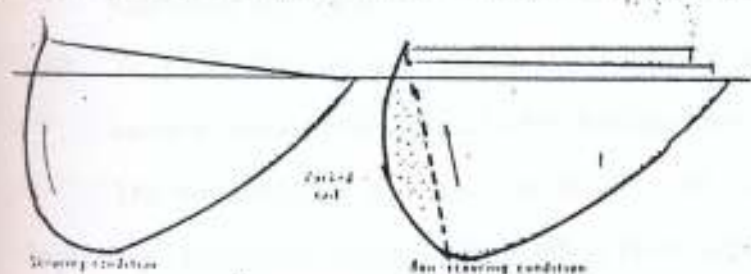


Fig.10: Soil Failure Pattern with Curved Blades(Spoor,1969).

2.3 Soil Tillage

Tillage has been defined by researchers. It is the manipulation of soil by mechanical forces (Gill and Vanden Berg, 1968). It is the mechanical manipulation of soil for any purpose (Kepner et al, 1978). It is the mechanical manipulation of the soil aimed at improving soil conditions affecting crop production (Hillel, 1980). It is the practice of modifying the state of the soil in order to provide conditions favourable to crop growth (Culpin, 1986). It is the mechanical manipulation of the soil for any desired purpose, but in agriculture, the term is usually restricted to the changing of soil conditions for the enhancement of crop production (ASAE standards, 1989).

Objectives of Tillage

According to Kepner et al. (1978), the objectives of tillage include the following

- (i) To prepare a suitable "tilth" or soil structure
- (ii) To control soil moisture through rapid infiltration and good retention of rainfall
- (iii) To control weed or unwanted crop plants
- (iv) In corporation into the soil of crop remains (inducing cereal straw) fertilizers and manors and agro chemicals for weed or pest control chemicals for weed or pest control
- (v) To minimize soil erosion by following such precaution as contour tillage, listing and proper placement of trash
- (vi) To establish specific surface configurations for planting irrigating, drainage, harvesting operation etc
- (vii) To accomplish segregation. This may involve moving soil from one layer to another, removal of rock and other foreign objects, or root harvesting.

The consumption of energy as well as the wear and tear of tractors and implements, increases steeply as the depth of tillage increases (Hillel, 1980). Thus the cost of deep tillage (to a depth of 45 to 50 cm) is roughly doubled the cost of

moderating (about 25 cm deep) and tenfold greater than the cost of shallow polishing (approximately 15 cm deep).

Recent trends in tillage research have been aimed at minimizing tillage operations and travel (both to reduce cost and avoid soil compaction) while tailoring each operation to its specific zone and objectives (Phillips and Young, 1973). The methods developed in one location where conditions can differ greatly (Hillel, 1980). Hence, there are no universal prescriptions for what constitutes efficient tillage some but not all soils have suitable tilth quite naturally and require little. If any, tillage to serve as fathomable media for crop growth. Others however exhibit pans or barriers which inhibit root penetration and hence can be improved by appropriate tillage (Gill, 1974).

2.3.1 Tillage Methods

Tillage operations for seedbed preparation are often classified as primary, Secondary or tertiary tillage (Kepner et al., 1978)

2.3.1.1 Primary Tillage

Primary tillage is defined as the initial breaking up of the soil (Kaul and Egbo, 1985). It is the operations performed to open up any cultivable land with a view to prepare a seedbed to growing crops. According to Kepner et al. (1978), primary tillage constitutes the initial major soil working operation, normally designed to reduce soil strength, cover plant materials and rearrange aggregates

2.3.1.2 Secondary Tillage

Secondary tillage has been described as some further operations (after primary tillage) carried out to break down the clods and prepare the seedbed ready for planting (Kaul and Egbo, 1985). According to Michael and Ojha (1989), it is the lighter and finer operations performed on the soil after primary tillage but before and after seed placement. These operations are generally done on the soil surface; very little inversion and shifting of the soil take place and consequently there is less power requirement per unit area. It was reported that secondary tillage operations are intended to create tined soil conditions following primary tillage.

2.3.1.3 Tertiary Tillage

Tertiary tillage operation, many be defined as further tillage operation carried out after secondary tillage operations. Such operation could be described as "lightest" and "finest" operations before and after seed placement.

2.3.2 Tillage Systems

The following tillage systems have been identified (Kepner et al., 1978; Culpin, 1986)

- (i) Conventional tillage.
- (ii) Minimum tillage.
- (iii) Zero tillage.
- (iv) Optimum tillage.
- (v) Conservation tillage.
- (vi) Reduced tillage.
- (vii) Ridge tillage.

Each tillage system designated after one or a combination of the following factors.

- (i) The degree of soil loosening, stirring, pulverization inversion, recompactng that is required.
- (ii) The amount of energy that is required
- (iii) The net return (yield) for a given crop under given conditions.
- (iv) The degree of residue cover
- (v) The loss or retention of water in the tillage soil .
- (vi) Extent of energy intensive operations
- (vii) Ckinste or topography of the area and land respectively .
- (viii) Type and condition of the soil

2.3.3 Unit Operations of Tillage

The unit operations of tillage are

- (i) Soil Cutting
- (ii) Soil lifting
- (iii) Soil inversion and
- (iv) Soil Pulverization

2.3.3.1 Soil Cutting

It may be defined as a slicing action that does not result in any major failure such as shear (Kepner et al., 1978). Conditions under which pure cutting can occur are determined by the soil characteristics and moisture content and to some extent by the degree of confinement (Gill and Vanden Berg, 1968). In many tillage operations, cutting is not a clearly defined independent action.

2.3.3.2 Soil Lifting

This is another unit operation of the tillage operations. Soil is lifted as tillage tools are moved through soil. The lift (or rise) of the soil depends on the lift angle, the lift height and the shape of the tools. Lift angle may be defined as the angle between the face of the tools and the horizontal (Gill and Vanden Berg, 1968).

2.3.3.3 Soil Inversion

Soil inversion may be defined as a process of putting upside down or in opposite order position or arrangement of the furrow slice that is severed in a cutting action preceding soil inversion (Gill and Vanden Berg, 1968).

It is normally carried out mainly to obtain control of weeds and to remove surface trash which could interfere with other crop producing operations.

2.3.3.4 Soil Pulverization

Soil pulverization may be defined as the snuggling completely or grinding to powder or complete chattering of furrow slice, aggregates or soil clods. This unit operation is normally accomplished by the action of a tillage tool as it moves through the soil.

2.3.4 Methods of Performing the Unit Operations

Methods of Soil Cutting:

The various methods that can be used to perform this unit operation of tillage operations include the following:

- (i) Pushing the tool
- (ii) Pulling the tool
- (iii) Throwing and pulling

- (iv) Thrusting the tool
- (v) Rotating the tool
- (vi) Oscillating (or vibrating) the tool.

2.3.4.1 Pushing the Tool

In this method, the tool is set on the surface of the soil and in front of the prime mover. The force or effort required to cut the soil is applied to the tool/implement through

- (a) the handle of the tool when the source of power is human.
- (b) The yoke or harness when the source of power is animal.
- (c) The hitch linkage when the source of power is mechanical (internal combustion engine) as in tractorization.

In each of the above cases, the force is applied horizontally or at an angle to the direction of travel. As the prime mover moves forwards, the tool or implement is pushed and the soil is being cut.

2.3.4.2 Pulling the Tool

In this method of soil cutting, the tool is set on the surface of soil but behind the prime mover. Like in the pushing method, the prime mover can be animal, human, internal combustion engine or tractor. The mode of application of the source of power to the tool is similar to that of the push method. The force is also being exerted horizontally at an angle to the direction of travel. As the prime mover moves, the tool follows and the soil is being cut.

2.3.4.3 Throwing and Pulling

This is a double-action method of soil cutting as the name implies. The source of power is usually human. The tool is held in the hand(s) in certain position while the operator stands astride the work space (as in being). The operator then throws the tool into the soil and in front of him with a blow to achieve penetration of the soil (by the tool) and simultaneously pulls the tool to himself.

The effort or force required for cutting is applied to the tool through the handle of the tool.

Cutting of the soil is accomplished mainly by the throwing action.

2.3.4.4 Thrusting the Tool

In this method, the source of power is human power. The tool is held in one or both hands by the handle at an elevated height and in a starting position. In the working position, the operator exerts sufficient force on the tool to cut the soil.

This thrust-method is quite different from the throwing and pulling method. The working position of the operator is also different. Here the tool is normally light.

2.3.4.5 Rotating the Tool

Rotating tools are tools that move with circular motions. They are multi powered tools, that is, tools that obtain the energy required to move them through the soil in more than one manner. The power need not be supplied by more than one source of energy; but the energy, regardless of the source, must be applied to the tool in more than one manner.

The first means of applying mechanical power to tillage tools and the one still most widely used is simply to draw or pull the tool through the soil. Tools mounted on modern tractors are powered by this method. It should also be noted that rotary tools actually propel themselves through soil.

While these tools are being pulled along the soil is being cut by the blades.

It should also be recalled that in traditional rotating tools, the source of power is human or animal.

When least power is required to propel the tool, human power is supplied by pushing the tool along.

When greater effort is required than what human can possibly supply, animal power is used. This is connected usually by harness.

2.3.4.6 Oscillating (or Vibrating) the Tool

In this method, the tools vibrate or judder as they are drawn through the soil, and the soil is being cut.

Paths of oscillation may be controlled by mechanical means such as eccentrics, cams or crank shaft and connecting rod arrangements. These

mechanisms provide the means for applying oscillating energy to the tools as it is being drawn through the soil.

Oscillations can be induced by variations in soil resistance. When high resistance is encountered, a tine displaces; when resistance decreases, the restoring force of the spring returns the tine to its original position. In the process of oscillation or vibration of tools, the soil is being cut.

Oscillating tools are multipowered tools.

Table 1. Summary of Methods and Tools for Tillage Operations

Tillage tools for	Soil	Soil	Soil	Soil
Each named method	Cutting	Lifting	Inversion	Pulverization
(i) Pushing the tool				
Pushing hoe	**			*
Weeding hoe	**			
Wheeled push hoe	**			
Wheeled push cultivators	**			
Rakes	*			**
(ii) Pulling the tool				
Mouldboard plough	**	**	**	**
Share	**			
Mouldboard (General Purpose)		**	**	*
Stubble mouldboard		**		**
Sod or breaker		**	**	*
Slatted mouldboard		**		
Disc edges-plain-	**			
-scalloped	**			
Disc couller	**			
Shin (of mouldboard)	**			
Pulling hoes	**	*		
Disc plough	**	*	*	*
Chisel plough	**	*		

Table 1 continued

Tillage tools for Each named method	Soil Cutting	Soil Lifting	Soil Inversion	Soil Pulverization
Subsoilers	**	*		
Harrows-				
Disc	**	*	*	**
Diamond	**			**
Triangular	*			**
Broadtooth	*			**
-Spiked tooth bar	*	*		**
- Single section walking	*			**
- Square	*			**
- Zigzag	*			**
- Chain	*			**
- Flexible	*	*		**
- Rotary	*	*		**
- Spring – tooth	*	*		**
Ridgers	**	**	**	**
Tillers	**	**		**
Cultivators				
- Spring tined	**	*		*
- rigid tined	**	*		
Rotary cultivators				
- rotary hoe	**			**
Cultivator shares	**	**		*
Tines	**	**		*
(iii) Throwing and Pulling Method				
Spades	**	**	**	*
Forks	**	**	**	**
Rakes	**			**
Diggers	**	*		*
Traditional hoes	**	**	*	*

Table 1 continued

<i>Tillage tools for</i>	<i>Soil</i>	<i>Soil</i>	<i>Soil</i>	<i>Soil</i>
Each named method	Cutting	Lifting	Inversion	Pulverization
Mattocks and Pick axes	**	*		
Digging hoes (various)	**	*	*	*
Weeding hoes(various)	*	*		*
(iv) Thrusting method				
Cutlasses	**	*		
Spades (various)	**	**	**	*
(v) Rotating method				
Tiller blades (various)	**	**	*	**
Disc Plough blades	**	*	*	**
Disc harrow blades	**	*		**
Rotary cultivator blades	**	**		**
(vi) Oscillating method				
Cultivators				
- Flat-spring-top tines	**	**		*
- Spring-tined				
(double coil)	**	**		**
- Harrow with s-type tines	**	**		
tines	**	**		*

** *Equipment very well suited for the operations specified key*

* *Equipment moderately suited for the operations specified.*

2.4 Tillage Implements

Tillage implement according to Kepner et al. (1978) consists of a single tool or a group of tools, together with the associated frame, wheels, control and protection devices and any other structural and power transmission components. Michael and Ojha (1989) classified tillage implements according to the source of power use as:

- (i) Hand operated tools
- (ii) Animal drawn implements
- (iii) Tractor drawn implements

Moreover, tillage implements have also been classified according to types of tillage operations as:

- (i) Primary tillage implements
- (ii) Secondary tillage implements
- (iii) Tertiary tillage implements

2.4.1 Primary Tillage Implements

Primary tillage implements are implements that are used to carry out primary tillage operation. They are mainly ploughs mould board plough, disc plough, subsoiler, chisel plough (Kaul and Egbo, 1985; Michael and Ojha, 1989). The materials of these implements are usually high carbon steels. Because soil types and ploughing conditions vary widely many different shapes of mould boards have been developed. Mouldboard specifications are presented in Table 2.

Table 2: Typical Mouldboard Plough Body Specifications

Furrow width (mm)	Depth (mm)	Interbody clearance (mm)	Underbeam clearance (mm)	Approx weight (kg)	Approx hp reqd
305	255	750	600	380	30
to	to	to	to	to	to
305	305	900	675	843	115

Source: Kepner et al.(1978)

Some mouldboards are essentially cylindrical sections, some tend towards an spiral or helical shape and others are modifications of these geometrical shapes (Kepner et al, 1978; Barrett, 1967).

Disc ploughs are favoured in areas where the climate is dry and where the soil is rough and stony. Disc specifications are show in Table 3

Table 3: Typical Disc Ploughs Specifications

		Standard Disc Plough	Disc tiller
No of Disc per gang		3 to 6	2 to 32
Site (DIA) of Disc		610 to 710	510 to 610
Width of cut per disc (mm)		180 to 300	
Tilt angle (degree)		15 to 25	-
Disc angle (degree)		42 to 45	35 to 55
Disc spacing (mm)		300	300
Disc radius of curvature (mm)		450 to 680	
Weight per disc (kg)		180 to 540	45 to 90
Ploughing deep (mm)		250 maximum	75 to 100
Thickness of Disc (mm)	660 plain	4.8 and 5.5	4.8 and 5.5
	660 cutaway	5.5	
	710 plain or cutaway	6.4	

Source: Kepner et al.(1978)



Disc tiller has action intermediate between that of the true disc plough and the disc harrow.

Subsoilers and chisel ploughs are used to break up the hard soil pan or compacted soil. They have deep tines which operate at considerable depth to break open the subsoil. Subsoiler may have two or three legs while chisel plough may have about nine tines. Table 4.

Table 4: Subsoiler and Chisel Plough Specifications

	Subsoiler		Chisel Plough
Overall width (cm)	218		300
No of Legs	2	3	9
Let to leg clearance (cm)	104 to 196	50 to 98	100 to 200
Working depth (cm)	45 to 75	45 to 75	45 – 55
Weight (kg)	533	622	500
HP Required	60 to 80	780	60 to 80

Source: Kepner et al. (1978)

Shows specifications of subsoilers and chisel ploughs replaceable steel or cast iron points may be fitted to the tines.

2.4.2 Secondary Tillage Implements

Secondary tillage implements are implements that are used to carry out secondary tillage operations. They are mainly harrows. They are used to break clods cut weeds, pulverize soil, cover seeds and smooth the surface. The three general types

of disc harrows are: single acting, tandem and right-hand offset harrows. Typical disc harrow specifications are presented in Table 5

Table 5: Typical Disc Harrows' Specifications

Type	Blade diameter (cm)	Blade spacing (cm)	Available width (m)	Mass per unit width (kg/m)
Tandem, mounted	41, 46, 51, 56	18 to 23	1.5 to 4.0	150 to 170
Tandem, wheel type				
(light duty)	46, 51, 56	18 to 24	2.4 to 6.4	270 to 370
(Medium duty)	41, 51, 56	19 to 24	3.4 to 9.5	370 to 480
(Heavy duty)	56, 61, 66	23 to 28	3.4 to 13.7	480 to 700
offset, pull-type				
- with wheels	56, 61, 66, 71	23 to 28	2.1 to 7.3	400 to 750
- without wheels	61, 66, 71	23 to 28	2.7 to 9.1	390 to 650

Source: Kepner et al. (1978)

2.4.3 Tertiary Tillage Implements

Tertiary tillage implements are implements that are used to carry out tertiary tillage operations. They are mostly trailed tined harrows. Examples include:

- (i) Spike tooth harrows
- (ii) Chain harrows
- (iii) Diamond harrows
- (iv) Triangular harrows
- (v) Square harrows
- (vi) Zig-zag harrows
- (vii) Single section walking harrows

- (b) Those with flat tines flat or curved
 - (i) broad tooth harrows
 - (ii) flexible harrows
 - (iii) spring tooth harrows
 - (iv) rotary harrows
 - (v) coil-tine harrows

Still in the group of tertiary tillage implements are the cultivators, classed on the basis of the type of tines used:

- (i) Rigid tine cultivator
- (ii) Spring tine cultivator

Typical specifications of cultivators are presented in Table 6

Table 6: Typical Cultivators' Specifications

Model	C70	C83.S6	C87	C90
Cultivating width (m)	2.89 & 3.20	2.59	4.72	2.89
Number of rigid tines	9 or 11 11 or 13	- 7 or 9	15 15	- 7
Number of spring leaf tines	-	7 or 0	254	-
Maximum working depth (mm)	228	304	304	304
Spacing between tines (mm)	304 or 254	304	304	381
Underbeam clearance (mm)	508	609	609	711
Mainframe construction (mm)	Z - section 104 x 85 x 9	100 x 100	100 x 100	114 x 190
Transport width (m)	2.69 & 3.20	2.59	4.72	2.89
Depth wheels	Cast iron wheel optional	Prienmatic Wheels optional	prenmatic wheel standard	Pnenmatic Wheel Standard
Weight approximate (kg)	267	472	752	469
Maximum tractor h.p				
- 2 wheel drive	75	95	125	125
- 4 wheel drive	-	95	120	125
- Track layer	-	70	90	90
Linkage category	1 and 2	2	2 and 3	2 and 3

Source: Ransomes, Ipswich, Ransomes Sins & Jefferies Ltd., England. No. 21820G (1976)

The rigid tine cultivator has strong tine with a cutting shovel or sweep. The shape of the shovel or sweep may take different forms like half sweeps, furrower, weed knives (or beet hoes,), double point shovels, single point shovel, hoof shovel or spear head.

Roller:- This implement is useful for breaking down soil clods that may not have been broken down by the cultivator or harrow (Kaul and Egbo, 1985). It is designed to be drawn quickly behind the tractor so that the clods are broken down by impact rather than being buried or pushed down into the soil. Cambridge or ridged rollers are the best for clod crushing and consolidation prior to drilling (Shippen and Turner, 1978).

2.4.4 Mode of Attachment of Tillage Implements

2.4.4.1 Mounted Implement

A mounted implement is one that is attached to the tractor as an integral part. It is hydraulically controlled and is kept raised during transport. It is steered directly by the tractor and hence requires minimum space for turning. Such an implement may be rear or front mounted or it may be mounted in the middle of the tractor body. The linkage usually provide rotational stability about the longitudinal axis and it permits depth or height control by vertical support from the tractor, if desired, while the tool is in the operating position. Most primary tillage implements are mounted

2.4.4.2 Semi-mounted Implement

A semi-mounted implement is one that is rigidly attached to the tractor and has a rear wheel or wheels to support part of its weight. Attachment and detachment take more time but the control is much easier. In the usual situation, the hinge axis is

transverse at the rear of the tractor and the hitch provides rotational stability about the longitudinal axis. The implement may respond directly to tractor steering, but if a vertical hinge axis is superimposed on the horizontal axis (as on large, semi-mounted ploughs), the rear of the implement is guided by its own wheel or wheels. (Kepher et al., 1978).

2.4.4.3 Trailed Implements

A trailed implement is one that is attached to the tractor drawbar by a pin joint. The main body of the implement is supported on the ground. Such an implement can be quickly attached to or detached from the tractor. Most tertiary tillage implements are trailed.

2.5 Tillage Tool Design Factors

The purpose of a tillage tool is to manipulate (change, move or form) a soil as required to achieve a desired soil condition. In tillage tool design a number of factors become of primary importance. The factors are:

- (i) initial soil condition
- (ii) shape of the tool
- (iii) movement of the tool and
- (iv) final soil condition.

These factors are not defined quantitatively.

Another factor to be considered while designing tillage tool are the forces acting on the tillage tool whose magnitude can be determined by instrumentation (Kepener et al., 1987; Baloch et al., 1991; Gill and Vanden Berg, 1968). Various forces such as horizontal force, vertical force and side force act on tillage tool. The

resultant of these forces plus the weight of the tillage and parasitic forces if available is called pull. From equilibrium conditions, the pull, P that is required to move the wheel must be equal in magnitude but opposite in direction to the sum of the horizontal components of all forces in the contact surface.

2.5.1 Initial Soil Condition

Initial soil condition is the state of the soil before it is manipulated by a tillage tool or implement. The factors that can be used to describe initial soil condition are illustrated in Figure 11.

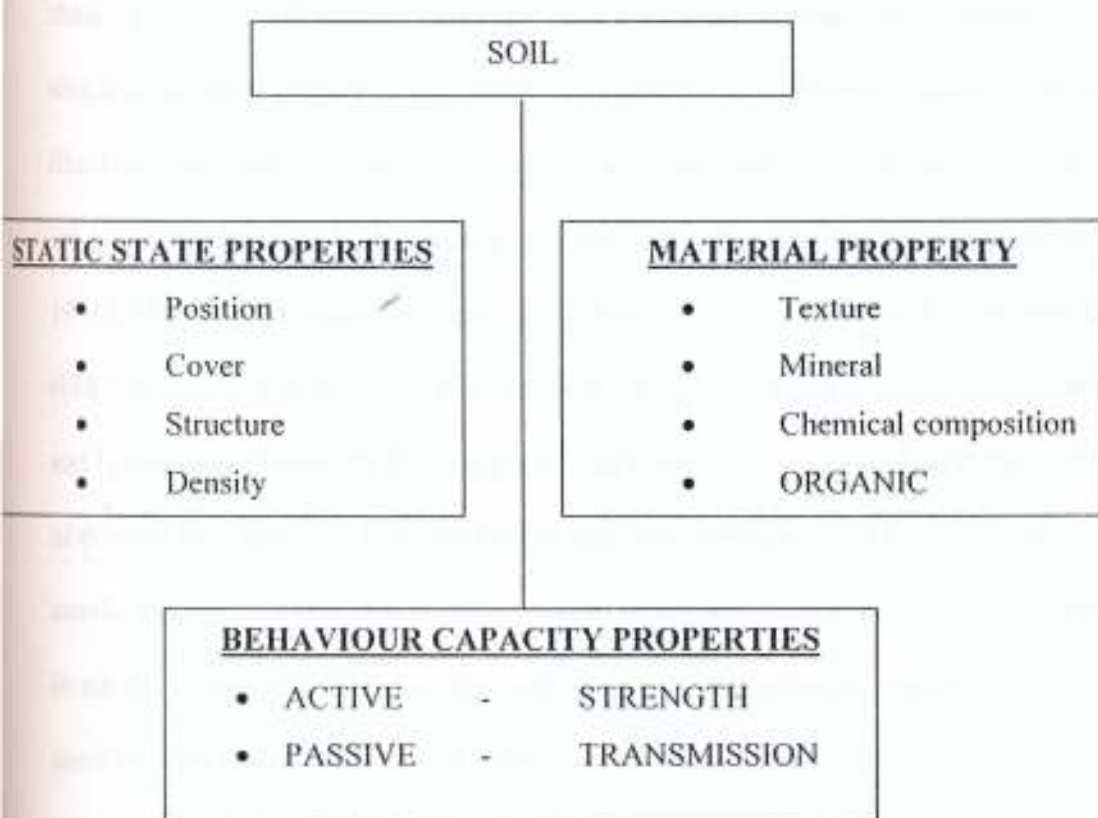


Fig. 11: Factors Characterizing Initial Soil Condition (Gill and Vanden Berg, 1968)

The position property has to do with shape, the surface roughness and crusting. The cover of the soil should also be described: vegetation, weeds, thrash or bare soil. The type of structure can also be described: size, shape, aggregates-size, distribution.

The type of soil has profound affect in considering initial soil condition. Clay soil offer more shearing resistance to the tillage tools as compared to that offered by sandy soils. The reaction of the soils forces applied by tillage tools is affected by the resistance of the shear, adhesion and frictional resistance (Baloch et al., 1991). As the tool advances, the soil in its path is subjected to compressive stresses which in a friable soil condition result in a shearing action.

With any given structure, the soil properties of resistance to compression and shear, as well as friability, plasticity and stickiness depend upon moisture content which is the most important soil factor contributing to soil-metal friction. The zone of friable consistency represents the range of soil moisture in which condition for tillage are at an optimum. Soil are usually in good tilth when they are friable (Baloch et al., 1991). The individual granules are soft, cohesion is at a minimum. Koolen and Kuiper (1983) reported soil moisture content in three phases: friction phase; adhesion phase and lubrication phases. In friction phase, adhesive forces are small and the coefficient of friction is essentially independent of moisture content. Soils in friable consistency usually have moisture content in this range. Moisture content in this phase is 0 to 10% in silt loam and 0 to 15% in silty clay loams. In the adhesion phase, moisture films develop between the soil particles and metal thus creating adhesive forces that cause apparent coefficient of friction to increase rapidly with moisture content. When the soil has enough moisture to act as lubricant, the coefficient of friction decrease as more water is added.

2.5.2 Shape Factor

Of the three design factors of shape, manner of movement and initial soil condition, the designer has complete control only over shape. The user may vary the depth, or speed of operation and may use the tool through a wide range of initial soil conditions. However, the tool shape cannot be considered independently of the manner of movement or initial soil condition. Different initial soil conditions sometimes require different shapes for example many different shapes of moldboard ploughs have been developed for different soil types and conditions.

A mathematical description of the shape of a tool is the most versatile means of representation. Attempts have been made to use graphic representation of shapes that cannot easily be represented by mathematical equations.

Since shape is the most difficult design factor to vary, it is perhaps the first factor that should be quantitatively developed.

2.5.2.1 Macroshape

The surface over which soil moves as a tillage tool is operated constitutes the shape that is of concern in design (Kepner et al, 1978; Gill and Vanden Berg, 1968).

Soehne (1959, 1960) defined a number of parameters of shape descriptions and attempted to relate them to plough performance. He used the light slit technique to represent shape along gridlines. The performance of the plough was judged by draught resistance, and coverage and movement of the soil. Soehne's parameters could not be considered as the ultimate for describing a mouldboard plough. While his optimum values are very useful, they represent an initial qualitative approach to describe, but these values have not been related either to force or to the resulting soil condition.

Nichols and Kummer (1932) developed a tracing apparatus that could provide empirical equations to describe the path of soil movement over a mouldboard plough; the used of predetermined physical path along which to establish plough shape.

Nichols and Reaves (1958) measured the draught of a series of subsoilers with macroshapes that range from the normal straight configuration to a deeply curved configuration. Draught was measured in several soil conditions and the results indicate that the deeply curved subsoiler required the least draught.

2.5.2.2 Micro Shape and Friction

Soil slides over the surfaces of tools which has been described by macroshape. Clearly, friction between the soil and the surface must be present so that two identical shapes could produce different results because of different soil-metal frictional relations at the interface. Consequently, the microshape on the surface may influence shape-design relations. Surface roughness caused by rust, polish, scratches, or small depressions is an example. Frictional resistance may be such a small proportion of the total draught that large changes in the microshape and, consequently, the coefficient of friction may cause only a very small change in total draught. On the other hand, microshape could affect other aspect of soil movement such as scouring so that it is important even if draught is essentially unaffected. As a general rule, frictional resistance should always be minimized and control of microshape is the most practical way to do this (Gill and Vanden Berg, 1968). Another aspect of microshape lies in the irregularities in a surface. Pits or other low spots, sharp changes in surface direction or even shapes having different radii of curvature without a gradual transition may "trap" soil. Providing either a moving or smaller surface or a combination of both is another means of reducing friction. According to Wismer et al

(1968), friction resistance can account for as much as 30% of the total draught of a mouldboard plough.

2.5.2.3 Edge Shape

Edgeshape refers to the shape of edges of the finite tool surface that comes in contact with the soil. Usually, the overall tool shape has no relation to its edge shape for example the basic form of several spherical discs is modified by notched and wavy edges. Thus the same macroshape of the tool may be modified by different edgeshapes. On the other hand, the macroshape of reversed curvature, spherical and cone discs are basically different, but the discs could have the same edge shapes. By sharpening disc, tine or blade edges, different edge shapes could be produced (Gupta et al., 1989; Yadav and Pandey, 1984).

In spite of the small area of the edge as compared to the total area of the tool, the shape of the edge can affect the total draught of the tool (Fielke, 1996). Furthermore, the work of Fielke (1996) highlighted the ability of sharp cutting edge on tillage implements to minimize the draught and vertical upward forces and to give a minimum of soil disturbance below the tillage depth. In comparison with a sharp cutting edge a blunt cutting edge increased the draught force by about 80% and increased the vertical upward force by a similar magnitude.

2.5.3 Manner of Movement

Once the shape of a soil manipulating has been selected, only the manner in which the tool is moved through soil can be altered to effect different manipulations. Manner of movement involves orientation of the tool (angle of approach), to path through soil (depth of cut), and its speed along the path (Gill and Vanden Berg, 1968;

Kepner et al, 1978). Once fabricated, the shape is usually not easily altered, so that the manner of movement is generally changed during actual use in order to effect the best performance. Manner of movement is primarily controlled by the user. But each tool has inherent limitations in its practical method of operation that limit variation in manner of movement.

2.5.3.1 Orientation

Orientation relates the shape of a tool to its direction of travel. Since shape must be quantitatively described with respect to some coordinate system, orientation can be described by specifying the shape coordinate reference system with respect to the direction of travel, for example as long as a plan tool is operated horizontally, the orientation of its inclined plane is given by one angle – the angle between its surface and its direction of travel. Even with complex shaped tools, shape reference areas can be orientated by specifying only two angles.

It is reported (Gill and Vander Berg, 1968) that other convenient means may also be used to specify shape orientation. For simple shapes, angles that refers to a mounting device, a straight side, or the bottom of the tool, or any other convenient plane or line can be used. For a curved surface, the orientation may be described with respect to a diameter, a line of symmetry or an axis of rotation. It is also reported that the approach angle (lift angle) of an inclined plane greatly affects both the normal pressure on the tool and the amount of soil disturbed by the tool (Gill and Vanden Berg, 1968). Orientation is sometimes used to control depth of tools, particularly mouldboard plough through the concept of “suction”. A tool that has good suction is considered to penetrate well – it is sucked into the soil .

2.5.3.2 Path of Motion

Path of motion or travel is the second element involved in specifying the design factor, manner of movement. Path of motion is the path the tool travels when passing through soil. For a tool that operates in a straight line, the path of motion through soil is usually specified completely by the depth of cut and width of cut. Both depth and width are readily changed, and they are the means used most often to "adjust" design when the force required to move the tool is greater than can be easily supplied. In a uniform soil condition, the draught of a tool almost universally increases with increasing depth or width of cut. However, rotating and oscillating tools have paths of travel that require relatively complex mathematical descriptions.

2.5.3.3 Speed

If the orientation and path of motion of a tool are known, the manner of movement will be completely determined if speed is specified. Specification of speed is simply describing the velocity of the tool, or in a more general sense, the velocity of the shape frame of reference along its path of motion. When the path of motion is a straight line, the speed is easy to express. The effect has been widely studied. As one might suspect, an increase in speed increases draught (Ademosun, 1990; Grisso et al., 1996; Ademosun and Agbetoye, 1995). The trend has been sufficiently consistent so that quantitative relationships between speed and draught have been obtained as presented in detail in section 2.7. Typical operating speeds for tillage are shown in Table 7.

Table 7: Typical Operating Speeds of Tillage Tools/Implements

Tool/Implement	Speed m/s (km/h)	Reference/Source
Plough mouldboard	1.0 (3.6)	Kuczewski (1981)
Plough mouldboard	0.4 to 3.5 (1.4 to 12.8)	O'Callogham and McCoy (19654)
Plough mouldboard	0.33 to 0.49 (1.1 to 1.7)	Cowel and Sial (1976)
Plough mouldboard	0.9 to 4.5 (3.2 to 16.2)	Reaves and Schafer (1975)
Tillage implements	0.1 to 2.5 (0.3 to 9.0)	Godwin et al (1980)
Subsoiler wing	0.1 (0.3)	Ahmed and Godwin (1983)
Sweeps	1.1 to 4.4 (3.9 to 15.8)	Fielke (1996)
Blade tools	0.3 to 0.9 (1.0 to 3.2)	Yadav and Pandey (1984)
Tandem disc	1.3 to 2.7 (4.6 to 9.7)	Grisso et al (1996)
Field cultivator	1.3 to 2.7 (4.6 to 9.7)	Grisso et al (1996)
Chisel plough	1.3 to 2.7 (4.6 to 6.4)	Grisso et al (1996)
Winged shares	1.1 to 1.8 (3.9 to 6.4)	Weise and Eichhorn (1977)
Rigid & plane tines	2.0 to 5.0 (7.2 to 18)	Stafford (1984)
Single & Multiple tines	0.3 to 5.6 (1.0 to 20.1)	Wheeler and Godwin (1996)
Tine implement	0.9 to 1.5 (3.2 to 5.4)	Ademosun (1990)
Spike tooth harrow	1.6 to 2.7 (5.6 to 9.7)	Kepner et al. (1978)
Rotary hoe	2.2 to 5.0 (8.0 to 18.0)	Kepner et al. (1978)
Roller (cultipacker)	1.3 – 2.7 (4.6 to 9.7)	Kepner et al. (1978)

2.5.4 Final Soil Condition

Three aspects of final soil conditions that may be of interest, depending upon the function or purpose of a specific tillage operation are: the degree of soil breakup; segregation of clod sizes in relations to depth, and uniformity of mixing throughout the tilled depth (Gill and Vanden Berg, 1968; Kepner et al, 1978; Yadav and Pandey, 1984).

2.5.4.1 Evaluation of Soil Final Condition

The amount of soil breakup, pulverization and aggregate distribution can be determined by a sieve separation of the soil as reported by Kepner et al (1978), Yadav and Pandey (1984). Sieving provides a simple means for measuring the range of clod sizes and the relative amount of soil in each size class (Deleenheer and DeBoodt, 1958; Gardner, 1956; Van Bavel, 1949; Singh and Panesar, 1991).

2.5.4.2 Indexes for Aggregate Size Distribution

Aggregate size distribution is a determinant of pore-size distribution and has a bearing on the erodibility of the surface particularly by wind as reported by Hillel (1980). Various indexes have been proposed for expressing the distribution of aggregate size:

(i) Mean Weight Diameter (MWD)

A widely used index is the mean weight diameter (Van Bavel, 1949; Youker McGuinness, 1956) based on weighing the masses of aggregates in the various size classes according to their respective classes. It is thus defined by the following:

$$\text{MWD} = \sum_{i=1}^n w_i d_i \quad (5)$$

Where, d_i is mean diameter of any particular size range of aggregates separated by sieving and w_i is the weight of the aggregate in that size range as a fraction of the total dry weight of the sample analysed. The summation account for all size ranges including the group of aggregate smaller than the opening of the finest sieve from the formula developed by McGuinness and Youker (1967)

$$MWD = 0.876 x - 0.079 \quad (6)$$

Where, x represent the product of the midpoint of each diameter class and the percent retained in each diameter class size. This same index was reported by Thakur et al (1988) as:

$$MWD = \left(\sum_{i=1}^n w_i d_i \right) / W \quad (7)$$

Where w_i is weight of soil retained over the i th sieve (gm), d_i is Class of mean size of i th sieve and W is the total weight of soil sample (gm).

The same index was used by Singh and Panesar (1991) but expressed in the following way:

$$MMD = \frac{\sum_{i=1}^n [M_i (D_{i-1} + D_i) / 2]}{\sum_{i=1}^n M_i} \quad (8)$$

MMD = Mean mass diameter

M_i = Mass of the soil, retained on the i th sieve, from top (kg)

D_i = Size of the i th sieve, (mm)

D_0 = Size (second major dimension) of the largest clod on top sieve (mm)

The sieve set consisted of sieves with square openings of 38.1, 25.4, 19.0, 12.7, 9.5 and 4.8mm and pan. Clod size distribution was determined by sieving a representative area (20cm x 20cm) of the tilled soil.

(ii) **Geometric Mean Diameter (GMD)**

This is an alternative index of aggregate size distribution calculated according to the equation reported by Mazurak (1950):

$$\text{GMD} = \exp \left[\sum w_i \log d_i \right] / W \quad (9)$$

Where,

W_i = weight of aggregates in a size class of average diameter, d_i and

W = total weight of the sample.

Gardner (1956) reported that the aggregates of many soils exhibit a logarithmic normal distribution which can be characterized in terms of two parameters namely: the geometric mean diameter and the log standard deviation.

(ii) Other indexes proposed for characterizing aggregate size distribution are: the coefficient of aggregation reported by Retzer and Russel (1941) and the weight mean diameter and standard deviation reported by Puri and Puri (1949)

No universal prescription can be offered on which of these alternative indexes are to be preferred.

(iv) Current indexes proposed for characterizing aggregate size distribution are: the index of soil granulation, k_n , and the index of soil texture, k_t . (Natsis et al., 1999). The index of soil granulation, expresses the degree to which the soil is

granulated while the index of soil texture indicated how well the seed bed is prepared. Expressed mathematically,

$$K_n = W_{50}/W \quad (10)$$

$$K_t = W_{0.25,10}/W_{10,0.25} \quad (11)$$

Where, W_{50} is the mass in kg of the soil portion of the sample with clods smaller than 50 mm, W is the total sample mass in kg; $W_{0.25,10}$ is the mass in kg of the soil portion in the sample with clods between 0.25 and 10 mm and $W_{10,0.25}$ is the mass in kg of the soil portion of the sample with clods larger than 10 mm or lower than 0.25 mm.

2.5.5 Forces Required to Manipulate the Soil

The engineer is concerned with the forces acting upon a tillage tool or implement from the standpoints of total power requirements, proper hitching or application of the pulling force, designing for adequate strength and rigidity and determination of the best shapes and adjustments of tools.

2.5.5.1 Analysis of Forces of the Tool

A tillage or implement moving at constant velocity is subjected to three main forces or force systems, which must be in equilibrium (Kepner et al., 1978). The forces are:

- (i) Force of gravity acting upon the implement.
- (ii) The soil forces acting upon the implement.
- (iii) The forces acting between the implement and the prime mover.

If torque from rotary power transmission is not involved, the resultant of these forces is the pull of the power unit upon the implement. Clyde in Kepner et al. (1978) subdivided the total soil reaction into useful and parasitic forces. He defines useful soil forces as those which the tool must overcome in cutting, breaking and moving the soil, and parasitic forces as those including friction of rolling resistance that act upon stabilizing surfaces such as the landside and sole of a plough or upon supporting runner or wheels. Under a given set of operating conditions with a specific implement, the operator has little control over the useful soil-resistance forces. However, both the designer and the operator have some control over parasitic forces.

When a tool is not symmetrical about the vertical longitudinal plane though its centre line, the useful soil forces usually introduce a rotational effect (Kepner et al., 1978).

2.5.5.2 Type of Ways by which the Forces are Measured

The following methods by which soil forces may be measured have been identified (Collett and Hope, 1988; Chesmond, 1982; Vanden Berg, 1968; Reece, 1961; Mayaukas, 1958). They are:

- (a) Elastic force-to-deflection Transducers. The principle of applying a force to an elastic body and measuring the deflection produced is the one mostly used in the task of force measurement (Morris, 1988) Example includes: -
 - (i) Extension force transducer.
 - (ii) Spring-type dynamometer.
 - (iii) Ring-type force transducer.
- (b) Bonded strain gauge force Transducers. It was reported by Collett and Hope (1988) that strain gauges used shall conform to the following requirements:

- (i) Small in size, giving low profile and quick response.
- (ii) Low cross-sensitivity.
- (iii) Must have easy and stable calibration.
- (iv) High speed of response.
- (v) Gauges should be inexpensive, reliable and readily available.

Examples are found in the following:

- (i) Strain gauge force transducers.
- (ii) Strain gauge mounted proving ring dynamometer.
- (iii) Instrumented tools.
- (iv) Ring transducers.

(c) **Hydraulic Transducers**

Culpin (1986) recorded that for agricultural work, hydraulic dynamometer are widely used. The pressure set up in the fluid contained in a hydraulic link is transmitted to a small recording cylinder in which the plunger acts against the force of a spring. The movement of the plunger may be read directly or may be recorded on a moving chart. The recording type of dynamometer is sometimes employed for accurate research work, but the direct indicating type is more suitable for rapid tests and demonstration (Kepner et al., 1978).

The following advantages and disadvantages of hydraulic systems were reported by Chessemmond (1982):

- (i) Very high power to weight ratio.
- (ii) Very high peak torques (or forces).
- (iii) Very short time lags enabling fast response.
- (iv) Smooth operation even at low speed.

- (v) Large holding forces when stationary.
- (vi) High power efficiency.
- (vii) Rugged.
- (viii) Self lubricating and cooling.
- (ix) Linear and rotary motions available.



Disadvantages

- (i) Clumsiness of connections.
- (ii) Mess from oil leaks.
- (iii) Danger from large oil leaks (high pressure, toxicity and flammability).
- (iv) Oil properties change with temperature.
- (v) Inertia of oil can degrade system performance.
- (vi) Expensive when power supply is included in the cost.
- (vii) Fluid must be kept clean and gas free.
- (viii) Severe non-linearities may necessitate special treatment.

2.6 Tillage Factors, Parameters and Methods of determining them

2.6.1 Soil Factors and Parameters

The performance of soil in actual practice is greatly influenced by the natural environmental conditions and conditions imposed by tillage tools or implements. Soils do not have simple well-defined uniform or constant physical properties. Because of the varied soil conditions encountered and the uncertainties involved, it is possible to know completely only certain limited aspects of real soil phenomena. The aim of testing should be to obtain reasonably representative values of the soil factors that are reliable and have a direct and significant bearing upon the practical problems involved.

Parameter is defined as a quantity or constant whose value varies with soil conditions or circumstances (Gill and Vandeen Berg, 1968).

2.6.1.1 Soil Type and Condition

Terzaghi and Peck (1967) described the following soil types: sand, hard pan, inorganic silt, clay, organic clay, peat. However, the soil textural class represents in the main, the soil types that are often found in agriculture. These have been discussed in Section 2.1.2 of this report. Soil condition refers to initial and final conditions, that is, before and after it is worked by a tool or implement either in the laboratory soil bin or in the field. The properties that determine the condition of the soil include: bulk density, moisture content, degree of compaction, organic matter content and so on.

2.6.1.2 Bulk Density

The bulk density of a soil is the mass of soil that occupies a unit volume. Dry bulk density is the mass of dry soil that occupies a unit volume. It is commonly defined as the oven-dried mass of soil divided by the undisturbed volume of the sample. By way of equations:

$$\text{Bulk density, } \rho_b = \frac{M}{v}$$

$$\text{Dry Bulk density, } \rho_{bd} = \frac{Md}{v} = \frac{\rho_b}{1+mc}$$

Where,

Mc = Moisture content, decimal

M = Mass of wet soil, kg or Mg

Md = Mass of oven-dry soil, kg or Mg

V = Volume of undisturbed volume of the sample, m³

The bulk density of a soil influences soil strength for structural purposes and for trafficability of vehicles, animals and humans. It affects plant growth, water infiltration into soil and drainage from soil, power required to till soil, and performance of tillage tools (Erbach, 1987). Bulk density is often measured to evaluate the effectiveness of tillage operation or the damage caused by passage of a wheel.

(i) Measuring Bulk Density

These usually consist a cylindrical metal sampler that is driven or pressed into the soil to desired depth and carefully removed to preserve a known volume of soil as it existed in situ.

(ii) Excavation Method

To determine bulk density by excavation method, a quantity of soil is excavated and the volume of excavation is determined (Blake, 1965). The soil removed is oven-dried and weighed. The difficult part of this procedure is accurately measuring the volume of soil excavated. Sand funnel, ballon and high viscosity methods are used to determine the volume of soil excavated (Erbach, 1987). Instead of the balloon, other thin waterproof films may be used or the surface of the excavation may be sprayed with a waterproof resin to prevent seepage from the hole. Another method is to pour a high viscosity fluid into the hole. The high viscosity slows the penetration of the fluid into the soil. Beckett (1928) used heavy road oil, heavy fuel oil or heavy cane syrup. Larinov (1971) poured molten paraffin wax into the excavated hole. After the wax solidifies, it is removed and its volume determined by water displacement.

(iii) Radiation Methods

Vomicil (1965), proposed the use of gamma ray absorption for soil density measurement. The transmission of gamma radiation through soil or scattering within soil varies with soil properties, including density. Soil density can be related to the change in attenuation of gamma radiation in the soil as compared with attenuation in the air (Revut and Rode, 1969).

(a) Scattering: The gamma-ray scattering method uses a source and detector located in either a surface gauge or a single probe. The instrument records reflected gamma radiation (Rozhkov, 1970) and must be calibrated for the conditions to be measured. The volume of soil that influences the count rate varies with soil density and is roughly hemispherical with a diameter approximately equal to the distance between the source and the detector (Freitag, 1971).

(b) **Attenuation:** The gamma-ray attenuation method uses two probes. The radiation source is in the tip of one and the detector in the tip of the other. The transmission count measured is proportional to the mass of soil between the probes (Van Bavel, 1959).

The limitations of the radiation methods according to Erbach (1987) are:

- (i) The moisture content of the soil must be known.
- (ii) Calibrations a potential source of error
- (iii) They are expensive
- (iv) The risk of exposing oneself to nuclear radiation in the case of nuclear densiometer.
- (v) Cone Index

Attempts have been made to relate cone index, the force per unit base area required to push a penetrometer through soil, to soil density. Ayers and Perumpral (1982) developed the following equation to predict soil density from cone index and moisture content.

$$DD = \left[(CI / C_1) C_2 + (MC - C_3)^2 \right]^{1/4} \quad (14)$$

Where,

DD = dry density (g/cm^3)

CI = cone index (kPa)

C_1, C_2, C_3, C_4 = Constants that depend on the soil type.

MC = Moisture content (% dry weight).

This relationship fit the data from prepared soils in the laboratory with R^2 of 0.94 for sand and 0.98 for clay soils. They concluded that with additional research, the cone penetrometer may be used as an instrument to develop subsurface density profiles for insitu soils.

2.6.1.3 Moisture Content

The amount of moisture in the soil can be estimated by techniques ranging from looking at or feeling the soil to use of sophisticated instruments. The Australian Water Resources Council (1974) and Schmugge, et al (1980) are among those who have surveyed and evaluated methods for soil moisture determination including gravimetric, nuclear, electromagnetic, tensiometric and trygrometric techniques. Moisture content is commonly expressed as a percentage of dry soil weight, dry basis (db).

Insitu Methods

(i) Tensiometer

The tensiometer method is based upon attractive force between soil and water. The principle of operation is well reported in Erbach (1987). Tensiometer readings are affected by temperature and by hysteresis due to wetting or drying (Riouchards and Gardner, 1936).

(ii) Radiation Methods

Neutron Scattering. Neutrons are affected by hydrogen atoms and therefore may be used to measure soil water content (Revuat and Rode, 1969). A neutron moisture gauge is an instrument with a fast neutron source and slow neutron detector (International Atomic Energy Agency, 1970). The count rate of thermal or slow neutrons is calibrated for volumetric moisture content in a spherical volume of soil. The neutron moderation technique measures the water content in a sphere approximately 15 cm. in diameter in wet soils and up to 50 cm in dry soils (Thien, 1983). In reviewing the literature, Hanus et al (1972) found that the most important factors influencing measurement of soil water content made with neutron gauges are silt and clay contents and soil density.

(iii) **Gamma-ray Attenuation**

Gamma-ray attenuation can be used to measure soil moisture in a 1 to 2 cm thick layer of soil. The technique uses the principle that scattering and absorption of gamma-rays are a function of the density of matter in their path. If it is assumed that the density of soil remains constant, the moisture content changes can be determined from changes in gamma ray measurement of wet density (Erbach, 1987).

De Vries (1969) measured moisture content with gamma-ray attenuation and found that collimation is essential for measurements within 1 cm of the soil surface but not required for measurements within the bulk of a layered system.

Disadvantages of gamma-ray technique are costly, difficult to use instrumentation, potential health hazard and large variations in moisture content readings that occur in stratified soils.

(iv) **Other Methods**

Other methods of moisture content determination techniques too lengthy to be presented here were reported by Erbach (1987) to include:

- (a) Electrical resistance instruments.
- (b) Thermo couple psychrometer.
- (c) Thermo electronic.
- (d) Nuclear magnetic resonance.
- (e) Time-domain reflectrometry.

Removed Sample Methods

(v) **Gravimetric:** This is the most commonly used means of determining soil moisture content. It involves drying a soil sample in an oven at 105° to 110°C. The moisture content is the weight reduction during drying expressed as a percentage of the dry weight of the sample.

(vi) **Immersion:** The immersion method uses the principle that the dry weight of a moist soil sample can be obtained by weighing the soil in water (Wilde and Spyridakis, 1962).

Calculation of the moisture contents, in percentage dry basis, requires that the specific gravity of soils be measured or estimated. By use of this method, moisture content can be estimated within 1% (Erbach, 1987). The advantage of the immersion method is that it is much faster than over-drying.

(vii) **Sulphuric Acid:** Gupta and Gupta (1981) evaluated the sulphuric acid method for determination of soil moisture content of disturbed samples. Concentrated sulphuric acid is added to the soil. The mixture is swirled and the maximum temperature reached is recorded. The maximum temperature and the soil moisture determined gravimetrically are linearly related with correlation coefficient of greater than 0.98. The sulphuric acid method requires small soil samples and is limited to soils with low organic matter content.

2.6.1.4 Length of Crescent

Payne and Tanner (1959) reported that for clay loam the distance in the direction of travel from the line of emergence of the tine to the limit of the crescent increased more rapidly as the rake angle of the tine became more acute. According to them, a knowledge of this relationship may be of direct value to engineers or designers, for instance in avoiding the loading of the disturbed area by such parts as depths wheels which would thus increase the draught unnecessarily. Of more direct value, however, in understanding the cleavage pattern, they noted, is the relationship between the horizontal distance,* from the bottom of the tine to the leading edge of the crescent and the proportions of the tine. The distance x expressed as in the

previous work (Payne 1956) as a ratio to width was plotted against the depth/width ratio for the soils they considered. The plot enabled them to observe that the elongation of crescent with acute-angled tines was due to the change in position of the bottom edge of the tine relative to its line of emergence rather than to an increase in the true length of the crescent. They observed that the horizontal distance from the bottom of the tine to the limit of the crescent was at its smallest with acute-angled tines.

It might be expected that the length of the shear path in the direction of travel would be closely related to draught, since it is an approximate measure of the area of soil being instantaneously sheared by the tine. It is difficult to measure the true length of this slightly curved path, but the error involved in assuming it to be straight is very small. Payne and Tanner (1959) plotted the distance, z , from the bottom of the tine to the leading tip of the crescent for tine widths and rake angles against draught. The correlation coefficients R for the curves were so high that it was probably safe to regard the length of the shear path as a sensitive test of the resistance that will be offered by tines of any of the proportions or angles of rake used in the work.

2.6.1.5 Width of Crescent

The width of the disturbance produced at the surface by a tine extends beyond the sides of the tine by an amount corresponding to the maximum width of the crescent (Payne and Tanner, 1959). They noted that this extra distance (y) from the side of the tine to the crescent perpendicular to the direction of travel is of importance in understanding the pattern of cleavage. In the work on vertical tine (Payne, 1956) it was suggested that y is independent of the width of the tine provided that the tine is

wide enough to bring the soil into plastic equilibrium. On most soils with vertical tines, this was found to mean a width of at least 38.1 mm.

The width of the crescent and hence of the disturbed area must be of direct importance in assessing the usefulness of a tine in breaking the soil to increase air and water permeability (Payne and Tanner, 1959). Where this is of importance, the draught per unit width of disturbance is, therefore, a measure of efficiency and was plotted against rake angles (Payne and Tanner, 1959).

2.6.1.6 Surcharge

This is an unusual extra or additional load or force on soil surface that is called into play when a tillage tool or implement disturbs the soil.

In a narrow tine soil failure, a wedge of soil moves up the face of the tine and if this impinges on the undersurface of the beam, a surcharging load will be produced (Tanner, 1960).

Badly placed tines and depth wheels can interfere with soil failure patterns and may increase the surcharging load and hence soil shear strength and the draught force. A similar surcharging effect could be produced by the tractor rear wheels with closely mounted acute angled tines (Dransfield et al, 1964).

2.6.1.7 Soil Material Adhesion

Among the forces acting in the mutual contact surface of the rigid bodies of different materials is a force often required to pull the two bodies apart. The force results from an attraction between the two unlike materials and is defined as adhesion (Hill and Vandeen Berg, 1968). Adhesion is a dynamic property in that it is made manifest only through movement of the soil (Gill and Vandeen Berg, 1968).

When soil slides on metal, adhesive force between the soil and the metal has a marked influence on the friction force (Kepner et al, 1978). According to them, adhesive forces are primarily due to the moisture films and their magnitude varies with the moisture content. The adhesive force has the effect of increasing the normal (perpendicular) load on the surface, thus increasing the tangential friction force. Since it is impracticable, to separate the effects of these two components, the usual practice in a laboratory testing is to represent their combined effect by an "apparent coefficient of friction" (Koolen and Kuipers, 1983)

The general relation between soil-metal friction and soil moisture content is well established in literature. In the friction phase, adhesive forces are small and the coefficient of friction is essentially independent of moisture content. Soils in a friable condition usually have moisture contents in this range. In adhesion phase, moisture films develop between the soil particles and the metal, thus creating adhesive forces that cause the apparent coefficient of friction to increase rapidly with moisture content. When the soil has enough moisture to act as a lubricant, the apparent coefficient of friction decreases as more water is added.

The type and smoothness of the material on which the soil slides affects the apparent coefficient of friction. Materials such as Teflon, which resist wetting, do not develop large adhesive forces with soil and therefore have substantially lower apparent coefficients of friction.

Frictional properties for a boundary surface are generally measured by measuring τ_s at different values of σ_n . Generally, τ_s is approximated by

$$\tau_s = \mu \sigma_n \quad (15)$$

Or more accurately (Koolen and Kuipers, 1983) by

$$\tau_s = a + \mu' \sigma_n \quad (16)$$

The parameters, μ , a and μ' are called apparent coefficient of soil-material friction, adhesion and true coefficient of soil-material friction, respectively.

Ademosun (1990) recorded that for any tine implement working in a soil, the value of adhesive force is much larger than the value of sideways failure force or the vertical failure force. Koolen and Kuipers (1983) reported some methods (Figure 12) to measure soil-material frictional properties.

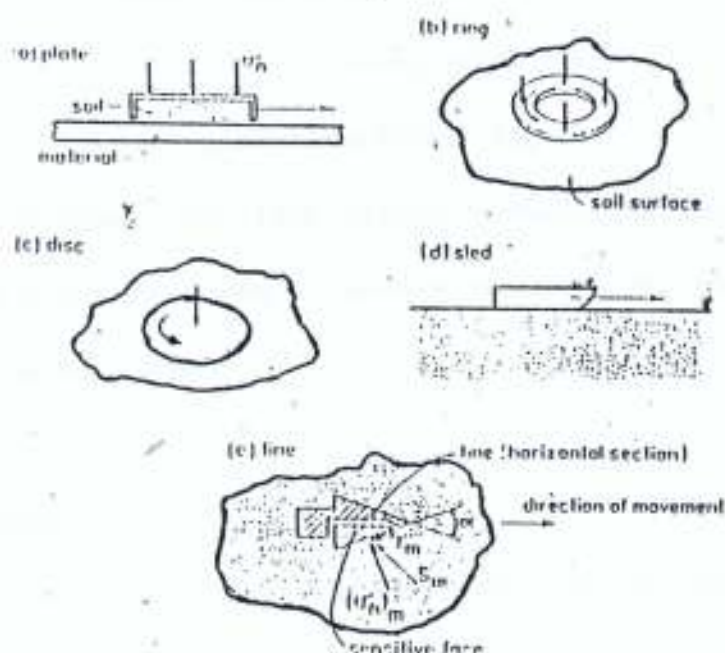


Figure 12: Methods to measure soil-material frictional properties

2.6.1.8 Soil-Material Friction Angle

Soil-material (soil-metal) friction can be identified as the angle of sliding friction δ or the tangent of the angle, μ . Gill and Vanden Beig (1968) reported the importance of adhesion on the sliding friction of metals on soil. The relation is expressed in the form

$$\mu = \frac{F}{N} = \tan \delta \quad (17)$$

where

μ = apparent coefficient of sliding friction

F = force to cause sliding (N)

N = normal force on sliding surface (N)

δ = angle of soil metal friction (degree).

Gill and Vandeen Berg (1968) reported the force required to pull a slider over different soils having a wider range of moisture contents. They reported the apparent coefficient of sliding friction μ .

2.6.1.9 Cohesion

Cohesion has been defined as the force that holds two particles of the same kind together (Kepner et al., 1978). Common values for the cohesion of many loam soils when being cultivated in the friable state are 1.0 to 1.4 kN/m² (Spoor, 1969). Spoor (1969) also reported that soil cohesion is a function mainly of the soil moisture and can have two forms:

(a) Molecule Cohesion

At low soil moisture contents, there is strong bonding between the clay particles.

This is the main factor influencing the bond strength.

(b) **Film Cohesion**

At higher soil moisture contents, there is bonding between the clods themselves due to surface tension forces. Organic matter and plant roots also contribute to the total cohesive force during soil shear. Kepner et al (1978) reported that cohesion C and internal friction angle ϕ are only parameters of shear as indicated by the Coulomb's equation:

$$\tau = C + \sigma \tan \phi$$

For pure sand, $C = 0$ and for pure clay, $\phi = 0$.

When pressure is applied to fine-grained soil, the load is initially carried by the pore water, but is gradually transferred to the soil particles as water is extruded (Smith, 1995).

$$\text{Effective stress } \sigma' = \sigma - u \quad (19)$$

and Coulomb equation may be written more correctly,

$$\tau = C' + (\sigma - u) \tan \phi'$$

$$\text{or } \tau = C' + \sigma' \tan \phi' \quad (20)$$

Where,

τ = shearing stress (at soil failure), N/m^2

C = cohesion, N/m^2

σ = stress normal to plane of failure, N/m^2

ϕ = angle of internal friction, degrees.

In equation (20) C' is sometimes termed the true cohesion and is, referred to as effective stress instead of total stress; ϕ' is the true angle of internal friction. To measure C and ϕ , it is necessary to keep void ratio, density, etc. constant during the test, and as this is difficult in practice, it is more usual to find the arbitrary parameters C and ϕ .

2.6.1.10 Angle of Internal Friction

According to Kepner et al. (1978), internal friction results from interlocking of particles within the soil mass cohesion. C and angle of internal friction (or angle of shearing resistance), ϕ may be determined by measuring the shear stress for several values of normal stress, σ . Koolen and Kuipers (1983) reported that C and ϕ depend on soil type, moisture content, pore space etc. and can therefore be regarded as soil properties. Equation (18) is called Coulomb's law. Koolen and Kuipers (1983) reported that the most accurate measurement of C and ϕ can be done with Triaxial Test.

In contrast to tri-axial tests, the soil in direct shear tests is forced to break along a certain predetermined surface. Koolen and Kuipers (1983) distinguished between translational and torsional shear tests. An important shortcoming of the translational shear test in determining C and ϕ is that the normal force and the shearing force are not evenly distributed over the failure plane because the shearing force is applied from one side.

For torsional shear tests, many differently-shaped torsional shear devices have been used. The most common type include the following : an annulus with grousers on the bottom (Bekker, 1969; Bailey and Weber, 1965), a cylindrical torsional shear box (Payne and Fountaine, 1952); a shear annulus that consists of two concentric

cylinders with connecting radial grousers (Koolen and Kuipers, 1983) and a shear Vane. The height of the blades is usually 1.5 to 2 times, the diameter of the vane.

For unsaturated soil ϕ varies between 25° for moist, relatively loose, fine particles and 45° for drier, relatively dense, coarse particles (Koolen and Kuipers, 1983).

2.6.1.11 Compaction

Compaction is the compression of soil due to the expulsion of air from the voids (Smith, 1975) and the state of compaction is measured by dry (bulk) density. According to Godwin (1990), compaction is the increase in bulk density resulting from loads supplied for short periods of time by machinery and equipment. It was reported by Hillel (1971) that soil compaction can be described as the densification of unsaturated soil due to reduction in air volume without change in mass wetness.

Ghildyal and Tripathi (1987) reported that in a dynamic sense, soil compaction is a physical deformation (volumetric strain) and in the static sense, it is the characteristic related to resistance to increase in bulk density.

While soil compaction is essential in engineering work, it is considerable in agricultural production, because it alters the soil structure and reduces the water transmission of soils (Warkentin, 1971). This results in reduction in crop yield (Frost, 1988).

Compaction of agricultural fields results mainly from rainfall and farm traffic. Farm traffic causes more compaction than rainfall and its effects on compaction of agricultural fields, growth and yield of crops have been well studied (Dawkins, 1983; Frost, 1988; Oni, 1991; Aina et al., 1985). Other artificial compaction is achieved by rolling, tamping, vibrating or compressing the soil by any means. The degree of

compaction depends upon soil-water—content, the compactive energy, nature of soil and the amount of manipulation.

The state of compaction affects the soil-air-water-temperature relationship profoundly and determines the physical, chemical and biological properties of soil. The objective of common tillage practice is to achieve an optimum state of compaction favourable for crop production.

Gill and Vandeen Berg (1968) reported that compaction is caused by drying. In this case, the action of soil compaction is termed shrinkage. They also noted that compaction caused by drying can be as great as that caused by mechanical forces.

Koolen and Kuipers (1983) reported that in wet conditions, soils with a high content of organic matter are more resistant to compaction than soils low in organic matter content; under dry conditions, the reverse holds true. This means that during drying, the soil resistance to compaction increases most in soils low in organic matter (Kuipers, 1959a).

Ghildyal and Tripathi (1987) reported that a dry pulverized soil cannot be compacted to high density due to incompressible nature of soil particles and high internal friction. But as soil water content increases, the thickness of water film around the particles increases thereby reducing the cohesion between particles and allowing them to slide over each other under the applied load. The soil can then be compacted readily to a greater density. The water film around the particles act as a lubricant reducing the friction between soil particles and aggregates facilitating the re-arrangement and closer packing of the particles. With increasing water content, the density after compaction progressively increases up to a certain limit beyond which further compression is not possible due to incompressible nature of soil solids and water. With further increase in water-content (at liquid limit), the soil behaves like a

fluid and loses its load bearing properties (Koolen and Kuipers 1983; Olu et al, 1991; Godwin, 1990).

According to Koolen and Kuipers (1983), the degree of soil compaction can be expressed by the following quantities:

- (a) Porosity (n) of a soil volume element is the volume of pore water (water + air) divided by the total volume. This ratio is termed porosity (n).
- (b) Void ratio (e) is the total volume of pores divided by the total volume of solids.
- (c) Dry volume weight (or dry bulk density), ρ_{bd} is the weight of solids in a unit of volume (Mg/m^3). For a given pore space ρ_{bd} depends on specific density of the solids.
- (d) Bulk weight volume (BWV). It is the reciprocal of dry bulk Density, that is

$$1/\rho_{bd}$$

Baver et al, (1972) reported that the pressure required to compress soil to a particular density decreases rapidly as the moisture content increases. Also, the density at a given moisture content increases rapidly as the applied pressure is increases. For a given compactive effort on the soil, the density increases with moisture content to a maximum and then decreases at higher moisture content (Koolen and Kuipers, 1983; Godwin, 1990).

2.6.1.12 Shear Strength

Soil strength is the ability or capacity of a soil in a particular condition to resist or endure an applied force (Gill and Vanden Berg, 1968). Godwin (1990) reported that the strength of a soil is important in relation to load bearing capacity, compaction resistance, tillage forces and root penetration. Low strength is desirable

for ease of cultivation and root penetration, but high strength is necessary to resist compaction under machinery loading and to enable good traction to be achieved.

According to Johnson et al., (1978), the stress state that causes soil fracture or plastic flow is a measure of the soil's shear strength.

The principal factors which influence strength are soil moisture content, density, texture (particle size) and organic matter content (Godwin, 1990). It was reported by Ohu et al., (1986) that shear strength of soil is increased by compaction irrespective of moisture content, while organic matter incorporation decreased soil shear strength. Koolen and Kuipers (1983) reported that a very useful approach to shearing strength is the theory of Mohr based on the functional relationship between normal stress (σ) and shear stress (τ). The relationship has been expressed in the form of Coulomb's equation (Eq. 18). Expressed in terms of force, the Coulomb's equation can be written thus:

$$H = CA + W \tan \phi \quad (21)$$

Where,

H is shear force and A is the cross-sectional area of sheared soil and W is the normal weight.

Shear Measurement Methods

Much apparatus and many techniques have been contrived to quantify soil shear strength. But all the apparatus and techniques are primarily based on one of two methods of measuring failure by shear in soil. Both methods do attempt to quantify C and ϕ of equation (18) or the shear failure envelope for the soil.

- (a) **Direct Shear Method** – involves controlling and measuring the stresses on that plane. Maximum shear stress is measured for a number of normal

stresses. These data can be plotted, then C and ϕ determined from a straight line fitted to the data (Johnson et al., 1987). The principal direct shear devices that have been used to measure shear strength of agricultural soils include:

- (i) Grouser Plate – a rectangular plate that may be placed on a soil Surface and pulled to cause shear of the soil (Gill and Vanden Berg, 1968).
- (ii) Translational Shear Box – is a direct shear device in which a two piece rectangular box is the soil container and loading device (Lambe, 1951; Osman, 1964). In this test, the soil is sheared to failure by moving one part of the shear box relative to the other.
- (iii) NIAE Shear Box – This was developed to measure strength of agricultural top soils in the field (Koolen and Kuipers, 1983). It is a torsional shear device in which solid cylindrical sample of soil is sheared on a plane perpendicular to the axis of the cylinder. The shear stress, τ for a given normal load is calculated as

$$\tau = \frac{3M}{2\pi r^3} \quad (22)$$

where, M is the moment or torque required to create shear and r the radius of the shear box or cylinderal soil sample.

- (iv) Sheargraph – It was developed by Cohron (1962). It is a torsional device that shears a column of confined soil at the outer surface of a grouser shear head. Its usage is based on the same principle as the NIAE shear box and consequently equation (22) applies to the sheargraph.
- (v) Annular Torsional Shear Apparatus – Various annular torsional shear devices have been created and studied for various purposes (Taylor, 1967; Hvorslev, 1970; Dunlap et al., 1966; Willis, 1963; Bailey and Weber, 1965; Janasi and

Karafiath, 1981). These devices consist of a groused ring with some inside radius r_i and an outside radius r_o . The shearing stress, τ for a given normal load is given by the expression.

$$\tau = \frac{3M}{2\pi(r_o^3 - r_i^3)} \quad (23)$$

- (vi) Other Direct Shear Devices – Schafer et al. (1963) conducted tests in agricultural soils with a shear vane. Both C and ϕ cannot be determined from tests conducted with a shear vane. Ohu et al. (1986) used shear vane to determine the shear strength of soils and were able to develop predictive equations useful for the quick estimation of shear strength of compacted soils, especially when studies are needed on the soil-machine-crop interactions.

According to Ohu et al. (1986), the best equation that described the maximum shear strengths of the soils at all organic matter levels related to the pressures applied in compaction was found to be.

$$\tau_{\max} = a + rP_c \quad (24)$$

here,

$\tau_{\max}$ = maximum shear strength, kPa

a = Value of shear strength of the soil at zero pressure, kPa

r = rate of increase in shear strength with increase in pressure, kPa

P_c = Pressure applied for compaction, kPa (P_c is the static equivalent pressure of proctor compaction blows).

The effect of moisture content on shear strength can be described by a rising part as moisture first increases and by a falling part with further increases in moisture content. The rising part as reported by Ohu et al. (1986) can be described as:

$$\tau = (MC/0.55LL) (a + (0.55LL - \tau_{pc}/MC)) \quad (25)$$

where

τ = shear strength of the soil at M_c , Kpa

MC = gravimetric water content at which the shear strength is required, %

LL = Liquid limit of the soil, %

From equation (23), the maximum shear will occur when $MC = 0.55LL$

The shear strength at moisture contents higher than $0.55LL$ can be described as:

$$\tau_1 = \tau + (1 - MC/0.55LL) (a + (MC - \tau_{pc}/0.55LL)) \quad (26)$$

where all the parameters are as defined in equations (24) and (25) and τ_1 is the shear strength of soil at moisture content equal to fifty-five percent of the liquid limit.

(b) Triaxial Shear Devices

The conventional triaxial cell has been used by civil engineers for soil shear measurement under saturated or cemented soil conditions, at high stresses. These conditions are not normally observed in agricultural soils during most field operations. Other devices similar to the design and concept of conventional triaxial shear apparatus are the unconfined compression test apparatus and the three-dimensional shear apparatus. The main advantage of those triaxial devices over direct shear method is that stress state can be more precisely controlled and measured (Koolen and Kuipers, 1983).

2.6.1.13 Deformation Modulus

In considering off-road mobility problems it is necessary to take into account the relationship between soil shearing strength and soil deformation. The relationship is complex and varies with the type and condition of the soil.

Various attempts have been made to fit a mathematical equation to the observed stress/deformation relationship. The most widely used of equation is the Simplified Exponential Equation (SEE) which relates the shearing stress τ at deformation j to the maximum soil shearing stress by the equations.

$$\tau = \tau_m (1 - e^{(-j/k)}) \quad (27)$$

(Bekker, 1956; Janosi and Hanamoto, 1961),

Where K is a "deformation modulus" which serves as an indicator of the initial elasticity of the soil and of the rapidity with which it builds up to its maximum shearing strength as deformation increases. Soil deformation modulus varies with the degree of compaction and looseness of the soil (Gill and Vanden Berg, 1968). Laboratory experiment has been used to measure K using the translational shearing box, but the short coming of this is that there is likely to be a scale effect depending on the thickness of the soil layer in which the shearing deformation is taking place. This is because the shearing displacements are likely to occur in a soil layer only a few millimeters thick. However, other field methods exist for measuring K .

- (i) Measuring K using locked wheel or track.
- (ii) Measuring K using Komandi's method (Komandi, 1968).

The family of curves given by Equation (27) is shown in Appendix A7.

2.6.1.14 Cone Index

The cone index (CI) is measured as the force per base area required to penetrate this cone into the soil at the rate of 1829 mm per minute (Ayers and Perumpral, 1982). The cone index thus determined provides some indication of the shear resistance of the soil which in turn depends upon the strength properties of the soil. Guruswamy and Verma (1995) reported that cone index is a widely accepted

parameter of penetration. It is an indication of soil hardness required for a cone to penetrate the soil. For agricultural soils, cone base diameters of 12.8 mm and 20.3 mm are widely used while cone angle of 30° is most common. Cone indexes have been used to assess.

- (iii) Tractive ability of an off-road vehicle (Freitag and Richardson, 1968; Wismer and Luth, 1972).
- (iv) Characterization of soils in terms of crop growing ability (Raghavan and Mckyes, 1977).
- (v) Rootability. Investigations show that if cone index is approximately 3 MPa root growth is almost impossible (Taylor and Burnett, 1964; Taylor and Gardner, 1963; Camp and Lund, 1968; Morton and Buckele, 1960).
- (vi) An assessment of compaction caused by vehicle traffic (Raghavan and Mckyes, 1977; Sloane, 1973; Chessness et al., 1972).
- (vii) Prediction of draught force (Johnson et al, 1978; Gill and Vanden Berg, 1968).
- (viii) Cone indexes were also used to determine the effect of wheel size and vehicle weight on soil compaction as well as earth embankments (Guruswamy and Verma, 1995).
- (ix) Resistance against trampling of grassland. Koolen and Kuipers (1983) reported that penetrometer measurements were carried out on many Dutch grasslands and the measured average bearing capacities were related to observed trampling damage from cattle. This showed that grassland with an average C.I of 0.5 MPa will be severely trampled in grazing, whereas a CI of 0.7 MPa or higher indicates that trampling resistance is sufficient. It was also reported that for resistance against trampling of Dutch grassland, for a cone with 5 cm^2 base, he found $\text{CI} = 0.6 \text{ MPa}$ and $\text{CI} = 0.9 \text{ MPa}$ as the boundary

values between grasslands having low, medium or high resistance against trampling.

- (x) Sportsfield Damage. Koolen and Kuipers (1983) reported that CI must be at least 1.4MPa on intensively used parts of a soccer field when severe turf damage as a result of soccer playing is to be avoided. The CI values were measured at 2 to 3 cm depth with a steel cone having a tip angle of 60° and a base area of 1 cm^2 . These CI values apply to Dutch circumstance.
- (xi) Uniform Tests. Suppose that a series of tires or tools must be tested under equal soil conditions. Penetrometer tests are then very feasible to check the uniformity with place and time of the selected test area. The same holds for soil bins or containers that are prepared for laboratory tests (Koolen and Kuipers, 1983).

Previous studies indicated that moisture content, density and soil type considerably influenced the penetration resistance or cone index (Chessness et al., 1972; Wells and Treesuwan, 1977; Mulqueen et al., 1977; Ayers and Perumpral, 1982; Smith, 1984; Knight, 1948).

2.6.2 Tool/Implement Factors and Parameters

Tillage tools have been defined by Gill and Vanden Berg (1968) as mechanical devices that are used to apply forces to the soil to cause some desired effect such as pulverization, cutting, inversion, or movement of the soil. Tillage tools usually produce several effects simultaneously. The factors and parameters of tillage tools and implements are those quantities which the designer has control over and which affect the draught of the tool or implement.

2.6.2.1 Type of Tools

A tillage tool has been defined as an individual soil-working element such as tine, plough body, a cultivator shovel or sweep. Tines and plough bodies have been discussed in Section 2.2.

According to Koolen and Kuipers (1983), tines usually have a curved of shape, the share cutting angle being between 30° to 60° . The larger this angle, the less upward is the soil movement, but the higher the draught, the more the crumbling, and the more difficult it is for the tine to penetrate. Larger tines often have a smaller cutting angle than smaller tines. The set working depth is generally stabilized by supporting wheels. Normal range of traveling speeds is 6 to 8 km/h. Crumbling increases with increasing traveling speed. Other types of tools: Chisel ploughs, spike-tooth harrows, cultivators, P.T.O. driven implements for seed preparation, weeders, subsoilers, oscillating tines and others have been discussed in Section 2.4 above.

2.6.2.2 Share of Tool and Tool Wear-shape, Geometry and Material

Share is that part of the plough which penetrates into the soil, cuts the furrow slice and passes it on to the mouldboard. The share takes the greatest amount of wear (Culpin, 1986).

The exploration of the action of soil-tillage tool systems has shown that variation of tool geometry factors may be associated with the behaviour output (Gill and Vanden Berg (1968). It has also been observed that variations in the geometry of soil-tillage tool systems result in different draught requirements for tillage and in different soil reactions. Usually, the tool is introduced into the soil and all failure occurs in the soil, rather than in the tool. Therefore, the mode of soil action can be

controlled by varying the geometry of the soil-tool system so that forces, their distribution and the soil reactions vary.

Gill and Vandzen Berg (1968) reported that the forces on tool(s) remain constant only as long as the geometric conditions of the tools are maintained. According to them, if abrasion changes, the geometry of the tool, the forces on the tool may not remain fixed. Gavrilov and Koruschkin (1964) stated that the stability of the tool may be reduced because of the worn edge.

Wear occurs over the entire surface of the tool, but this type of wear normally changes geometry less than wear at a tip or cutting edge. Varnish covering the surface of the tool will be worn away by soil abrasion. The progress of wear, as determined by the loss of varnish with the distance of travel, indicates the leading edge to be the zone of high pressure and wear.

Wear is a most important practical consideration in maintaining proper microtool geometry. Data are not available to indicate the extent to which geometrical changes caused by wear affect soil reactions or forces on tools. Until data of this type are available the economic importance of maintaining geometry of tools cannot be determined (Gill and Vanden Berg, 1968).

Variations in the geometry of soil-tillage tool systems result in different draught requirements for tillage and in different soil reactions. Gill and Vanden Berg (1968) reported on alteration of tool geometry by the formation and adherence of soil bodies. They observed that buildup of soil along the sliding surfaces of tillage tools may alter their shape. Soil adhering to the tool can form a body of soil that acts as part of the tool. The presence of this soil body on the forces and soil reactions is of great importance. Any description of the shape of a tool that does not include the geometry and action of the soil body will not represent the true system (Gill and

Vanden Berg, 1968). Payne identified this type of soil body as a wedge and that the absence of scouring creates the situation in which soil bodies are formed.

Gill and Vanden Berg (1968) reported that simple geometrical tool parameters such as length, width, depth of operation and rake angle cannot be used in a soil-tillage tool mechanics without caution. These values may be of little physical significance when soil bodies are formed. Indeed, formation of soil bodies may have limited the success of the principles of dimensional analysis and similitude in a study of dynamic action of tillage tools.

Blade wear rates and resistance to impact shocks and fatigue are of concern to users and manufacturer. In laboratory and field tests with disc-harrow, blades, made from SAE 1080 steel and heat treated to various hardness (Reed and McCreery, 1954), the lowest wear rate was obtained when the hardness was in the range from 44 to 48 on the Rockwell C Scale (Rc). Wear rates were greater when steel of the same composition was either harder or softer. When steels having carbon contents from 0.45 to 0.95% were tested, the wear rate for any particular hardness decreased as the carbon content was increased. The wear rate with SAE 6160 steel was a little greater than for SAE 1080 steel at any given hardness (Kepner et al, 1978). Results from additional laboratory tests (Reed and McCreery, 1954) indicate that both impact and fatigue resistance for disc blades made from SAE 1080 steel decreased rapidly as the hardness was increased from Rc 36 to Rc 52. In general, field experience has indicated that alloys steels (such as SAE 6160) have better impact resistance than carbon steel and will stand up better in large discs subjected to extreme impact loads under severe operating conditions.

2.6.2.3 Tool Arrangement and Tool Gang

An efficient tillage system is one which minimizes the amount of energy required to till the soil consistent with achieving the desired soil condition (Chisholm, et al, 1970).

A tillage tool does not act independently but operates in a combined tool system. When two tools are brought close to each other, the interference of one in the boundary conditions of the other causes a considerable change in the energy requirement of both tools and influences the resulting soil disturbance (Soomro et al, 1982). As a result of tine interaction, the draught on individual tines mounted on the third row of a cultivator have been found to be four times lower than the draught on tines mounted on first row (Koolen and Kuipers; 1983).

Tilling the soil in layers reduces draught. If the top soil layer is loosened first, the surface confining stresses on the deeper layers are relived and deeper layers could be tilled with less effort. A double cut plough required 20 to 25% less draught than conventional mould board plough to cut the same volume of soil (Gill and Vanden Berg, 1968). Two shallow tines when placed in front of a subsoiler main tine reduced the draught of three-tine combination by 10 to 15% together with better soil rearrangement than the subsoiler main tine alone.

Koolen and Kuipers (1983) reported the interaction of two vertical straight tools. The draught resistance of two interdepending tools was found to depend on the ratio of distance between the tines ' d ' and the working depth ' t '. Minimum draught was found when the tools were placed at $d = 0.34t$, the draught being 10% higher than that of a single tool. Draught became maximum at $d = 0.043t$ when tools were working very close and at $d = 2.5t$ when they were working independently.

The depth over which upward soil movement occurred could be increased if the surface soil layers are loosened first before a deep cultivation operation (Spoon, 1975). Hence, any effort to relieve the surface confining stresses of the soil or to utilize the beneficial effect of time interaction or both could help minimize the power requirement of a tillage tool and would enhance the efficiency of operation.

Soomro et al (1982) reported the following conclusions:

- (i) The most effective position of the leading shallow tines can be determined from a knowledge of the rupture planes developed by the tines working independently.
- (ii) Leading shallow tines working at half the depth of the trailing deep tine are particularly efficient when spaced at between 1.0 and 1.5 times the working depth of the deep tine, the efficiency increasing between 30 to 50% compared with single.
- (iii) Interacting tines working at the same depth and spaced at 1.0 to 1.5 of their working depth produce greater soil disturbance for a lower draught than non-interacting tines.
- (iv) Combined interaction between depths and at the same depth increase tillage efficiency when preceded by shallow tines. Two deep interacting tines spaced at 1.0 to 1.5 times their working depth produce a greater soil disturbance for the same draught requirement as deep interacting tines alone. The efficiency increases by approximately 15 to 20%.

2.6.3 Operational Factors and Parameters

Operational factors and parameters affect the draught requirements of tillage tools. The operator has direct control over operational factors and parameters.

Ademosun (1990) identified three operational parameters (rake angle, depth of work and speed of operation) while working on a typical Nigerian loamy soil.

2.6.3.1 Tool Linear Forward Movement (Speed)

Typical speeds of tillage tools and implements are discussed in Section 2.5.3.3 and specifically in Table 6.

Wegscheid and Myers (1967) recorded a range of speed of 2.2 m/s (8.05 km/h) to 5.4 m/s (19.3 km/h) as they worked in Deere soil bin facility in the Engineering Research Division of Deere and Company at Moline, Illinois. The dynamometer carriage was towed by cables operating along both sides of the bin. Power for the system was from an 11.0kw reversible a.c motor equipped with an eddy current brake. Godwin (1980), in the design and operation of a simple low cost soil bin recorded a speed range of 0.1m/s (0.36 km/h) to 2.5 m/s (9 km/h). The speed of the carriage was monitored using a magnetic impulse tachometer mounted adjacent to a notched pulley in the winch system.

Yadav and Pandey (1984) in a soil-bin investigations of blade tools worked within moisture range of 4 to 8% (db). For their experiments, a 7.5kw., 3-phase electric motor coupled with a gear box having five forward speed gears and one reverse gear was used to operate the trolley at different speeds.

Past research on high speed ploughs has concentrated mainly on examining the performance of existing ploughs at high speeds (Sohne, 1959; 1960; 1962 and Poesse and Van Ouwerkerk, 1967). These experiments show that the performance of commercial ploughs was unacceptable at speeds above 1.9 m/s (7.0 km/h) to 2.2 m/s (8.0 km/h) and they provided information on plough body shapes for higher speed work.

Kermis (1978) reported that the total length of mould board plough is directly proportional to the ploughing speed. This means that ploughs designed to move at 3.3 m/s (12.0 km/h) for instance would have lengths up to 1.8 m. He therefore concluded that total plough length could be a limiting factor in high speed plough design. Stafford (1979) worked on experimental tillage tool that was supported on a carriage which ran on rails suspended above the tank. Propulsion for the carriage was provided by a cable and winch driven by a 20kw electric motor with thyristor speed control. His speed was 0.05 m/s (0.18 km/h) to 5.5m/s (19.8 km/h).

Culpin (1986) reported that where the soil is in a suitable condition for tilth formation, the higher the speed within normal limits, the greater is the pulverizing effect. According to him, the most effective application of power by modern outfits calls for speeds of 1.8 m/s (6.4 km/h) to 2.2 m/s (8.0 km/h).

2.6.3.2 Depth of Work/Cut

The depth of work can be shallow or deep depending on the type of tillage implement used and the purpose of the tillage operation. Experiments shows that on some soils, use of a shallow plough especially designed for high speed work at only 7.5 mm to 100 mm deep can provide effective stubble breaking with good weed control (Culpin, 1986). The following are typical values of depth of work for common tillage tools and implements:

- (i) Disc ploughs normally work at depths up to 25 cm.
- (ii) Harrows work at shallow depths within the first 1.5cm of the top soil.
- (iii) Cultivators work at depths varying from 22.8 cm to 30.4 cm.
- (iv) Mounted and semi-mounted ploughs working depth range from 25.5 cm to 30.5 cm.

(v) Sub-soilers working depth vary from 45 cm to 75 cm.

The depth of work is usually regarded as deep when the implement operates below 15.0 cm of the soil surface. Deep tillage and subsoiling are usually beneficial in conserving moisture.

The depth of work is usually measured with a rule. Owen et al, (1987) used a linear displacement transducer to measure operating depth. The transducer indicated the distance between the tool bar and a fixed point on the wheel axle support. The distance was calibrated to the operating depth and converted during analysis.

2.6.3.3 Rake Angle/Tool Angle

Rake angle is defined as the angle which the plane of the tool makes with the horizontal plane (Yadav and Pandey, 1984). It is usually measured in degrees. When the tool is perpendicular to the direction of travel, the rake angle is equal to 90°.

Spoor and Fry (1983) reported that low rake angle narrow tines are used for a wide range of agricultural operations including soil loosening, mole drainage, and trenchless drain pipe laying.

2.6.3.4 Tool Oscillation/Vibration

Oscillating multipowered tillage tools are tools that move the shape reference system in a path that swings within the implement reference system (Gill and Vanden Berg, 1968). Any distinction between rotating and oscillating multipowered tools is only in the path of motion, not in the method or principle of energy application.

Interest in oscillating tools has risen because of reports that the use of oscillations has reduced draught requirements of tools. Paths of oscillation may be controlled by mechanical means such as eccentrics, cams, or crankshaft and

connecting rod arrangements (Gill and Vanden Berg, 1968). These mechanisms provide the means for applying oscillating energy to the tool as it is being drawn through the soil.

A spring tine is a practical oscillating tool that is not multipowered and that has uncontrolled oscillations. The oscillations are induced by variations in soil resistance. When high resistance is encountered, the tine is further stretched; when resistance decreases, the restoring force of the spring returns the tine to its original position. Presumably, oscillation of a flexible tine permits the tool to take advantage of minor irregularities in soil strength. Gill and Vanden Berg (1968) reported that the draught of spring tines may be 20 to 30 percent less than the draught of rigid tines.

2.7 Relationship Between Tillage Parameters and Draught

General

The specific draught of agricultural tools and implements varies widely under different conditions, being affected by such factors as the soil type and condition, ploughing speed, plough bottom, shape, friction characteristics of the soil-engaging surfaces, share sharpness, and shape, depth of ploughing width of furrow slice, type of attachments, and adjustment of the tool and attachments. A great deal of work has been done in evaluating these various factors and investigating possible means for reducing draught. Mathematical methods and models have been developed by researchers for predicting draught (Reece, 1965; Stafford, 1984).

Soil type and condition are by far the most important factors contributing to variations in specific draught. Table 8 shows typical specific draught and soil types.

Table 8: Typical Specific Draught and Soil Types

Soil Type	Specific Draught (KN/m ²)
Sandy soils	14.0 to 20.0
Sandy or Silt loams	20.0 to 50.0
Clay loams, heavy clay loams	40.0 to 80.0
Heavy Gumbo soils	100.0 to 140.0

Source: Kepner et al., (1980).

2.7.1 Draught Prediction Models

A number of force prediction models have been developed directly or indirectly from theories of soil failure associated with civil engineering structures (Stafford, 1984). They have been based primarily on passive earth pressure theories for movement of vertical retaining walls and bearing loads for footings where a dead wedge of soil is formed. The models of Payne (1956) O'Calaghan and Farrelly (1964) were of this kind.

2.7.1.1 The Existing Models

- (i) **Kawamura (1952):** used Coulomb's and Rankine's theory to calculate draught force.. Neither theory gave sufficiently accurate results. Kawamura (1953) attempted to use the plastic equilibrium concept. For yield criterion, he used the snear-failure model as given by Coulomb. The calculated and the measured values on an inclined tillage tool were reported to agree well.
- (ii) **Payne (1956)** analyzing the forces on soil wedge attempted to predict the minimum draught from the relationship

$$D_{\min} = D_{\max} \frac{C_r}{C} \quad (28)$$

Where

$D_{\max}$ = Maximum draught

C_r = residual cohesion

C = Cohesion

(iii) **Soehne (1956)** analysed the action of a simplified inclined tool and concluded that 4 simple behaviour equations described the tillage action:

- (a) soil-metal friction;
- (b) shear failure;
- (c) Acceleration force for each block of soil;
- (d) cutting resistance.

The following equilibrium equation was written for the force, in the horizontal direction.

$$W^* = N_o \sin \delta + \mu' N_o \cos \delta \quad (29)$$

Where:

W^* = draught without the cutting component

N_o = normal load on the inclined tool

δ = lift angle of the tool

μ' = coefficient of soil-metal friction.

The measured values were approximately 18% lower than the values calculated.

(iv) **O'Callaghan and Farrelly (1964)** proposed a mathematical model to predict the draught of a vertical plate tine. **O'Callaghan and Mc Cullen (1965)** reported that the above model proposed for vertical plate tines could be extended to plane and wedge-shaped tines. Raking a tine forward in the

direction of travel caused reduction in draught owing to persistence of the mechanism of cleavage to greater depths.

- (v) **Reece (1965)** showed tht the soil load P on a loaded interface can be written more specifically in the form of the additive equation.

$$P = \gamma z^2 N_\gamma + C z N_c + C_\alpha z N_\alpha + q z N_q \quad (30)$$

Where

C = apparent cohesion

C_α = soil-interface adhesion

$N_\gamma, N_c, N_\alpha, N_q$ = dimensionless Reece factors

q = Surcharge

z = depth of cut

α = rake of interface

γ = bulk density of soil.

The four terms in this equation represent the gravitational, cohesive, adhesive and surcharge components of the soil reaction per unit width of interface respectively.

The "N-factors" represent pure numbers, which describe the shape of the soil failure surface and are thus functions of ϕ , δ (angles of shearing resistance and soil-interface friction resp.) and the geometry of the loaded interface.

- (vi) **Hettiaratchi et al. (1966)** based their analysis on the assumption that the failure boundary is a composite one, composed of a curved portion, assumed to be a part of an equiangular spiral represented by

$$r = r_0 \exp(\omega \tan \phi) \quad (31)$$

where

r_0 = initial radius of the spiral

ω = spiral angle

ϕ = angle of internal friction

and a plane section. An advantage was taken of the simple nature of Reece additive equation (Reece, 1965) to produce a family of curves from which it will be possible to obtain a ready solution to most two dimensional passive pressure problems.

Hettiaratchi and Reece (1974) presented a method of computing passive earth pressure, based on a rigorous mathematical solution of plastic equilibrium. From the soil-blade system, Hettiaratchi et al, (1966) derived the following expression for draught force, F

$$F = w (\gamma z^2 N_\gamma + c z N_c + C_a z N_a + q z N_q) \sin (\alpha + \delta) \quad (32)$$

Where w = blade width,

(vii) **Wang and Liang (1970)** developed a method by which the draught of tillage tools in any chosen soil and operating at any chosen velocity can be predicted by a single testing of a geometrically similar tool. The soil-model approach was used. It was shown that for geometrically similar agricultural implements, the following dimensionless equations can be used to relate soil and implement variables.

$$\frac{R}{\rho L^3} = f \left[\frac{V^2}{gL}, \frac{C}{\rho L}, \mu, \phi \right] \quad (33)$$

Where

g	=	gravitational constant	LT^{-2}
μ	=	parent soil-material friction angle	
C	=	apparent cohesion	FL^{-2}
V	=	velocity of tool	LT^{-1}
L	=	characteristic length	L
R	=	draught force	F

ρ = bulk volume weight FL^{-3}

ϕ = soil-soil friction angle

In the above equation, the effect of soil-material adhesion is considered to be included in the apparent soil-material friction angle.

According to them, predicted draught generally is accurate to within 20% of actual prototype draught.

2.7.1.2 Current Models

(i) Stafford (1984) proposed force prediction models for brittle and flow type of failure: The effect of tool speed on forces, which can be very significant, is taken into account. It is shown that in brittle failure, the effect of speed is due to inertial forces and rate effects on soil metal friction. With flow failure, the inertial effects are negligible and the large effect of strain rate on soil shear strength dominates. For brittle failure, the prediction equations for forces acting on a tine are:

$$\text{Horizontal: } F_H = b (CZ K_c) \sin(\alpha + \delta) + \gamma a/g v^2 \frac{\sin \alpha \cos(45 - \phi/2)}{\sin(\alpha + 45 - \phi/2)} \quad (34a)$$

$$\text{Vertical: } F_V = b (cz K_c) \cos(\alpha + \delta) + \gamma a/g V^2 \frac{\sin \alpha \sin(45 - \phi/2)}{\sin(\alpha + 45 - \phi/2)} \quad (34b)$$

where K_c , δ and a are functions of tine speed. For flow failure, the prediction equations are:

$$\text{Horizontal: } F_H = bz [r + s \log(1 + tv)] k \sin(\alpha + \delta) \quad (35a)$$

$$\text{Vertical: } F_V = bz [r + s \log(1 + tv)] k \cos(\alpha + \delta) \quad (35b)$$

- a = cross sectional area of furor formed by interface
- b = width of interface
- F = force on interface of unit width
- K_c, K = non-dimensional coefficients in force models
- V = horizontal velocity of interface
- γ = soil specific weight
- Z = depth of interface
- α = rake angle (to forward horizontal) of interface.
- ϕ = soil internal friction angle
- δ = soil-interface friction angle.

(i) Gupta et al (1989) developed an analytical model to predict the draught force of convex blades. They also concluded that the model can be used for prediction of the draught forces acting on the wide cutting blades. The new analytical model applicable to convex – type wide cutting blades was developed in terms of tool, soil and tillage system parameters.

(ii) The soil-wedge model for the flat blade of McKyes and Ali (1977) was improved by McKyes and Desir (1984) by including the tangential force acting on inclined area of the tool owing to soil metal adhesion. The draught force derived therefrom does not take into account the effects of the acceleration force and cutting resistance of the soil. These were consequently included to develop the complete equation given by:

$$(iii) \quad D_{th} = (\gamma d^2 N_{\gamma H} + cd N_{CH} + vd N_{qH} + a_j d N_{adH} + \gamma w / g d v^2 \frac{\sin \alpha \cos \beta + \pi P_{0t} l}{\sin(\alpha + \beta)}) \quad (36)$$

Where

- D_{th} = theoretical draught
- H = horizontal force excluding accelerating and cutting forces

L	=	actual length of soil cut by the tool
P_0	=	maximum pressure at the centre of the cutting edge of the tool
C	=	cohesion
β	=	angle between the horizontal and soil failure plane
q	=	surcharge
μ	=	soil-metal adhesion
α	=	rake angle of the tool
N_{gr}	=	gravitational dimensionless number
N_{CH}	=	cohesion dimensionless number
N_{adH}	=	adhesion dimensionless number
W	=	wet bulk density of soil (Kgcm^{-3})
V	=	velocity of the tool
t_c	=	thickness of the sharp cutting edge of the tool.

The average deviation of the experimental draught values from the theoretical one was found to be in the range of 0.02 to 33.14%

2.7.2 Effects of Soil Parameters on Draught

Soil moisture content: This is an important factor in regard to both draught and quality of work. A dry soil requires an excessive power and also accelerates wear of the cutting edges. In USDA soil bin tests, an increase of moisture content from 9.1 to 11.7% (db) reduced the specific draught in a fine sandy loam by 15 to 35% (Gill and Vanden Berg, 1968).

Other pertinent factors include the degree of soil compaction, the previous tillage treatments and the type, presence or absence of cover crop. For example, Gill and Vandeb Berge (1968) reported a 15 to 35% increase in draught when the apparent specific gravity of a fine sandy loam was changed from 1.68 to 1.83.

Ademosun (1990) reported that draught decreases linearly with increasing soil moisture content within the range of 12 to 16% (wb).

Cupta and Surendranath (1989) reported that draught increased with moisture. Content gradually at lower moisture contents of about 6.9%(db) until it reached 18.9%. Upon increasing the moisture content further, a steep rise in draught was observed in Bangkok clay. This according to them may be explained by the increased cohesion at higher moisture contents requiring greater force for failure.

Koolen and Kuipers (1983) reported a general formula for specific draught (D) as:

$$D = C_1 - C_2MC + C_3 (MC)^2 \quad (37)$$

Where, MC is moisture Content

C_1 , C_2 , C_3 are positive constants. This is the formula of a parabola with its vertex being a minimum value. The soil moisture content at this minimum is called optimum moisture content.

2.7.3 Effects of Tool/Implement Parameters on Draught

- (i) Shape of Tool: Lift angle and the slope of the standard have a marked effect upon draught and the vertical soil force (Kepner et al. (1978). Shattering is accomplished with the least effort when the tool exerts an upward shearing force on the soil, rather than a longitudinal compressive force. Spoor, (1969) reported that numerous bursting line shapes are possible but their efficiencies vary with working depths. Three possible shapes of standards are: Straight (vertical or inclined) and curved. At medium depth inclined and curved tines produce lower draughts than straight vertical tine. However, at great depth inclined or raked tine will have the lowest draught, followed by vertical

straight tine and finally by curved tine. At the great depth, the upper part of the curved tine exerts a downward surcharging force on the soil, so increasing the shear strength and hence, the draught. In all cases, the beam or mounting frame is behind the tine to eliminate possible surcharging effects which would occur at greater depths due to the soil wedge formation.

(ii) Effect of Tool Width on Draught

Gupta and Surendranath (1989) considered experimental blades having widths varying from 15 cm to 30 cm. They reported that at all levels of soil moisture (in Bangkok Clay), the draught per unit width of the 20 cm tool was minimum, the 15 cm was found to require the maximum draught per unit width under all condition. Specific draught ranged from about 1.6 kg/cm to 6 kg/cm.

(iii) Effect of Thickness of Cutting Edge on Draught

Natsis et al. (1999) reported experiment to determine the influence of soil water on the wear of the share cutting edge of mouldboard ploughs. The study showed that draught force, D , increased exponentially with the thickness of the cutting edge, h , after the model.

$$D = 10.23 e^{0.10h}, \quad (R^2 = 0.957) \quad (38)$$

The thickness of cutting edge varied from 1 mm to 6 mm. Average speed was 3.6 km/h (m/s) in the field. Draught varied from 11.5 kN to 20.00 kN. Fielke (1996) reported the effect of cutting edge thickness of experimental sweeps on sandy loam and clay loam soils. According to the report draught increases linearly with cutting edge height. The cutting edge height varied from 1 mm to 10 mm. In sandy loam soil draught varied from 480 N to 900 N while in clay loam soil, draught varied from 1 kN to 1.5 kN.

(iv) **Tool Spacing:** Gill and Vanden Berge (1968) reported the effect on draught force of the distance of spacing interaction between two simple vertical tools. At shallow depths according to him, the distance between tools at which the minimum draught occurred was only slightly influenced by the depth of operation. The minimum draught increased from a point where the spacing between the tools was 5cm to a point where the spacing between the tools was 7cm as the depth increased from 9 to 18cm.

It was reported by Soomro et al. (1982) that tine positioning greatly influenced the combined tool performance and soil disturbance. They also concluded that by carrying out tillage operations in two stages with appropriate tine positioning, the draught requirement from each stage can be significantly reduced (50% reduction) compared with performing the operation in one pass.

2.7.4 Effects of Operational Parameters on Draught

(i) **Depth of Operation:** Ademosun (1990) reported that draught increases linearly with depth of work. According to him, the increase in draught is caused by the large soil force acting on the implement surface to oppose its motion. Gill and Vanden Berg (1968) reported that the draught and depth were parabolically related according to the relation.

$$D = Cd^n \quad (39)$$

Where, D is cutting force (draught) of a horizontal blade

C is Coefficient of soil resistance

d is depth of operation

n = is coefficient

Based on a wide range of soil conditions, the value for n was found to be approximately a constant whose value was 1.35.

(i) **Speed of Operation:** It has been reported that increased forward speed increases draught with most implements mainly because of the more rapid acceleration of the soil (Spoor, 1969; O'Callaghan and McCoy, 1965; Olson and Weber, 1965). Greater forces are required to provide this acceleration and since they also increase the reaction at the interface, a higher sliding resistance results. The increased sliding resistance contributes most to the increased draught force. To reduce the effect of speed on draught, these acceleration forces should be kept to a minimum, particularly those acting at right angles to the interface (Spoor, 1969). Ademosun (1990) reported a linear relationship of draught with speed for tined implements.

It is generally accepted that draught of a mouldboard plough increases approximately with the square of speed (Gill and Vanden Berg, 1968; Soehne, 1956; Koolen and Kwipers, 1983) according to the relation:

$$D = C_1 + C_2 V^2 \tag{40}$$

Where D is specific draught, C_1 and C_2 are constants and V is linear speed. Equation (40) has been accepted by many investigators (Soehne, 1960; Zoz, 1974). Poesse and Van Ouwerkerk, (1967) reported that for heavier soils equation (40) has to be modified thus:

$$D = D = C_1 + C_2 V^x \tag{41}$$

Where x is a constant that may be used to improve the accuracy of the relationship.

Stafford (1979) on the performance of rigid tine reported two distinct force-speed relationships in sandy clay loam and clay soil. At low moisture content, draught

increased at an increasing rate with speed, that is, a similar relationship to that observed with mouldboard ploughs. It was reasonable therefore to fit polynomials to these data. However, at high moisture content, draught increased at a decreasing rate with speed. At the highest speed (5 m/s) under this condition, the draught appeared to reach an asymptotic value for the wettest soils. The simplest curve that would fit these data was of decaying exponential form.

Al-Suhaibani and Al-Janobi (1997) reported that specific draught increases exponentially with speed. Draught varied from 1 N/mm to 6.5N/mm in speed range of 0.6 m/s to 2.5 m/s in the field.

(iii) **Speed and Depth by Speed Interaction:** It was reported by Grisso et al. (1996) that a field cultivator draught in a silty clay loam soil on disked surface was linearly dependent on speed and speed by depth interaction, and quadratically dependent on depth according to the relationship:

$$D = C_1 d + C_2 d^2 + C_3 V + C_4 dV \quad (42)$$

(iv) **Rake angle of Tool:** It was reported by Ademosun (1990) that the rate of decrease of draught was constant with increasing rake angle when the depth of work was kept constant. On the other hand when the depth of work varies with the rake angle, the rate of decrease of draught became smaller at an acute rake angle and it became larger at an obtuse rake angle, with increasing rake angled for tined implements.

Payne and Tanner (1959) concluded that draught was relatively insensitive to inclination between 20° and 50° , but thereafter increased very rapidly, the 160° tines having at least five times greater draught than 20° tines.

Gupta et al, (1989) reported the effect of rake angle on specific draught for six different tools at two working depths (2.5 cm and 7.5 cm). At 2.5 cm working depth, it was reported that straight, convex, concave and triangular tools behave in a similar

way, in that as the rake angle increases, the specific draught decreases up to a certain angle and afterwards increases. In a concave tool, it does, however start to decrease again after 55° rake angle. The minimum specific draught were obtained at rake angles of 39° , 47° , 35° and 48° for straight, convex concave and triangular tools respectively.

Osman (1964) reported that the fluctuation in specific draught with depth and rake angle for different tools is caused by change of soil failure plane angle and depends upon the geometry of tools. He further reported that draught increases with rake angle gradually for the range 30° to 50° , thereafter sharply. He also concluded that by extrapolation, draught is almost independent of rake angle below 30° , so that the optimum rake angle for earthmoving machines as well as cultivation implements is about 30° , as more acute angles will result in excessively long components. Spoor (1969) reported that draught increases slowly from rake angle of 10° to 50° , the rate of increase is very rapid indeed. He concluded that for minimum draught, rake angles of less than 50° should be used provided that tines set at these inclinations will do the job satisfactorily.

(ii) Oscillation or Vibration

Operating parameters for a Vibratory tillage system include travel speed, oscillation frequency, amplitude, direction and pattern of oscillating motion, tool shape, tool lift angle, and soil physical characteristics (Kepner et al, (1978). Research results indicate that, with appropriate combinations of values for the above parameters, draught requirements can be reduced by as much as 50 to 75% in comparison with non-oscillated tools (Verma, 1991). In general, it has been found that draught reduction is increased by increasing the vibration velocity and is decreased by increasing travel velocity (Kepner et al., 1978).

Shkurenko (1960) studied the effect of oscillation on draught in one soil condition of compacted clay at a moisture content of 26% (db). He reported that for

the condition studied, forward speed did not have a large effect on draught since a six fold decrease in speed produced only a 25% decrease in draught. However, there was at least a 50% reduction in draught due to the vibration of the tool.

Butson and MacIntyre (1981) reported that there was no change in draught when the velocity ratio (the ratio of the peak vibration velocity to the forward speed) was less than 1.0. When the ratio was greater than 1.0, draught reduction greater than 50% was observed, but this could only be achieved at the expense of a substantial increase in total power consumption. They also reported that the application of vibration always resulted in a power increase even when the velocity ratio was less than 1.0 and when there was no reduction in draught.

Butson and Rackman (1981) reported the general acceptance that vibration can greatly reduce the draught force needed to pull a blade or tine through soil, but this can only be achieved at the expense of an increase in total power consumed. Power increases of around 200% were not exceptional (Butson and MacIntyre, 1981).

From the results obtained, it was concluded that vibration was most likely to be effective for low speed, high draught operations, such as subsoiling (Butson and MacIntyre, 1981; Totten and Kianfman, 1971).

Szabo et al. (1998) reported that a harmonically varying force applied to model bulldozer, mouldboard and chisel plough blades decreased draught force by as much as 93%, 88% and 91% respectively.

A number of investigations showed that average draught of soil-working-tools is significantly reduced when the blades are oscillated at an optimum combination of frequency, amplitude and direction (Kawamura, 1985; Brown, 1978; Verma et al, 1976; Brixius and Weber, 1975; Venter, 1968).

2.8 Soil Bin

Following the decline of research in soil dynamics during World war II, the resumption of research was slow (Gill and Vanden Berg, 1968). Since 1950, however, the work has been expanding especially in countries of Asia and USA at an increasing rate and new research centres are being developed.

Not all research utilizes full-scale equipment; smaller bins are often used for studies with small tools or models. Small bins may be moved on tracks while the device to be investigated is held rigid. As the size of the soil bin increase, the tool is moved and the bin remains stationary. Limitations of speed and space are quickly encountered when small bins are used so that there is always a need to compromise between the size of the bin and the volume of soil that must be prepared. Because the preparation of soil becomes a problem when the required volume increases. Efforts are made to keep this operation to a minimum.

Existing designs of soil bin range from the large scale bins of the National Tillage Machinery Laboratory (NTML), Auburn, Alabama, USA where full scale implement testing is carried out to small automated soil bins similar to that described by Siemen and Weber (1964). These bins do not meet all the design requirements in that they either require high investment in specialist machinery or, where this is not the case, they do not permit the testing of full size equipment.

2.8.1 Small-Scale Soil Bin

From soil bin studies, small-scale soil bin is generally agreed as that whose length is shorter than 5.0 m and width shorter than 0.8 m (Stafford, 1978; Siemens and Weber, 1964; Godwin et al, 1980).

Stafford (1979) reported on small-scale soil bin. The laboratory soil bin was 3 m long by 0.7 m wide by 0.4 m deep. The experimental tillage tool was supported on

a carriage which ran on rails suspended above the tank. Propulsion for the carriage was provided by a cable and winch driven by a 20 KW electric motor with thyristor speed control. The tool was accelerated to the required speed which could be set within the range of 5 mm/s to 5.5 m/s, before entering the tank through a gate in one end. The experimental tools were plane tines of 40 mm width and 45° and 90° rake angle. The working depth was 150 mm for all experiments.

Processing of the soil before each experiment was accomplished with hydraulically powered equipment mounted on the carriage. The soil was broken into small aggregates by rotary cutting blades and then packed by rotating, oscillating rollers. The surface was then leveled by rotating cutters prior to an experiment.

Soil forces acting on the experimental tine were measured by suspending the tine support frame from the carriage by six strain gauged force links. The tine speed was measured by a tachometer driven by a carriage support wheel. The speed and force signals were passed through a signal conditioner and then recorded on magnetic tape for subsequent analysis by computer (Payne and Tanner, 1959).

The magnetic tape records of the force transducer signals were analysed by digitizing the tape signals corresponding to the centre 1.5m of the soil tank.

The soil failure pattern in front of the tine was monitored by a high speed cine camera mounted on the carriage.

2.8.2 Medium Scale Soil Bin

From soil bin studies, medium scale soil bin is generally agreed as that whose, length ranges from about 5 m to 15 m; width, 0.8 m to 2 m; depth 0.45 m to 0.5 m. Examples are shown in Table 9.

Table 9: Some Medium Scale Soil Bins' Dimensions.

Location/Site (Source)	Bin Dimensions			
	Length (m)	Width (m)	Height (m)	Soil depth (m)
(i) NCAE, Silsoe, Bedford, U.K (Godwin et al., 1980)	13.0	0.8 to 2	0.50	0.40
(ii) Indian Inst. Tech. Kharagpur (Gupta et al., 1989)	15.6	1.17	1.10	1.00
(iii) Asian Inst. Tech. Bangkok Thailand (Gupta & Surendranal, 1989)	10.0	1.00	1.00	0.60
(iv) Deere and Company Moline, Illinois (Wegscheid & Myers, 1967)	15.9	1.07	0.56	0.38
(v) Univ. Illinois, U.S.A. (Siemens et al., 1965)	10.6	0.76	0.50	0.40

Some of these soil bins are described below.

(i) Deere and Company Soil Bin

Allowing for storage of the soil, processing equipment, acceleration and deceleration, leaves about 6.0 m of test length for constant speed tests up to about 8 kmph. Maximum speed is 19.3 km/h (5.36 m/s). Maximum pull is about 4.45 kN. Speed regulation and repeat ability are normally both within ± 1 percent.

The dynamometer carriage and soil processing carriage move along the top of the bin supported by rails at either side. The dynamometer carriage is towed by cables operating along both sides of the bin. The reprocessing carriage is hitched to the dynamometer carriage when soil reprocessing is underway. Power for the system

is from an 11.2 kW reversible a.c motor equipped with an eddy current clutch and eddy current brake. Output speed is infinitely variable from about 100 to 1750 rpm.

The motor is coupled to a four speed manual shift transmission to allow the eddy current clutch to operate with less slippage when testing at lower speeds. Output of the transmission is delivered to a jackshaft at one end of the bin via a final shaft-mounted gear reducer. Sheaves mounted on this jackshaft drive the two cables which tow the dynamometer carriage along the bin.

A floor-mounted master control console and a smaller remote console on the dynamometer carriage allow control of the systems from either location. Three modes of operation are provided test, manual and remote. Speeds are potentiometer set; a test-turn potentiometer is used in the test-mode, a single-turn potentiometer in the manual mode and a single-turn potentiometer having a speed limiting series resistor for the remote mode.

Two variable transformers in the floor console power the eddy-current brake, which is connected to one transformer for normal operation and then switched to the other for deceleration and stopping. Thus an adjustable amount of "running brake" can be utilized in a test to help stabilize speed. Two pairs of limit switches along the track are activated by the dynamometer carriage. The inner pair (one toward each end of the bin) are spaced for normal operation and testing. Tripping of either shuts off the drive motor, switches power to the eddy current brake and removes power from the eddy current clutch. These limit switches may be overridden in both the manual and remote modes. The outside pair of limit switches are at the very ends of the bin. Tripping these turns off power to the motor and required restarting in the opposite direction.

Gupta and Surendranath (1989) reported on the facilities and mechanics of operation of this soil bin. The accessories are:

- (a) the soil processing trolley
- (b) tool carriage
- (c) pressure transducer
- (d) photographic accessories.

Inverted angle iron bars were set along the side walls of the bin, which served as guides for the soil processing trolley and tool carriage. The two were mounted on 'V' groove pulleys and aligned over the guides to operate anywhere along the length of the bin. The soil-processing trolley is basically a rectangular framework mounted on 'V' grooved pulleys which serve as wheels to move over the guides on the side walls of the soil bin. The processing trolley consists of a rotavator powered by 1.1kW motor, also mounted on the trolley and has provisions for mounting a leveling board and a compaction roller.

The tool carriage is also a similar rectangular framework mounted on 'V' groove pulleys. The carriage has a sub-frame fitted by nuts and bolts onto the main frame. The tool is mounted onto the sub-frame. The tool is mounted onto the sub-frame which has provision to set the tool at different depths of operation. The sub-frame can also be rotated about the horizontal and vertical axes to vary the rake and tool angles.

A 1.1kW motor with a set of speed reduction mechanism was set at one end of the soil bin, to power the drum of the winch mechanism driving the trolleys. The carriage was connected to the drum of the winch mechanism by a thick cable, which wound over the drum drawing the carriage forward. The cable was connected to the

tool carriage through a 200 kg capacity load cell which was mounted on the tool carriage. The draught of the tool and carriage operation was recorded from the load cell using a strain amplifier and X-Y recorder.

(iii) Indian Institute of Technology, Kharagpur, India Soil Bin

Gupta et al. (1989) reported on the facilities and mechanics of operation of this soil bin. The accessories are:

- (a) A soil processing trolley
- (b) A tool mounting trolley
- (c) A power transmission system with a 5.6 kW induction motor and Transmission gear box for varying forward and reverse speeds of the trolleys.
- (d) A tool mounting frame for the depth and angle adjusting mechanism was fabricated and mounted on the tool-mounting trolley.

The equipment and accessories included a 2-channel Beckman RS-Dynograph recorder, an extended octagonal ring transducer for horizontal and vertical force measurements, a hand-operated cone penetrometer and core soil samplers for measuring the soil bulk density and moisture content.

The soil-processing trolley was used for processing the soil in the bin mechanically in order to achieve uniform soil condition as desired for test run throughout the soil bed.

(iv) National College of Agricultural Engineering Soil Bin, Silsoe, Bedford, U.K.

Godwin, et al (1980) reported the design and operation of this soil bin.

The soil bin consists of two floor-located size walls whose spacing and length can be adjusted to suit the requirements of the test being conducted. Each wall is fabricated from a frame of 50 mm x 50 mm x 3 mm hollow section steel and clad on

both sizes with 1.5mm galvanized steel sheet. The walls are pinned to 100 mm x 75 mm channel sections set into the floor of the building at 1 m intervals. Access is provided at the end of the soil bin for the equipment used for soil preparation.

Test implements and wheels are mounted on carriages which run on the two size walls and the carriages are winched along by a single cable running via a pulley system from the power unit. The carriage width is adjusted for different soil bin widths by allowing the wheel units of the carriage to slide laterally on cross beams. The carriages are either on deep groove wheels on angle sections on top of the walls or on wheel assemblies that mount around a channel section on the side of the walls. A lift hoist suspended from an overhead gantry is available for lifting the carriage and bin walls when required.

Strain gauge dynamometer is used for all force measurements. The power unit is a standard 30 kW tractor supported on three anti vibration mountings, a winch drum replacing one of the drive wheels. A sheer bolt mechanism located in the wheel centre of the winch drum protects the system from overloads. Clutch, brake and differential lock control achieved using solenoid activated pneumatic cylinders. The solenoid valves are activated from a single switch in the control room and deactivated by micro-switches on the side walls of the soil bin.

The speed of the carriage is monitored using a magnetic impulse tachometer mounted adjacent to a notched pulley in the winched system.

A standard self-propelled pavement roller with a vibratory attachment is used to compact the soil to required densities. This offer advantages over surface vibrators (Osman, 1964) and drop hammers (Boyd and Nalezny, 1967). When preparing large areas of soils which have cohesive as well as frictional properties. To ensure a satisfactory bond between successive soil layers, the surface of each freshly

compacted layer is scored to a depth of 10 mm using narrow tines before placing the next layer.

The minimum length of processed soil for each test is dependent upon the forward speed. A length of between 2.5 and 3.0 m has been found satisfactory for speeds up to 1.6 m/s (5.76 km/h). Additional lengths of bin wall are required for running the carriage up to specific speed and as a holding section for the soil prior to re-processing. The former need only be rails as they do not contain soil.

2.8.3 Large Scale Soil Bin

Soil bin studies have shown that large scale soil bins are those whose lengths are greater than 15 m and width greater than 2 m. Examples include:

- (i) The National Tillage Machinery Laboratory (NTML), Auburn, Alabama, U.S.A.

This is a research facility of the Agricultural Research Service of the U. S. Department of Agriculture. It has 11 large bins of soil in which full-size wheels, tracks, vehicles and tillage tools may be operated. The various forces acting on wheels or tools and the soil can be studied to determine the basic dynamic relationships and soil reactions. The soil varies in mechanical composition from sand to clay and provides a wide range of soil material. The soils are prepared for the various investigations with specialized machinery, and moisture can be controlled to some degree by covering the plots or by watering them with a special mobile sprinkler apparatus.

The soil bins are 76.2 m long and 6.1 m wide.

- (ii) Soil Bin at the Institute for Agricultural Mechanization, Konosu, Japan (Gill and Vanden Berg, 1968)

These bins have many features of the bins at the NTML, Auburn Ala; including the tracks on which to operate the measuring and soil preparation machinery. The Institute is equipped with six soil bins 45.7 m long and 4.6 m wide. A transfer car is used to move the test machine from one bin to another or to the storage area. A single machine is used both for preparing soil and for conducting the tests.

2.9 Soil Bin Instrumentation and Equipment

Instrumentation has been defined by Morris (1988) as the science and technology of complete measurement systems with which physical quantities are measured so as to obtain data which can be transmitted to recording and display devices. According to Wegscheid and Myers (1967) instrumentation and operation of field tillage equipment to obtain the exacting data required for a real understanding of machine-soil relationship is hard. They opined that tool operating speed, depth and soil strength may change drastically throughout a test and may be difficult to correlate to the forces measured.

This section reviews instruments and items of equipment that can be used or that have been used by researchers in soil dynamics and tillage studies.

2.9.1 Instruments for Force Measurement

An unknown force may be measured by the following means:

- (i) Balancing it against a known gravitational force on a standard mass either directly or through a system of levers.
- (ii) Measuring the acceleration of a body of known mass to which the unknown force is applied.

- (iii) Balancing it against a magnetic force developed by interaction of a current-carrying coil and a magnet.
- (iv) Transducing the force to a fluid pressure and then measuring the pressure.
- (v) Applying the force to some elastic member and measuring the resulting deflection.
- (vi) Measuring the changes in precision of a gyroscope caused by an applied torque related to the measured force.
- (vii) Measuring the change in natural frequency of a wire tensioned by the force.

The above methods can be broadly grouped as: mechanical methods; hydraulic and pneumatic methods and electrical methods.

2.9.1.1 Elastic Force-to-Deflection Transducers

The principle of applying a force to an elastic body and measuring the deflection produced is the one mostly widely used in the task of force measurement (Morris, 1988). Some examples of these elastic elements include:

(i) Extension Force Transducer

An example of this transducer is the Hounsfield tensometer, in which the extension of the test piece due to the applied load is used to deflect a previously calibrated spring beam. The force is applied to the test piece by means of an operating handle and gearing.

(ii) Spring-type Dynamometer

Spring-type dynamometer makes use of springs which elongate under tension or shorten under compression. According to Michael and Ojha (1989), such a

dynamometer is suitable for rough measurement of draught because of the rapid fluctuation of the needle on the dial.

(iii) **Ring-type Transducer**

The proving ring is a ring of known physical dimensions and mechanical properties. An external tensile or compressive force applied across the ring diameter causes distortion which is proportional to that force (Beckwith and Buck, 1978; Collett and Hope, 1983). The amount of distortion can be measured using a dial gauge, micrometer or strain gauges.

2.9.1.1 Bonded Strain Gauge Force Transducers

Collette and Hope (1988) reported that gauges used for measuring strain should conform to the following requirements:

- (a) The gauge should be small in size and easy to attach to the specimen or component. Its profile should be as low as possible so that it will respond in unison with the changes in the surface to which it is fixed.
- (b) Calibration should be easy and once made should remain stable with time, dynamic loading, changes of temperature, pressure or humidity.
- (c) The gauge should be highly sensitive in the direction of the measured strain but of low sensitivity in the transverse plane (cross-sensitive). The strain/resistance characteristics should be linear.
- (d) Speed of response should be high so that time lag is negligible.
- (e) Gauges should be inexpensive, reliable and readily available. There should be a variety of types and sizes suited to a wide range of applications.
- (f) Immersion in liquids should not modify performance.

Resistance strain gauges have characteristics, which make them the most versatile existing devices for strain measurements

- (a) Gauge lengths are as small as 0.27 mm although those in most common use range from about 5 mm to 12 mm. The backing to which the gauge is fixed increases the overall length.
- (b) Weight is negligible and attachment to the tested body is fairly easy.
- (c) Strain sensitivity is quite low e.g. a Constantine wire gauge of 100 ohms resistance would show an increase of approximately 0.25 ohms on low-carbon steels strained to the elastic limit
- (d) Strain gauges can indicate static, transient and dynamic strain (50,000 Hz) or more, and remote indication and recording present little difficulty.

Metal resistance strain gauges are made in two basic forms: wire and foil. The foil types which are pressed from thin sheet foil, have the advantage that the gauge can take almost any shape that can be drawn. They also have a lower profile and very good linear cross-sensitivity, and because the grid is rectangular in form and very thin, heat is dissipated more readily than from wire gauges. Because of their generally superior qualities, foil gauges have largely superseded wire gauges except for post-yield applications and where grids in excess of 150 mm long are required.

The resistance R of a metal depends on its electrical resistivity, ρ , its area, a , and its length L according to the equation

$$R = \rho L/a \quad (43)$$

Thus, to obtain a high resistance gauge occupying a small area, the metal chosen has a high resistivity, a large number of grid loops and a very small cross-sectional area. When the gauge metal is subjected to strain, its electrical resistance

changes and the change is detected and used to monitor the cause of the stain. The usual method of detecting the resistance change of a strain gauge is to incorporate it into a wheatstone bridge.

(i) **Strain gauge force transducers:** The simplest type of strain gauge force transducer may be in the form of a bar or strip subjected to axial force. This type of transducer may be very rigid and ideal for tensile forces. When compressive forces are to be measured, it is more suitable for small forces, because of the tendency of the sensing member to buckle (Chesmond, 1982). A load-ring can be designed for this type of application.

(ii) **Strain gauge-mounted proving ring transducer:** Beckwith and Buck (1978) described a strain gauge type ring transducer for calibrating the tensile testing machines and for measuring large static loads. The capacity of the transducer varied between 150 and 150,000kg. RadheyLal (1971) studied a ring type dynamometer employing resistance strain gauges as secondary transducers. The strain gauges were mounted to the inner side of the ring at 90° spacing in the line and perpendicular to the load line. The ring was made of flat iron in rectangular cross-section. The material used was special alloy steel having a modulus of elasticity of $2 \times 10^6 \text{ kg/cm}^2$.

Singh et al. (1981) fabricated and tested strain gauge-mounted proving Ring Dynamometer for measuring the draught force required by the trailed type disc harrow. It was fabricated from mild steel bar having a modulus of $2 \times 10^6 \text{ kg/cm}^2$. The strain gauges (four in number) were type SA-10 manufactured by M/S Robits & Company (India). The resistance, gauge factor and length of the strain gauges were $117.1 \pm 0.2 \text{ ohms}$, $2.06 \pm 2\%$ and 10 mm respectively. The dynamometer has a maximum capacity of 300 kg. The soil was silty-clay-loam with an average moisture content of 12.21% at the time of testing.

As a tillage tool moves through the soil, forces act on the tool arising from the cutting, breakage and displacement of soil, as well as the parasitic (frictional) forces that develop between the soil and tillage tool. The nature of these forces and their resulting distribution have yet to be measured primarily due to the limitations of instrumentation. Glancey et al. (1989) undertook a study to develop an instrumented tillage tool that could measure the force distribution acting on it while moving through the soil. Since the bending stresses in a cantilevered tool are proportional to the soil forces tools are proportional to the soil forces acting on the tool, strain gauges located at discrete points along the tool can be used to obtain measurements of the bending moments acting on the tool. These discrete measurements of moments can then be interpreted by a mathematical model using an integral method to give an indirect measurement of the force distribution acting on the tool. Glancey et al. (1989) fabricated a special chisel that housed and adequately protected strain gauge bridges.

(iv) Extended Octagonal Ring Transducers (ORT)

Godwin (1975) reported an extended octagonal ring transducer for use in tillage studies. This was an alternative technique to the multi-dynamometer system and offers the following advantages.

- (a) Alleviation of the frictional problems arising from the dynamometer suspension bushes;
- (b) Simple component construction, compactness and simple mounting; which reduces the difficulties with precision alignment necessary for accuracy when a multidynamometer suspension system is used
- (c) Simultaneous monitoring of the two force components and the moment in the plane of these two forces.

The extended ORT consists of a machined block, normally of steel or aluminum. Strain gauges mounted at strain nodes, i.e. positions where there is not contribution to the strain from the other force component, are used to monitor the horizontal and vertical force components and the resulting moment. The accurate location of the strain nodes and subsequent positioning of the strain gauges is critical in producing a transducer with low cross-sensitivity between the force component channels.

Yadav and Pandey (1984) used extended octagonal ring transducer to measure draught of four different shapes of blades.

Baloch et al. (1986) used straining force transducers in soil bin studies of Tillage-Tine forces. The transducer was used to measure a horizontal component and a vertical component and the moment in the plane of these forces.

Thakur and Godwin (1988) reported on the design and construction of a dynamometer to measure the forces and resulting moments acting on a rotary tiller blade independently of their line of action. The dynamometer is based on an extended octagonal ring, provided with strain gauge bridges and can be fixed on the motor flange for monitoring the tiller blade.

Owen et al. (1987) reported the design and use of ORT for deep tillage research. The transducer was machined from aluminum, with a tensile yield strength of 254 MPa, and was designed to withstand maximum horizontal force of 40 kN. Banks of five strain gauges were installed on the top, bottom and on planes at angles of 34 degrees from the vertical. The design was similar to that described by Godwin (1975)

(iii) **Extended Ring Transducers:** An extended ring transducer fitted with strain gauges can measure strain proportional to two orthogonal forces and torque about the

centre of the ring interpedently (Cook and Rabinowicz, 1963). Johnson and Voorhees (1979) reported the design and use of a force dynamometer for three-point Hitches. The transducer base, on extended rings as sensing members was used to measure draught, vertical force and torque simultaneously and independently in vertical longitudinal plane caused by an implement. Aluminum alloy tube 6061-T6 was chosen because of its greater load sensitivity as compared with steel. Strain gauges were attached to the transducer subassembly as vertical and horizontal forces and torque in a longitudinal plane could be determined separately. Strain gauges (Constantine alloy gauges with flexible polyamide backing) were attached. The dynamometer was designed for two load ranges: high-load range of 44,500 N operating at 601 mm from the centre of the force sensing member or 66,700 N maximum draught force-whichever required greater structural strength in each component. The low-range maximum draught force was 36,000 N. The strain gauge bridges for each of the load components were attached to the necessary strain-gauge instrumentation for both excitation with input voltages and amplification of the output voltages from the bridges. These voltages were measured with a digital voltmeter.

2.9.1.3 Hydraulic Transducers

Kepner et al. (1980) reported that a hydraulic transducer transmitting pressure to a Bourdon gauge calibrated in force units, is easier to read than the spring type because force fluctuations can be dampened considerably by using a viscous fluid or having a restriction in the line to the gauge. Some hydraulic dynamometers record the pull on a strip chart driven by ground wheel.

Culpin (1986) reported that for agricultural work hydraulic dynamometers are widely used. The pressure set up in the fluid contained in a hydraulic link is

transmitted to a small recording cylinder in which the plunger acts against the force of a spring. The movement of the plunger may be read directly or may be recorded on a moving chart. According to Culpin (1986) the recording type of dynamometer is sometimes employed for accurate research work, but the direct indicating type is more suitable for rapid tests and demonstrations.

By using various grades of oil from a thin machine oil (e.g. SAEJ, 1703) to thick gear oil e.g. SAE 90, almost any desired degree of damping may be achieved. Another desirable feature is that the instrument may be adapted for use over a wide range of pulls by using springs of various strengths in the indicating mechanism.

The following are the advantages and disadvantages of hydraulic systems.

Advantages

- (i) Very high power to weight ratio
- (ii) Very high peak torques (or forces)
- (iii) Very short time lags enabling fast response.
- (iv) Speed operation even at low speed
- (v) Large holding forces, when stationary
- (vi) High power efficiency
- (vii) Rugged
- (viii) Self lubricating and cooling
- (ix) Linear and rotary motions available

Disadvantages

- (i) Clumsiness of connections
- (ii) Mess from oil leaks.
- (iii) Danger from large oil leaks (high pressure, toxicity and flammability)
- (iv) Oil properties change with temperature

- (v) Expensive when power supply is included in the cost
- (vi) Fluid must be kept clean and gas free
- (vii) Severe non-linearities may necessitate special treatment.

2.9.2 Instrument for Displacement Measurement

The assessment of the performance of soil-engaging implements in steady state conditions with level, uniform soils is straightforward. Variations in both the soil surface elevation and soil shear strength, however, affect the soil forces acting upon the implement and hence the depth of operation and altitude. These variations can have adverse effects upon the performance when either a constant depth of operation or a constant grade is required. To improve the design of the implement and linkage, it is necessary to have instrumentation to sense the effects of design changes (Godwin et al., 1987).

To study the behaviour of implements when changes in soil elevation and/or shear strength occur, it is necessary to know:

- (i) The magnitude, direction and position of the soil reactions.
 - (ii) The vertical displacement and angular position of the implement and linkage
- Godwin et al. (1987) reported that the characteristics of any instrumentation system to record the vertical, horizontal and angular displacement should be:
- (a) non-restrictive to the motion
 - (b) relatively light to prevent changes to the weight, centre and gravity and inertial characteristics of the implement
 - (c) Linear over range,
 - (d) Of adequate resolution.

2.9.2.1 Vertical Displacement

Under field conditions, the most convenient method of producing a horizontal datum is with the use of a commercially available rotating laser transmitter with light weight (20 kg) laser receiver masts (operated in surveying mode) to measure the position of both the hitch point and implement in relation to a datum. The principle of operation of the laser receive masts was reported by Godwin et al (1987).

For soil bin studies, the horizontal rails of the bin can be used as the reference datum from which linear variable displacement transducer LVDT (Cook and Rabinowicz, 1963) can determine the vertical motion of both the hitch point and the implement. The light ferrous core and follower (70 gm) of the LVDT rests against the implement or hitch point with the main body rigidly fixed to a carriage operations on the soil bin rails.

Owen et al. (1987) reported that the operating depth was measured by a LVDT which indicated the distance between the tool bar and a fixed point on the wheel axle support. This distance was calibrated to the operating depth and converted during analysis.

2.9.2.2 Angular Displacement

Godwin et al. (1987) reported the use of variable transformer-type inclinometers to obtain the inclination of

- (a) the implement leg over a range of $\pm 11^\circ$ from the vertical
- (b) the implement linkage over a range of $\pm 30^\circ$ from the horizontal.

These devices were used both in the field and soil bin and as with the vertical displacement transducers were of low weight (580g) exerting negligible restraint on the motion of the implement.

2.9.3 Recording Instruments

In recording instruments the values of the measured quantity are recorded on a chart, digital computer or data logger. Typical examples of chart recorders are pen recorders, $x - y$ plotters and ultraviolet light recorder. Magnetic tape recorders are also extensively used in instrumentation.

Chesmond (1990) reported types of instrumentation recorded. According to Chesmond (1990) recorders translate transducers signals into stylus movements across paper charts. Usually the chart is moved at constant speed by an electric motor (which may be either a synchronous or stepper type); occasionally a spring-powered clockwork motor or an air fluid motor may be used. The alternative processes for recording a trace are as follows:

- (a) Ink Pens – the ink reservoir may be directly over the stylus or it may be some distance away and connected to the stylus by a capillary tube, which may be pressurized. The stylus may be a finer metal tube or a fibre tip.
- (b) An electrically – heated stylus running over a heat-sensitive paper.
- (c) An electrically- energized (typically 400V) stylus running over a voltage-sensitive paper, the surface of which breaks down at the point of contact.
- (d) A sharp stylus cutting the surface of a wax-coated paper
- (e) A fine ultra-violet (UV) light beam being deflected across a photosensitive paper.

The ink pen of recorder will have the slowest response (bandwidth in the region of 1Hz) whilst the UV recorder will have the fastest with bandwidths up to 20kHz being possible.

With round chart recorders, the chart diameter can be up to 30 cm. The chart has a scale of concentric circles, with increasing values running from the inside outwards, together with timing arcs. Timing ranges can vary from 15 minutes to 28

days from the full revolution. The pen moves in an arc subtending an angle of 45 degree approximately, corresponding to a radial distance of approximately 10 cm.

With strip chart recorders, the paper may be prefolded or on a roll and the measurement lines are straight and parallel, running down the length of the strip. The timing lines may be straight and perpendicular to the measurement lines, or they may be circular arcs: this will depend upon the type of pen/stylus mechanism. Increasing values usually run from left to right with the paper moving downwards.

When choosing the type of recorder mechanism most suitable for a particular application, the following factors would be relevant.

The following factors would be relevant.

- (a) the nature and range of the input signal
- (b) the maximum rate of change of the input signal, in relation to the slew rate limit of the recorder
- (c) the number of input signals to be recorded
- (d) the accuracy required.

Chesmond (1990) reported seven alternative type of recorder mechanism

- (i) Pneumatic mechanism
- (ii) Moving coil mechanism
- (iii) Potentionmetric mechanism
- (iv) Bridge mechanism
- (v) LVDT mechanism
- (vi) Force balance mechanism
- (vii) Linear array mechanism

Magnetic Tape Recorders

The magnetic recorder/reproducer has a number of unique features derived mainly from its ability to record a voltage, store it for any time and then reproduce it in electrical form essentially identical to its original occurrence. Recording methods include the direct, FM, pulse-duration modulation (PDM), and digital techniques. (Aronson, 1961).

2.9.4 Other Instruments Used in Soil Bin Studies

2.9.4.1 Cone Penetrometer

Whiteley and Dexter (1981) reported that penetrometers are the customary diagnostic tool for gauging the resistance of soil to the penetration of plant roots. Their uses can be broadly separated into 3 categories. Firstly, field studies in which typically large (10 to 20 mm diameter) probes are driven downwards from the soil surface for identifying root-restricting horizons (Taylor, 1974) and for studying soil compaction in relation to root growth and development (Taylor, 1971); secondly, empirical investigations of relationships between penetrometer resistance and rates of root elongation (Gooderham, 1973) and thirdly, studies of root penetration of surfaces (i.e. interfaces) in structured soil (Dexter and Hewitt, 1978).

Ambruster et al. (1990) defines penetrometer as a simple measuring instrument used to express various soil characteristics in numerical terms. Normally a penetrometer consists of a metal, cone-tipped rod that is pushed into the soil. The amount of force required is measured in relation to the depth of measurement. The force per base area needed to penetrate the cone into the soil is referred to as the "cone index" (CI). One of the penetrometers which had been subjected to varied applications is the cone penetrometer developed by the United State Army Corps of

Engineering Waterways experiment station to determine soil trafficability. The cone penetrometer consists of a 30 degree circular cone with a 2cm^2 base area. The cone index is measured as the force per base area required to penetrate this cone into the soil at the rate of 182.9 mm/min. The cone index thus determined provides some indication of the shear resistance of the soil which in turn depends upon the strength properties of the soil.

The cone penetrometer has been employed for various applications, including prediction of the tractive capability of an off-road vehicle (Freitag and Richardson, 1968; Wismer and Luth, 1972), characterization of soil in terms of crop growing ability (Raghavan and Mckyes, 1977), determination of resistance to root penetration and seedling emergence (Bowen, 1976; Taylor and Gardner, 1963, Morton and Buchele, 1960), prediction of draught force (Johnson et al., 1978; Gill and Van den Berg, 1968), and assessment of compaction caused by vehicle traffic (Sloane, 1973; Raghavan and Mckyes, 1977; Chesness et al., 1972). Cone indices were also used to determine the effect of wheel size and vehicle weight on soil compaction, as well as earth embankments and foundations. (Ayers and Perumpral, 1982).

Perumpral (1987) reported a history of cone penetrometers, a description of the various types, an explanation of the factors affecting the penetration resistance. Armbruster et al. (1990) reported that depending upon the objective, different penetrometers can be selected but the interpretation of penetrometer results is often difficult. The amount of penetration resistance varies depending upon soil characteristics such as soil type, moisture content and density. Interpretation of the results also rely upon the specific penetrometer used, especially its form, length of tip and shaft, surface finish and penetration rate. With automation of penetration and

electronic registration of data, penetrometer measurement have become more accurate (Carter, 1969; Wilford et al., 1972; Wilkerson et al., 1982).

An important factor in accurate measurement that has not yet been considered is the amount of friction that occurs between the penetrometer shaft and the soil. Armbruster et al. (1990) reported the development of a cone penetrometer with a force transducer located directly behind the cone tip to eliminate the influence of this friction. The improved design achieve its purpose because up to 40% of the cone index, measured conventionally at the upper end of the penetrometer shaft, originates from friction.

Baloch et al. (1986) reported that measurement of tillage forces requires instruments like amplifier, oscillograph, oscilloscope, and digital voltmeter

2.9.4.2 Amplifier

Transducers produce very small signals in many cases (Douglas-Young, 1978). To get a useful reading on the indicating device (meter, digital readout, cathode ray-tube) an amplifier is necessary. The basic requirements of an amplifier therefore, are;

- (i) to boost weak signals
- (ii) to avoid disturbing the signal source

Amplifiers may be separate instruments used in conjunction with other test equipment, or they may be built in. they operate by introducing external power, which is controlled by the input signal in such a way that the output from the amplifier is an enlarged version of the input. Amplifiers may be divided into two broad types. D. C. amplifiers are capable of amplifying static, slowly changing or rapid repetitive input signals. A. C. amplifiers are only capable of dealing with rapid, repetitive signals but are usually simpler and cheaper when compared with the D. C. types (Adams, 1984).

2.9.4.3 Oscilloscope

Handel (1974) defines oscilloscope as an instrument used primarily to provide visible images of one or more electrical quantities which vary rapidly with time or with respect to other electrical quantities. The cathode-ray oscilloscope is the usual type and one of its main uses is as an indicator for a radar set. Douglas-Young (1978) reported that the peculiar power oscilloscope lies in its ability to produce an electronic picture to show the variation of one quantity or electrical signals as found in a circuit or obtained from a transducer. The use of transducers makes it possible for the oscilloscope to measure pulse rate, analyse engine performance or portray many other non-electrical quantities. However, oscilloscopes mostly are used to display variations in voltage amplitude over a period of time.

Douglas-Young (1978) also reported that oscilloscopes can duplicate all the measurements of voltage, current, resistance, frequency, phase and so on, performed by other instruments and in addition it can enable you to evaluate rapidly-changing phenomena including those events that happen only once and last only nanoseconds.

2.9.4.4 Oscillograph

Handel (1974) defines oscillography as an instrument which records electrical signals on film or sensitized paper using magnetic or optical means. In the cathode-ray oscillograph, the electron beam of a cathode-ray tube is used to make a photographic or other record.

2.9.5 Soil Bin Equipment

2.9.1.5 Prime Mover and Power Transmission Unit

Godwin et al. (1980) reported the use of a standard 30kW tractor as prime mover. The tractor was supported on 3 antivibration mountings.

Wegscheid and Myers (1967) reported the use of an 11kW reversible a.c. motor equipped with an eddy current clutch and eddy-current brake as source of power.

Yadav and Pandey (1985) reported the use of an 7.46kW, 3-Phase electric motor coupled with a gear box having five forward speed gears and one reverse gear as the power source to operate the trolley out different speeds.

Ademosun (1990) reported the use of an electric motor as the prime mover. Gupta et al. (1989) reported the use of a power transmission system with a 5.6kW induction motor and transmission gearbox for varying forward and reverse speeds of the trolleys. Gupta and Surendranath (1989) reported the use of a 1.1kW electric motor with a set of speed reduction mechanism, set at one end of the soil bin, to power the drum of the winch mechanism driving the trolleys.

Stafford (1979) reported that propulsion for the carriage was provided by a cable and which driven by a 20kW electric motor with thyristor speed control.

2.9.5.2 Implement Attachment Unit

Siemens et al (1965) reported the use of an automatically controlled carriage, cantilevered from two rails and equipped with a tool-mounting frame.

Godwin et al. (1980) reported that tests implements and wheels are mounted on carriages which run on the two sidewalls and the carriages are wrenched along by a single cable running via a pulley system from the power unit.

Soomro et al. (1982) reported the use of a carriage which could run on grooved wheels. A tool carrying mast bolted to the rear of the carriage, had two series of holes, one to bolt it to the carriage and the other for the attachment of an extended octagonal ring transducer on to which a tool carried could be fixed.

Yadav and Pandey (1984) also fabricated a tool mounting frame using mild steel angle and channel, provision for varying depth of operation was made by making a number of holes on the channel section.

Gupta and Surendranath (1989), Gupta et al. (1989), Ademosun (1990) reported the use of similar implement attachment units.



3. DEVELOPMENT OF SOIL TILLAGE DYNAMICS EQUIPMENT

This chapter contains the methods that were used to develop the soil tillage dynamics equipment. They are discussed under the major sub-headings of: design considerations of the soil bin and equipment; construction details and description; instrumentation; tools and finishing.

3.1 Design Consideration of the Soil Bin and Equipment

The following design aspects were considered in the development of the soil tillage dynamics.

3.1.1 Objectives of Soil Bin Studies

The soil bin used in this study was desired to meet the following objectives:

- (i) To provide consistent homogeneous soil conditions for studies concerned with the testing of model soil engaging implements and the validation of force prediction models.
- (ii) To utilize wherever possible commercially available equipment and/or tools and instrumentation, minimizing the need for specialized equipment.
- (iii) To minimize capital cost and moderate the hand labour requirements.
- (iv) To expand the frontiers of knowledge of draught and energy requirements of tillage implements which is essential for proper design of the implement, appropriate matching of the implements and their power sources and the selection of optimum operating conditions.
- (v) To increase knowledge of the factors affecting draught force of tillage tools including soil, implement and operational parameters.

- (vi) To design simple tests by which soils can be compared and/or their interactions with tillage implements accurately predetermined.
- (vii) To provide facility for research also in the area of soil dynamics in traction and tractive devices.

3.1.2 The Location of the Soil Bin

The soil bin is suitably located in the soil and materials laboratory floor of the Department of Agricultural Engineering in the School of Engineering and Engineering Technology of the Federal University of Technology, Akure, Nigeria.

The laboratory is adjacent to the machine shop. This would minimize labour requirement maintenance jobs that could arise in the course of usage of the soil bin. Moreover the terrain of the land is plain thus minimizing labour requirement that could arise when the soil in the bin needed to be changed.

The dimensions of the laboratory, that is, length, width and height are: 12 m x 9 m x 3.5 m. The laboratory is supplied with 3-phase alternating current. This would enable: three-phase machinery and/or equipment to be used along with the soil bin as may be required from time to time. The lighting is also bright enough to enable experiments to be carried out in the night.

3.1.3 Approximate Capacity of the Soil Bin

The minimum length of processed soil for each test is dependent upon the forward speed. A length of between 2.5 m and 3.0 m has been found satisfactory for speeds up to 1.6 m/s (Godwin et al., 1980). Additional lengths are required for running the carriage up to speed and as a holding section for the soil prior to re-processing.

The design should be such that multiple tests can be conducted for each soil preparation. For example two 200 mm wide lines could be achieved with a 0.8 m spacing between side walls.

A depth of 0.45 m was also considered adequate since most tillage operations fall within this range of depth except for very deep tillage operations.

3.1.4 The Characteristics of Soil to be Studied

Agricultural soil is desired to be studied realizing that the soil has weight and could have layers in the profile in the field. As a result of the weight of soil, it could exert lateral force on the sidewalls of the soil bin. The soil that could be studied very much varied from coarse textured soil of sand and loamy sand to fine textured soil of clay, sandy clay or silty clay. The soil would be worked (tilled) mainly in the dry and moist or friable consistency. Friable consistency being the optimum soil moisture for tillage practices (Ghildyal and Tripathi, 1987).

3.1.5 The Processing of the Soil

The soil in the bin would need to be processed in order to produce uniform soil condition or to simulate field conditions, which is non-uniform soil condition. The processing of the soil would include, tilling, moving and leveling and compacting the soil inside the soil bin. The processing of the soil would therefore require stirrers, levelers and compaction roller to be developed for the purpose.

The processing of the soil would also pre-suppose that there is enough length space in the soil bin for soil processing and storage.

3.1.6 The Variability of Soil Bulk Density

Investigations have shown that soil bulk density vary from soil to soil and influenced by the proportions of soil fractions of sand, silt and clay in a particular soil. To this end, soil corer, Proctor's compaction devices have been used by researchers. It was envisaged that soil bulk density up to about 1.75Mg/m^3 would be achieved in this study.

The whole set up of the soil bin and equipment enabled soil bulk density to be varied. This was accomplished through the provision of a compaction roller whose weight can be varied with ballast weights. The rails on which the processing trolley runs make it easy to increase the number of passes of the compaction roller at a particular ballast weight.

3.1.7 Variation in Soil Moisture Content

Soil water content is a single factor that largely affect soil condition as the soil moisture content varies from dry consistency through moist consistency to wet consistency of the upper plastic limit. It was considered to bring soil into the soil bin at very low moisture content so that the moisture contest can be gradually increased as the case may be.

Provision was made for enough space to process the soil as water is sprayed into it to increase the moisture content.

3.1.8 Experimental Tillage Tools

The soil bin and equipment were desired to be suitable for the operation of a wide range of tillage tools and implements. Models of tillage tines, blades, hoes, shovels, sweeps of different shapes, sizes and geometry could be operated inside the soil bin.

3.1.9 Operation of Tillage Tools in the Soil Bin

It was considered that the tillage tools are properly and rigidly held while they were pulled through the soil. To this end, provision was made through the use of bolts and nuts to fasten the tools to the tools' carriage subframe(s). The heights of the tools were such that, there were just sufficient for the maximum working depth of 45 cm within the soil bin. This depth covers most conventional tillage practices. The widths of the blades and hoes were such that two experimental runs could be performed side by side with one preparation of the soil inside the bin.

The soil bin is also suitable for the operation of interacting tines.

3.1.10 The Versatility of the Soil Bin Equipment

The soil bin and equipment were desired and designed for versatility. The whole system is capable and can be put to many uses in tillage studies to the studies in traction and transport devices. The equipment design was such that rake angle could be varied from acute angle of 15° to obtuse angle of 175° . The tool carriage subframes were designed such that their vertical heights could be lowered or raised, thus enhancing stability in operation.

3.1.11 The Desired Properties of Constructional Materials

Hardwood of high durability (e.g. *Mansonia*) were desired for the wooden walls. They were also seasoned to offer high resistance to termites from soils around us. High tensile steels were considered for the equipment so that maximum deflection of about 1mm was permissible.

The design for Teflon wheels was to reduce friction between carriage wheels and the railings on which they run, and at the same time strong enough to carry the loads on them.

3.1.12 The Behaviour of Soil Bin Components in Service

It was desired that the walls of the soil bin be strong enough so that they could withstand lateral soil pressure on them arising from the weight of the soil. This would eliminate the effect of buckling of the sidewalls. To this end flat steel sections were used to brace the walls to the floor of the soil bin.

It was envisaged that after some period of service, the soil bin components would need maintenance. To this end permanent joining methods like welding were minimized without sacrificing the necessary rigidity of the system. The use of fasteners therefore made maintenance easy.

The use of Teflon wheels on steel rails reduce noise compared with steel wheels on steel rails. Corrosion of the materials due to environmental conditions was minimized by application of suitable finishers like organic finishes, such as paint, enamel, varnish and lacquer.

3.1.13 Fabrication Techniques

Simplicity of construction was desired. The techniques including separating, assembling and finishing.

(a) Separating

The major techniques which can be grouped under machining, shearing and flame cutting include.

- Turning and related operations
- Milling and related operations
- Sawing, broaching and filing

- Shaping and planning
- Drilling, boring reaming and tapping
- Shearing operations

(b) **Assembling**

Assembling techniques were both temporary and permanent types. They include

- Mechanical fastening
- Adhesive bonding and
- Welding processes

(c) **Finishing**

The finishing technique considered was coatings.

3.2 **Design Details and Specifications of the Soil Bin and Equipment**

In this section, important design details and specifications of the main features of the soil bin and equipment are highlighted.

3.2.1 **The Soil Bin**

The soil bin is essentially a rectangular box of the dimensions of length, width and height 9.0 m x 0.85 m x 0.5 m respectively. The height of the bin being the vertical length from its base to the top of the steel rails. The effective length of the bin, therefore, is the overall length less twice the thickness of the end walls. Similarly, effective width, is the overall width less twice the thickness of the side walls. The wall thickness was the same all round and is 25 mm. The soil bin was made of four units, each 2.25 m in length. This is to facilitate transportation, maintenance and repairs where and when necessary by the dismantling process.

3.2.1.1 **The Steel Mainframe and Wooden Wall**

The steel mainframe and wooden wall is shown in Figure 13. The mainframe

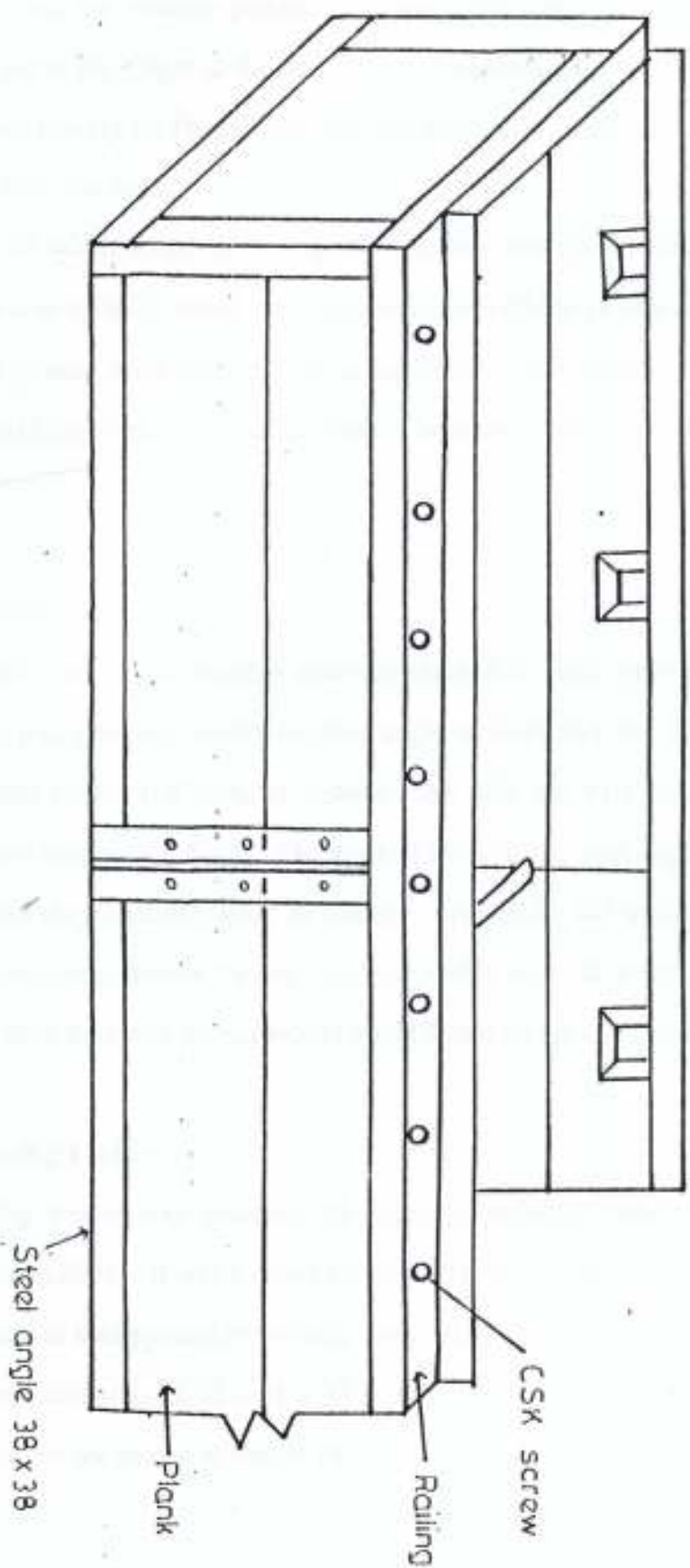


Fig 13 : The soil bin mainframe and wooden planks (Isometric)

is essentially an open rectangular box fabricated with 38 x 38 mm angle iron sections. The steel sections on top of the walls were inverted to allow both top and bottom frame sections to house the wooden planks. Also along the length of the bin were vertical steel bars, cut to the height of the mainframe. Their functions were mainly to reinforce and provide rigidity for the soil bin, and also to provide points of attachment of the wooden planks to the walls.

Also along the whole length of the top steel, section was placed another steel section of the same size to lap it. Along the length were drilled hole $\phi 8$ mm and 30 cm centre to centre for joining them together. The holes were counter sunk to enable the fastening screw head flush with the top of the plate. The vertical side of the angle iron served as the rails.

3.2.1.2 The Steel Rails

The steel rails are two in number and run paralalled to each other along the whole length of the bin. They are made from steel angle sections and 38x 39 mm and supported by vertical posts. The distance between the rails are 84.5 cm, and the thickness of the steel section is 3.6 mm. The vertical sides of the steel angle section served as guides and the horizontal sides as running surfaces for the trolley wheels. The width of the horizontal surface 38 mm was compatible with the running wheels (of the trolleys) 30 mm, thus with a clearance of about 8 mm on the other side.

3.2.2 The Processing Trolley

A processing trolley was designed for rigidity, stability, maneuverability, flexibility and maintainability. It was designed to run on four wheels. It was basically a four-wheeled cart four transporting processing equipment. It has over all dimensions of length, width and height to be 92 x 61 x 35.5 cm respectively. The main features of the processing trolley are shown in Figure 14.

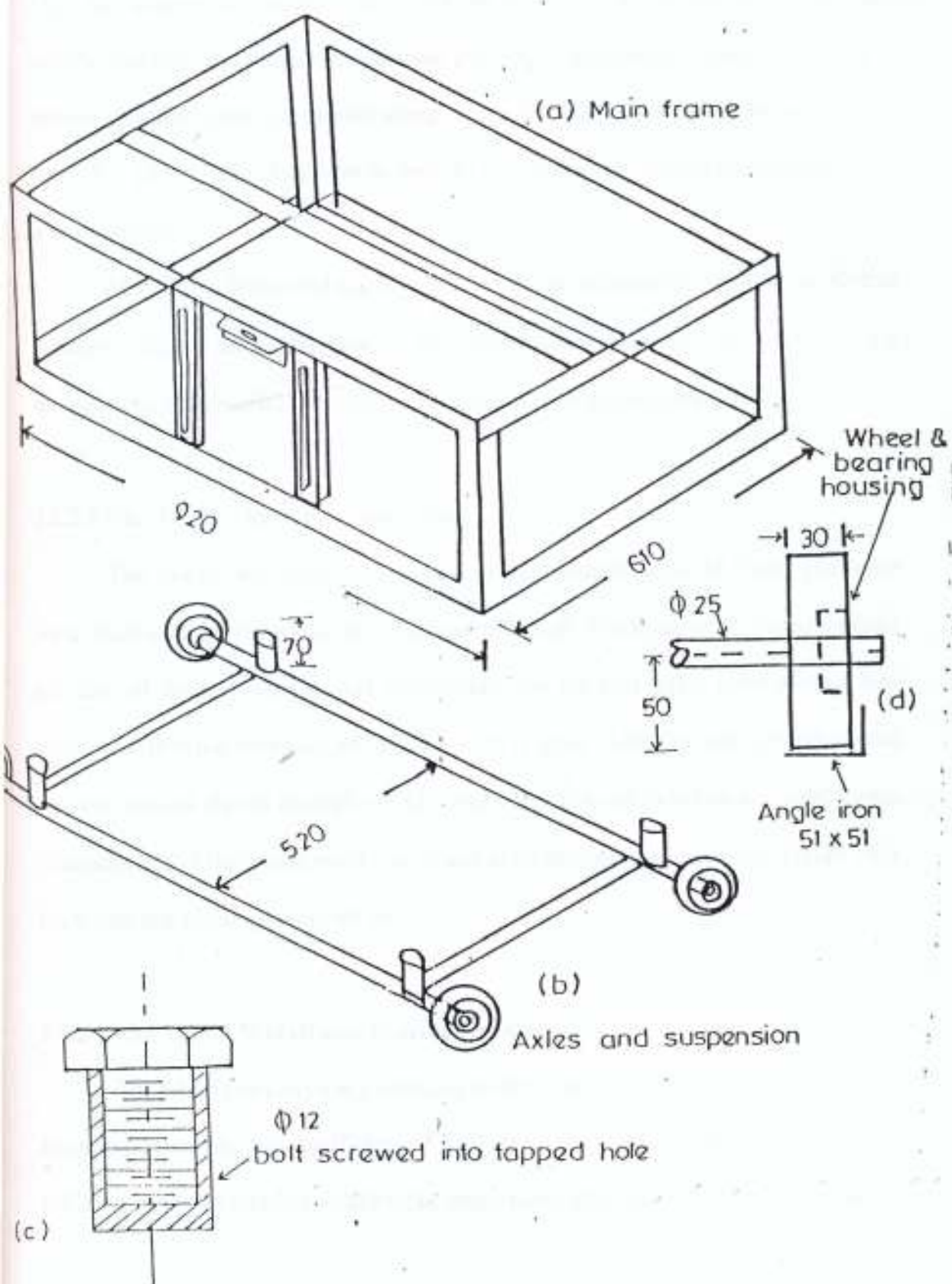


Fig. 14 Processing trolley mainframe and suspension.

3.2.2.1 The Trolley Mainframe

The trolley mainframe is basically a rectangular box without sides (Figure 13a). The dimensions are 92 x 61 x 35.5 cm as shown. It was designed to provide rigidity, stability and support for the soil processing equipment. There are two angle section members each one slotted along its length. The width and length of the slot was 1.1 x 15 cm. The slots were to provide facility for the vertical adjustment of the leveling board.

Also was a horizontal member welded to the mainframe between the slotted members. Below the centre hole in the horizontal member was welded a $\phi 12$ nut through which the vertical adjustment stud would raise or lower the leveling board.

3.2.2.2 The Trolley Axles and Suspension

The trolley was suspended on two axles of wheel bases 54.5 cm. The axles were made of solid circular shafts of diameter 2.5 cm. The axles were braced together for ease of maneuverability and assemblage. On the two axles were welded four vertical suspension rods each of height 7.0 cm (Figure 14.b). On each suspension rod was cut internal thread through a $\phi 12$ blind hole. The rod therefore provided means of attachment of the mainframe to the wheel axles through the use of nut (Figure 14c). Each axle has length equal to 92 cm.

3.2.2.3 The Teflon Wheels and Bearing Housing

The wheels to carry the processing trolley were made of Teflon. The reason is because Teflon has low coefficient of friction on steel. Also Teflon has lubricating effect on steel surfaces and would make lesser noise than steel wheel on steel surface.

The diameter of the wheels are 10,0 cm and thickness is 3.0 cm. This thickness was compatible with the leg of the steel rail which was 3.8 cm.

To be able to carry the axles the wheels had to carry a bearing each. Therefore a bearing housing was cut into a Teflon wheel (Figure 14d). A bearing housing has diameter 6.25 cm and 1.5 cm deep to securely fit the bearing.

3.2.3 The Compaction Roller

The compaction roller is a processing equipment. The main components of the compaction roller are: the cylindrical drum, the roller axle and wheels and the ballast weights (see Figure 15).

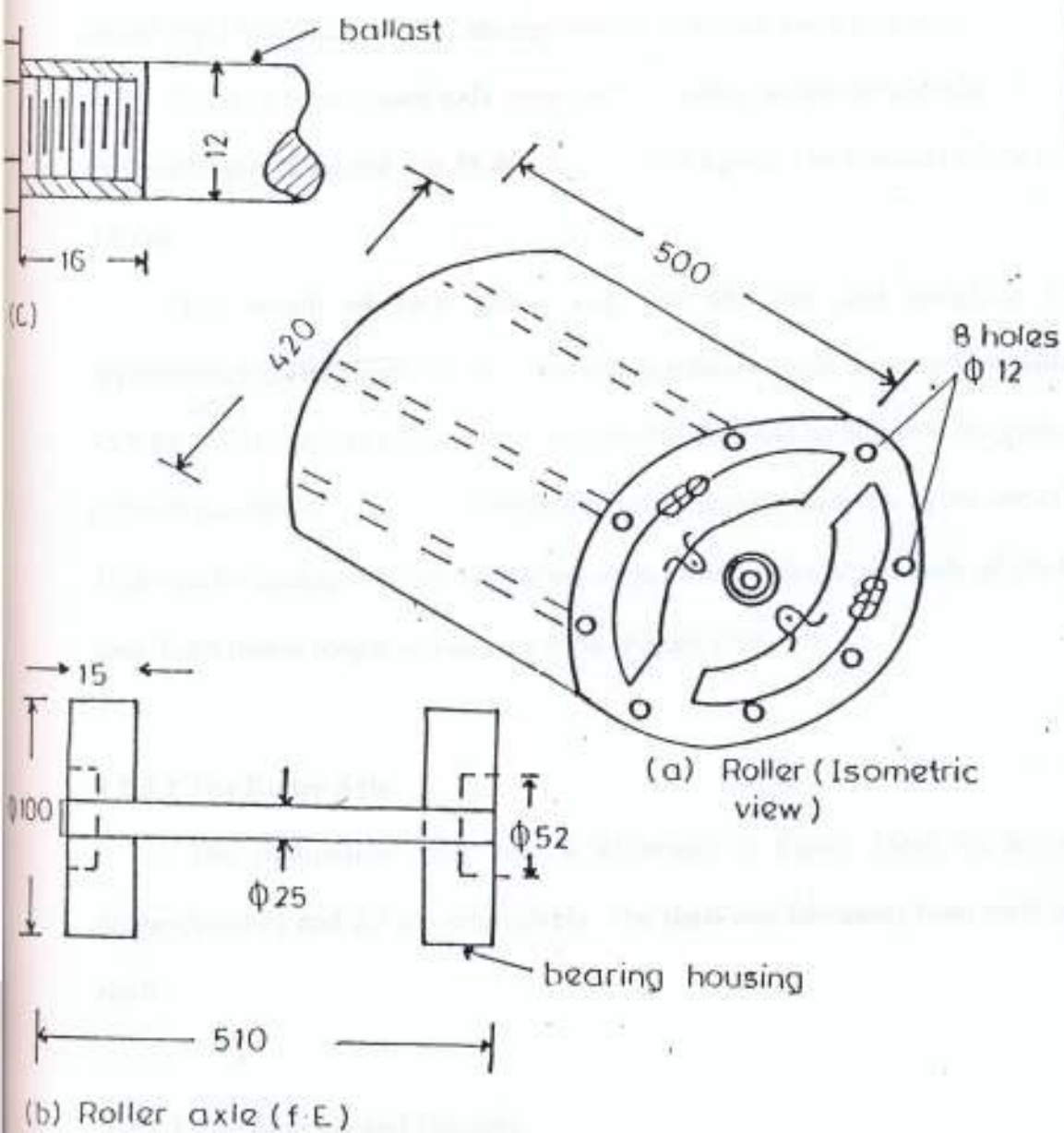


Fig-15 :Main components of compaction roller

3.2.3.1 The Roller Cylinder and Ballast Weight

The roller cylinder or drum was fabricated from sheet metal of thickness 2 mm. The diameter and length of the cylinder are 42.0 and 50.0 cm respectively. The two ends of the cylinder were covered by circular plates. On each circular plate were drilled eight holes diameter 1.2 cm equispaced on a pitch circular of radius 19.4 cm.

Solid circular ribbed rods were used as ballast weight (Figure 15a). The mass per unit length of the rod was 38.46 g/cm (or 3.86 kg/m). The diameter of the rod was 2.5 cm

The length of each ballast rod was 49.0 cm and weighing 1.9 kg approximately. The weight of the compaction roller without the ballast weights was 15.9 kg. Provision was made so that the ballast rods could be bolted to the ends of the cylinder through the provision of holes on the pitch circle diameter by the use of bolts. This was by cutting internal threads on tapped blind holes at the ends of the ballast rods. Each thread length was about 1.6 cm (Figure 15c).

3.2.3.2 The Roller Axle

The compaction roller axle is illustrated in Figure 15(b). Its length and diameter are 51 and 2.5 cm respectively. The shaft was fabricated from solid circular shaft.

3.2.3.3 The Bearing and Housing

The bearings were bought-out components. The external diameter of a bearing is 5.2 cm, the internal diameter is 2.48 cm and the width was 1.5 cm. The bearing was located to fit tightly and securely inside a housing cut into the Teflon wheel, as shown in Figure 15(b).

3.2.3.4 The Vertical Suspension Device

The roller can be suspended in space from the soil processing trolley through the vertical suspension device. This consists of a welded hitch and roller holding device (see Figure 16). The welded hitch has the dimensions shown in Figure 16(a).



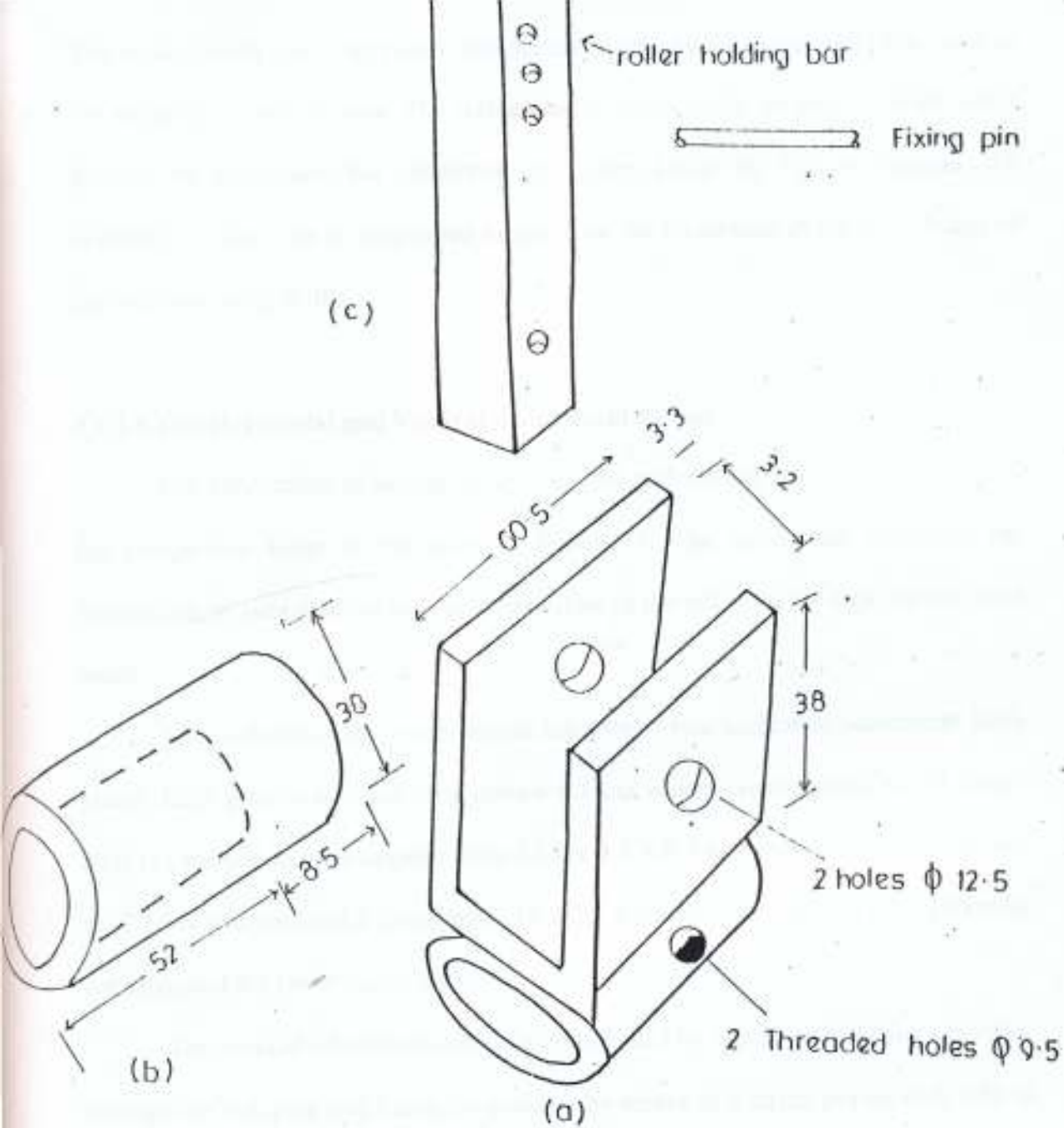


Fig.16: Welded hitch and roller holding device (All dimensions in mm)

The welded hitch which are two in number are attached each to the ends of the axle of the roller by means of nuts. The welded hitch inturn could be pinned to the roller holding or suspension bar illustrated in Figure 16(c). By this mechanism, the compaction roller can be suspended in space on the crossbeam of the main frame of the soil processing trolley.

3.2.3.5 The Horizontal and Vertical Adjustment Device

The mechanism of raising or lowering the roller relative to the cross-beam of the compaction roller is illustrated in Figure 17. The figure also illustrates the mechanism of lateral adjustment of roller either to the left or to the right on the cross beam.

The horizontal adjustment device consists of two horizontal adjustment hitch plates. Each plate was made up a hollow 4.1 cm square cross-section bar of length 20.0 cm welded to a rectangular plate 13.5 x 3.3 x 0.8 cm plate (Figure 17 (c), two M12 bolts and nuts and a fixing plate 13 x 2.5 x 0.8 cm (see Figure 17(b). The bolts are separated 8.2 cm centre-to-centre.

The vertical adjustment can be accomplished by raising or lowering the roller through the VA pipe and fixing the position by means of a fixing pin on each side of the horizontal adjustment plate.

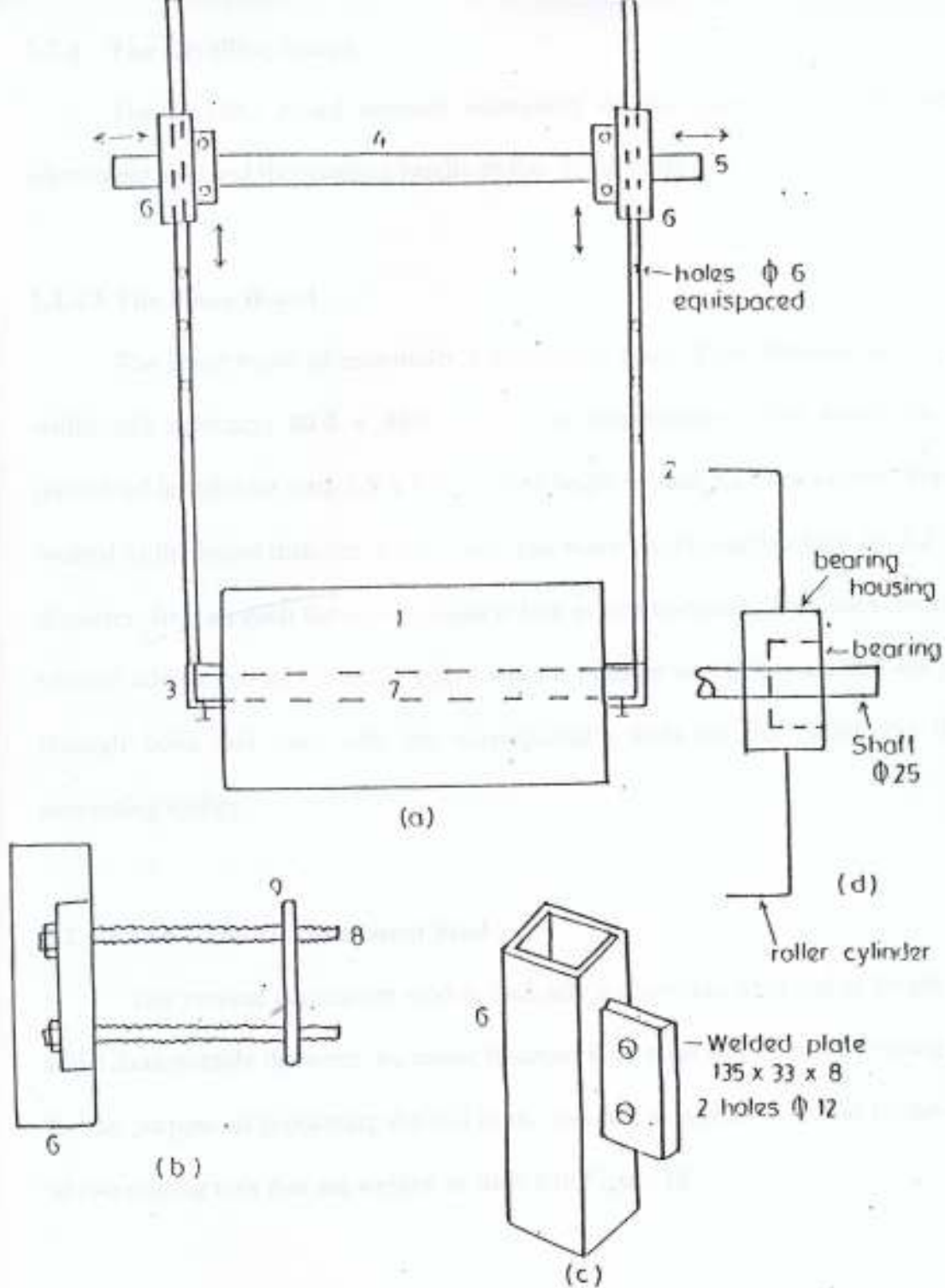


Fig 17: Compaction roller position adjustment device

3.2.4 The Levelling Board

The leveling board consists essentially of the plane board, the vertical adjustment stud and the winding handle as the major parts (see Figure 18).

3.2.4.1 The Plane Board

The plane board is essentially a rectangular plate of the dimensions of length, width and thickness 80.0 x 30.0 x 0.02 cm respectively. The board was also reinforced lengthwise with 1.9 x 1.9 x 0.3cm angle section bar. The support bar were welded to the board distance 40cm apart. The holes on the support bars are 1.2 cm in diameter, five on each bar and equispace 5cm centre-to-centre. The holes are for the vertical adjustment of the plane board and for balance or stability as they are mated through bolts and nuts with the corresponding slots on the mainframe of the processing trolley.

3.2.4.2 The Vertical Adjustment Stud

The vertical adjustment stud is basically a screw threaded rod of height 50cm and 1.2cm outside diameter. Its major function is to raise or lower the leveling board for the purpose of processing the soil in the soil bin. It is able to do this by the action of two mating nuts that are welded as shown in Figure 18.

3.3.4.3 The Winding Handle

The winding handle (Figure 18) was a bought-out component. It was screwed into the head of the vertical adjustment stud for the purpose of turning the stud, for raising or lowering operation.

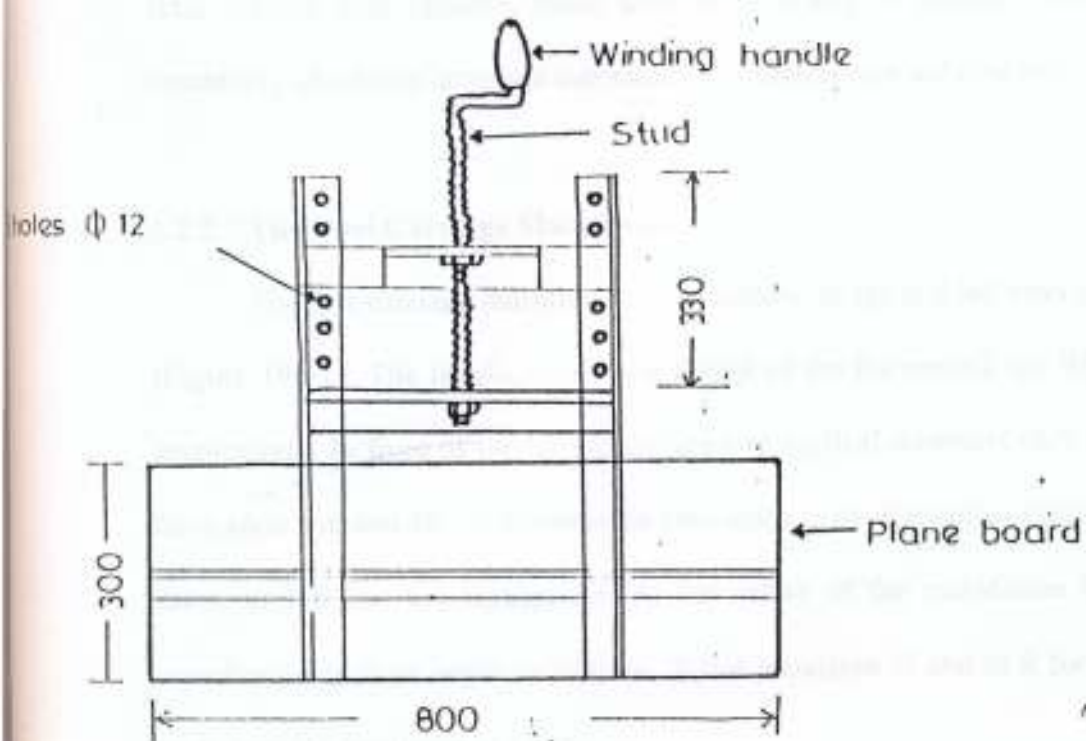


Fig-18 :The levelling board (front view)

3.2.5 The Tool Carriage and Tool Carriage Subframes

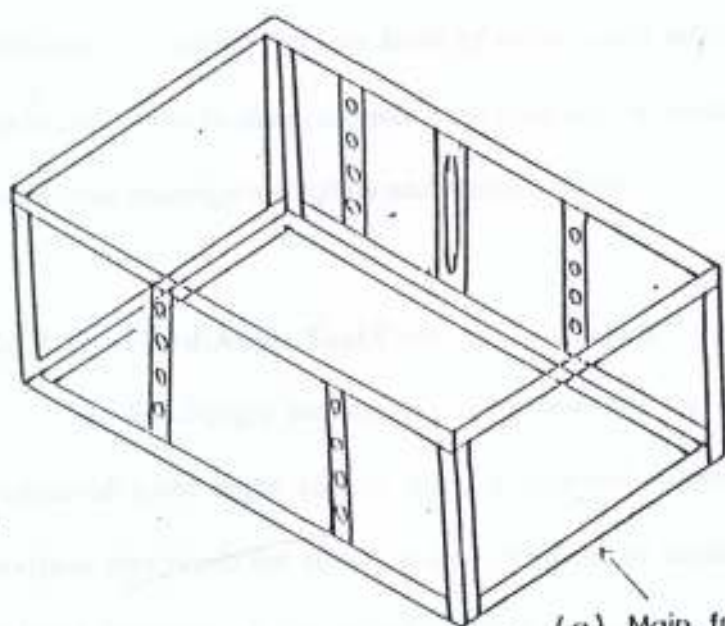
The tool carriage and tool carriage subframes were also designed for rigidity, stability, maneuverability, flexibility and maintainability. It was designed to run on four wheels with minimal noise level from wheel to surface contact. It consists essentially of a mainframe and subframes to which tillage are attached.

3.2.5.1 The Tool Carriage Mainframe

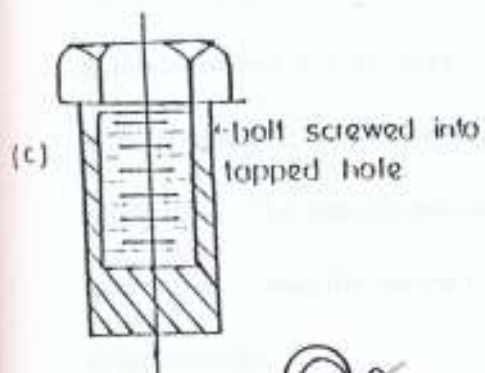
The tool carriage mainframe is essentially an open-sided steel rectangular box (Figure 19(a)). The length, width and height of the framework are 92 x 50 x 30 cm respectively. In front of the mainframe are two vertical members each distance 23 cm from each end and 46 cm between the two. Each vertical member carried four holes of diameter 0.8 cm and equispaced. At the centre of the mainframe is another steel member made from angle section bar. It has provision of slot in it for the attachment and vertical adjustment of tools.

3.2.5.2 The Axles and Suspension

The axles and suspension are illustrated as shown in Figure 19(b). The wheel base is 35 cm. The axles diameter is 2.5 cm and are braced for maneuverability and ease of assemblage. The suspension rods are 5 cm high similar to that of the processing trolley. The distance between two pairs of suspension rods are 70 cm across the width of the soil bin. The details of the suspension rods are shown in Figure 19(c).

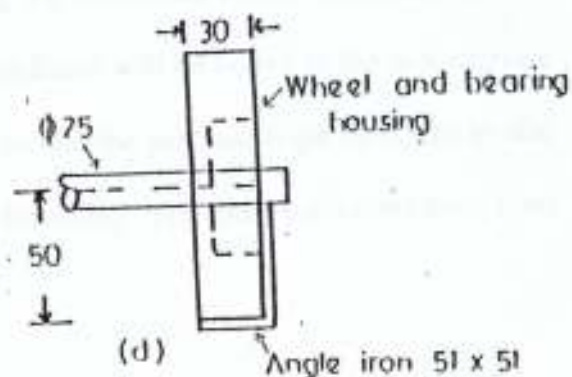


(a) Main frame



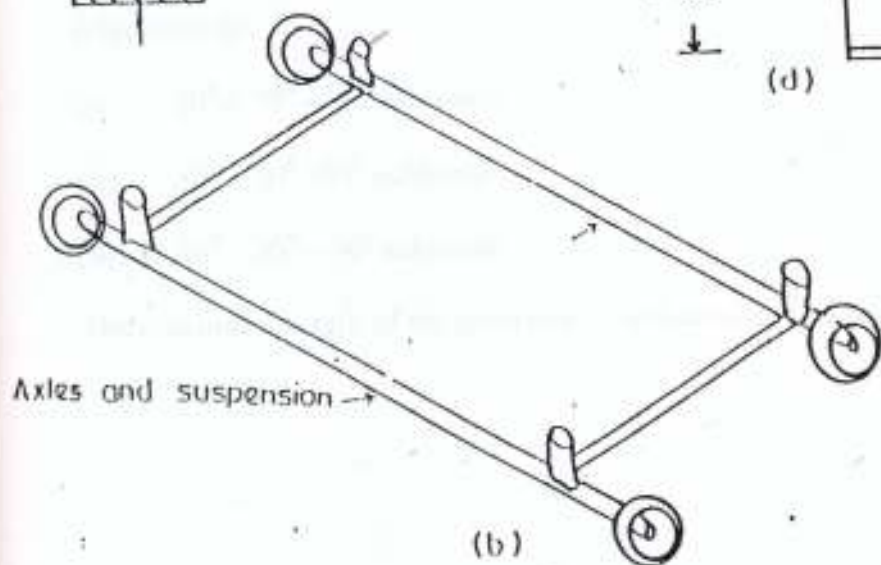
(c)

bolt screwed into
tapped hole



(d)

Angle iron 51 x 51



(b)

Axles and suspension →

Figure.19: The tool carriage mainframe and suspension

3.2.5.3 The Teflon Wheels and Bearing Housing

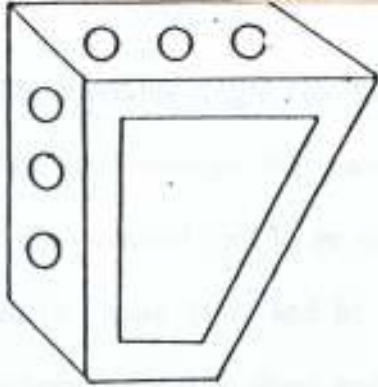
Teflon was chosen as wheel materials because of its lubricating effect, low coefficient of friction and low level of noise when moving on metal surfaces. The wheels are 10 cm in diameter and 3 cm wide. In the wheels are cut bearing housings to which the bearings are tightly and securely fitted.

3.2.5.4 The Fixed-Angle Tool Carriage Subframes

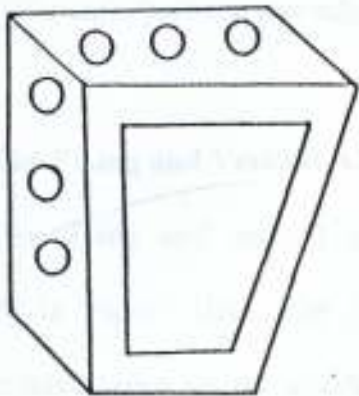
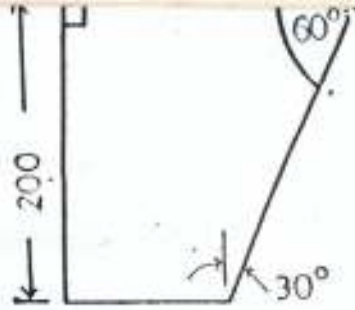
The fixed-angle tool carriage subframes are shown in Figure 20. They were constructed from angle section bars of sectional dimensions 3.8 x 3.8 x 0.3 cm. Provision was made for attaching tools to them by means of bolts and nuts through the holes diameter 1.2 cm drilled in them. A wide range of rake angel ranging from acute to obtuse can be obtained by selecting the subframes surface to which the tool will be attached, while another side of the subframe will be bolted to the tool carriage mainframe. The specifications were chosen so that the subframes are moderate in size and yet provision the necessary rigidity and flexibility. The three subframes have been referred to as:

- (i) $20^{\circ} - 70^{\circ} - 90^{\circ}$ subframe
- (ii) $30^{\circ} - 60^{\circ} - 90^{\circ}$ subframe
- (iii) $40^{\circ} - 50^{\circ} - 90^{\circ}$ subframe

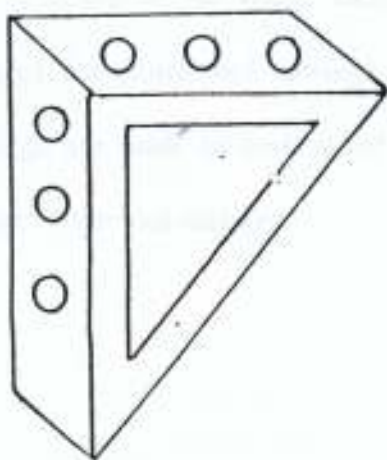
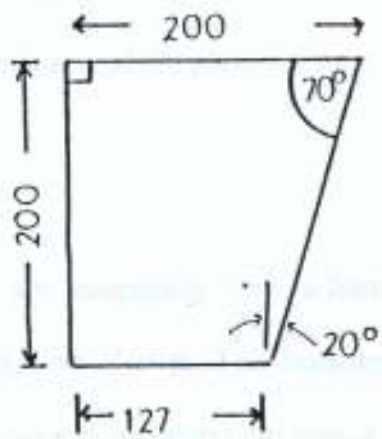
The maximum length of the sides of the subframes is 23.8 cm



(a)



(b)



(c)

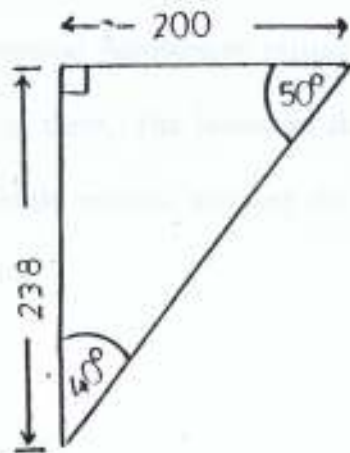


Fig. 20 The fixed-angle tool carriage subframes

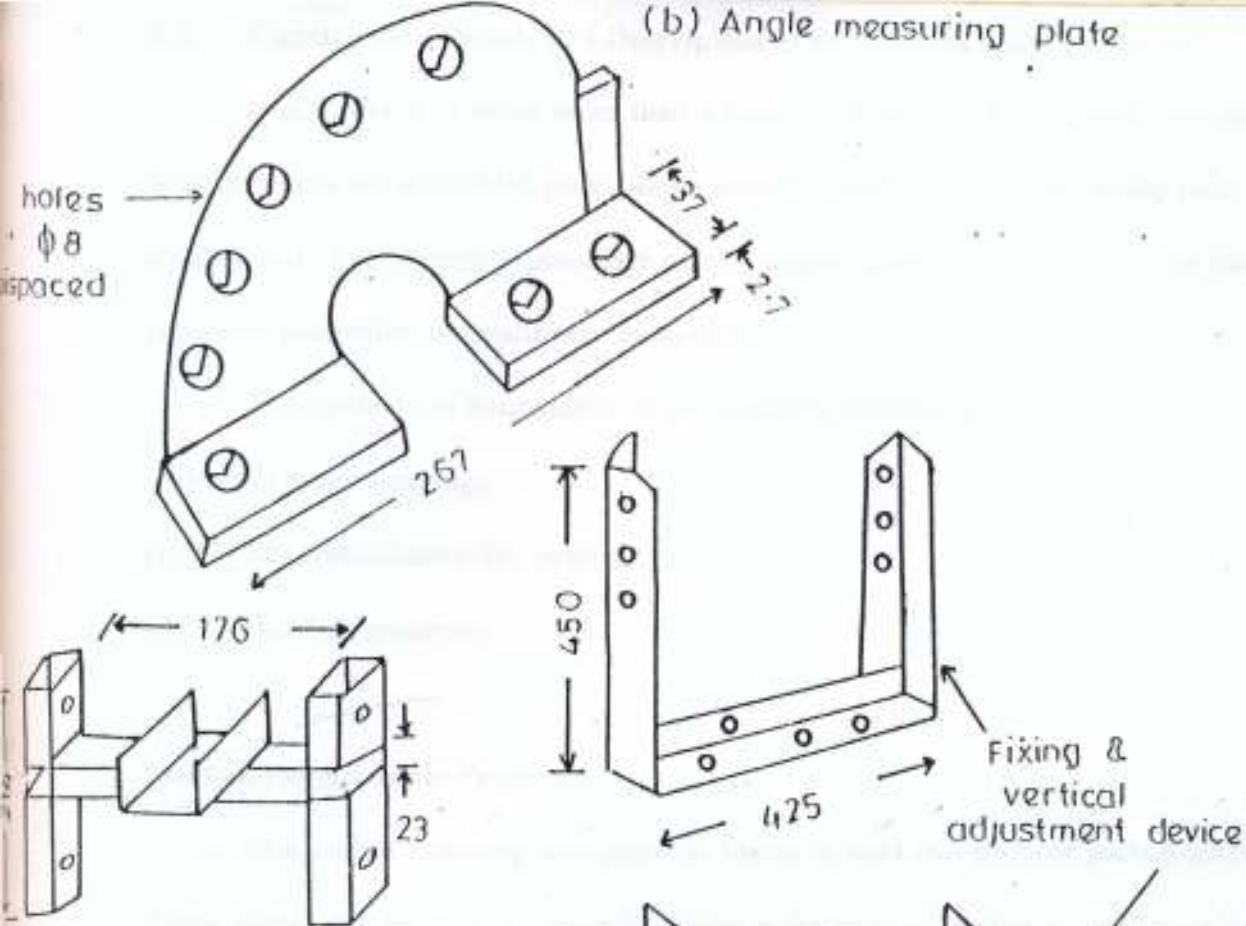
3.2.5.5 The Variable-Angle Tool Carriage Subframe

The variable-angle tool carriage subframe is a device that enables the rake angle of the attached tool to be varied; through a pivoted angle measuring plate illustrated in Figure 21 (a and b). The angle measuring plate (two in number) is basically semi-circular in shape and of diameter 18.2 cm. Holes 8 mm diameter are drilled on the plate on a pitch circle of radius 7.7 cm so that rake angle is measured in steps of 15° (angle between two adjacent holes). The thickness of the plate is 5 mm.

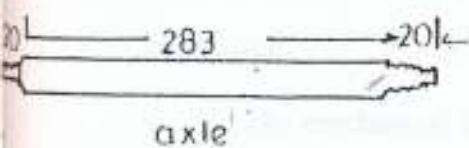
3.2.5.6 The Fixing and Vertical Adjustment Device

The fixing and vertical adjustment frames are essentially two u-frames illustrated in Figure 21(c). The major dimensions are as shown. The horizontal members have holes for the attachment of the angle measuring plates by means of bolts and nuts. The frames also have holes for the fixing of the pivot block axle. The vertical members of the frame carry holes for the vertical adjustment raising or lowering of the entire tool carriage subframe bolted to them. The holes on these vertical legs are made to correspond to that of the middle vertical member on the mainframe of the tool carriage.

(b) Angle measuring plate



(a) Pivot block



(c)

(c) The variable-angle tool carriage subframe and vertical adjustment device

3.3 Construction Details and Description of the Soil Bin and Equipment

It is difficult to name more than a handful of product having only one part. Most products are assembled (fabricated) or constructed from several mating parts or components. The assembly processes temporarily or permanently join two or more parts into assemblies or products or equipment.

The methods of temporarily or permanently combining parts may be grouped under two major headings.

- (i) Mechanical assembly processes
- (ii) Bonding processes

Mechanical Assembly Processes

Mechanical fastening uses physical forces to hold two or more parts together. These parts may be held in place by either a fastener or by the parts themselves. Typical mechanical fasteners used are screws, bolts and nuts, nails, staples, cotter pins, rivets and retaining clips. The fasteners squeeze or grip the parts and hold them in position.

The mechanical fasteners in this project were designed and selected for one of three basic uses. They are used for assemblies which are:

- (a) Temporary – that is, can be easily assembled, disassembled or adjusted.
- (b) Semi-permanent – that is, can be disassembled although this is not normally done.
- (c) Permanent – disassembly destroys the fastener(s) and sometimes the part.

Parts were also designed to position and hold one another. Some components were bent or machined to grip their mating part to form an assembly. Parts were also designed to be pressed together. The friction between surfaces hold them together.

Press fits were used. Bearings were pressed into their openings or housings or shaft. Pins were driven into holes.

Bonding

Parts were also assembled by the use of bonding techniques. There are two major bonding methods: cohesion and adhesion. Cohesive forces hold millions of molecules in a part together. Heat and/or pressure is used to bring the parts together. The result is a single piece made from the several parts. The area of joining becomes a uniform or monolithic layer. Cohesive bonding is developed through a group of processes generally called welding.

Adhesive forces were used to hold two different materials together. An adhesive materials was applied between two parts. It gripped the parts and hold them in place. Adhesives were used to assemble a full range of metallic, polymeric and ceramic materials. Some parts that were once bonded with cohesive forces (welded) or by mechanical means were glued.

3.3.1 The Soil Bin

The soil bin is a topless rectangular box constructed from mild steel angle sections, flat bars and wooden planks for the side and end walls. The planks were fastened to the mainframe by the use of screws, bolts and nuts. The metal frames were joined together by means of shield metal arc welding (SMAW) and/or oxyfuel gas welding (OFW)

3.3.1.1 The Steel Mainframe

The mainframe was fabricated from mild steel angle iron bars. The whole framework was designed in sections of four units. Each unit component were joined together by welding and the units fastened together by bolt and nuts. The overall dimensions of length, width and height of the bin are 9.0, 0.85 and 0.5m respectively.

On the mainframe were holes drilled through which fasteners were used to

- (i) fasten the steel rails to the mainframe
- (ii) hold the wooden planks in place
- (iii) hold the sections together

The screws used were in various sizes and the most common head styles used include: flat, oval, fillister, pan, round fillister.

The hexagonal bolt was most commonly used

3.3.1.2 The Steel Rails

Steel rails were made of mildsteel angle iron bars running through the whole length of the mainframe and one on each side. The rail on each side is made of two length units joined together and each unit lapped a joint of two sections of the mainframe.

Holes were drilled on the rails corresponding to those drilled on top of the mainframe. But the holes on the rails were countersunk so that the screw heads used to fasten them together can flush with the surface of the rail in order not to obstruct the smooth running of the carriage wheels on the rails. The machine screws used here have the same size but head styles of fillister, slotted, cross-recess type 1 could be used.

The vertical side of the steel rails also serve as guides for the soil-processing trolley and the tool carriage

3.3.1.3 The Wall Bracings

The wall bracings were made of mild steel flat rectangular bars cut in sizes of about 20 cm. One end of the piece is welded to a vertical steel frame and the other end to a floor located horizontal frame bar. The major purpose of these bracing was to counteract the effect of buckling of the walls that could result during the service life due to the soil lateral pressure.

3.3.2 The Soil Processing Trolley

The soil-processing trolley is basically a rectangular framework mounted on Teflon wheels to move over the steel rails of the side walls. It consists of a rectangular steel mainframe, Teflon wheels and bearing housings and the trolley axle and suspension.

3.3.2.1 The Rectangular Mainframe

The rectangular mainframe is constructed with mild steel angle section bars cut to design specification and welded by SMAW. The bar section is of dimension 51 x 51 mm. The frame-work members were arranged so that the outside corner of the bars form the edges of the mainframe. This arrangement is neater and would minimize operational hazards when the equipment is put to use.

A cross beam was welded to divide the top rectangular frame into two. This beam has box or square section of 51 x 51 mm produced by welding together two

similar angle section bars of the same length and size. This beam served as a cross-beam to which the compaction roller was attached or suspended for operation.

3.3.2.2 The Trolley Axles and Suspension

The trolley axles were cut from 25mm DIA steel rod and the ends were machined to specification of the roller bearings carrying them. Two holes one at each end were drilled on the shafts. Cotter pins were used in these holes to prevent the Teflon wheel from slipping or turning off.

The axles were framed in position with flat bars and hollow circular section galvanized pipes to make them an integral whole unit. The joining is by welding.

3.3.2.3 The Teflon Wheel and Bearing Housing

When assembled the Teflon wheel and bearing housing form a unit. Four units were made altogether for processing trolley.

The components of the Teflon wheel are:

- (i) A bearing housing turned from the Teflon to specification
- (ii) A roller bearing – brought out material
- (iii) A Teflon wheel

When the bearing was fixed in place, provision was made to ensure that the bearing did not pull off. This was in the form of metal stopper.

3.3.3 The Steel Compaction Roller

The compaction roller is basically a cylindrical “drum” with closed ends. The components of the roller are: the close-ends cylinder, roller axle, bearing, bearing housing, roller ends and ballast weights.

3.3.3.1 The Close-End Cylinder

The features of the closed-ends cylinder are:

- (i) The hollow cylinder was rolled into shape from a rectangular sheet metal, gauge 14 (2 mm thick).
- (ii) Circular sheet metal of the same gauge cut to specification to form the ends of the cylinder by welding process. Holes were drilled equispaced on a pitch circle at a predetermined distance from the periphery of the circular ends. The hole were used to connect or fix the ballast weights to the compaction roller through a system of bolts and nuts.
- (iii) At the centre of each circular end plate was cut a circular hole into which the bearing housing was welded.
- (iv) One of the end plates have two openings cut into it. The scraps cut out were fixed in place by the provision of hasp and staples welded to them. This provided openings which would be opened when ballast weight are to be installed and closed when the roller is in operation.

The circular end in which the opening are cut was also reinforced for adequate rigid during operation.

3.3.3.2 The Compaction Roller Axle

The compaction roller axle was cut from a 25 mm DIA solid circular steel shaft. The ends were turned to specification on a lathe machine, to fit the roller bearings. The materials of the shaft is medium carbon steel (containing 0.3 to 0.6% of carbon).

3.3.3.3 The Bearing Housing

The bearing housings are four in number. They were turned on the lathe machine from medium carbon steels through separating processes.

The limit or minimize the amount of separating works to be done, it was necessary to work with a workpiece that was disc-like or cylindrical. Using the lathe machine, blind cylindrical holes were bored on the work piece (to specification) to accommodate the bearing.

3.3.3.4 Vertical Suspension Device

The vertical suspension device consists of the following features:

- (i) A steel bar of square cross-section. It was made by welding together two angle steel sections to form the square or box-section. Holes at predetermined distance were drilled on the bar for the suspension of fixing of the compaction roller as the case may be.
- (ii) An end-fixing device or hitch was meant to hold the axle of the compaction roller in place through the provision of bolts and nuts. The fixing device was machined from a cylindrical solid circular shaft work piece. A central blind hole was bored into the workpiece to house a short length of the axle. Two holes were drilled and screw-tapped into the piece at right angle between them. When the axle ends enter the blind holes, bolts are used to hold them securely in place.

3.3.3.5 The Horizontal and Vertical Adjustment Device

Attached to the cross-beam are two similar fixing devices that can be used to position and hold the compaction in place through the vertical adjustment device. The

fixing device is more or less a "U-connector" with provision for attachment of the vertical adjustment device which in turn is attached to the roller.

The components of a fixing device are

- (i) A hollow pipe of square cross-section formed by welding two angle iron bar sections together.
- (ii) Two flat steel bars on which are drilled two holes each. The bars are similar in all respect. One of the bars is welded to the square section hollow pipe and the other is not.
- (iii) Two pairs of long bolts and nuts.

The horizontal adjustment of the roller may be accomplished by moving or sliding the U-connector sideways, either to the left or to the right.

3.3.3.6 The Ballast Weights

The ballast weight were constructed from solid circular cross-section ribbed iron rods. The average mass per unit length of the rod is 38.46 g/cm. The unit length of cut is 48.6 cm. At each end of a unit, the rod is bored and dies were used to cut screw threads on the inner surface of the bore. To increase weight, two or more ballast weight were tacked together.

3.3.4 The Levelling Board

The leveling board is essentially a rectangular sheet metal in a framework connected to the mainframe of the processing trolley. It consists essentially of

- (i) A reinforced board
- (ii) A vertical adjustment stud and
- (iii) A winding handling

3.3.4.1 The Reinforced Board

It is essentially a rectangular sheet metal cut from mild steel sheet of 2 mm thickness. It was reinforced with narrow bars and its edges and across its length through the midpoint. The reinforcement bar was mild steel angle of sectional dimensions 10 x 10 x 3 mm. The reinforcement minimized deflection of the board soil processing operation. The board was bolted to angle iron bars on which holes were drilled for vertical adjustment of the leveling board. A cross-bar was welded at its ends to the vertical adjustment bars. The cross bar had a hole drilled through its midpoint. The stud passed through the hole. Lock nuts were put at the end of the stud below the hole. This arrangement enabled the stud to move the leveling board up and down in a vertical position.

3.3.4.2 The Vertical Adjustment Stud

It is essentially a solid circular rod. Dies were used to cut screw threads on its cylindrical surface along its length. Through a system of assemblage, the stud connected the leveling board with the mainframe.

3.3.5 The Tool Carriage and Tool Carriage Subframe

The tool carriage and tool carriage subframe are two components that are fastened together by means of bolts and nuts in order for them to form an integral whole for operation. The tool carriage is similar to the soil processing trolley in shape and construction. It is also a rectangular framework mounted on Teflon wheels. The carriage is provided with two types of subframes fitted by bolts and nuts on to the mainframe. The tool is mounted on a subframe. The two types of subframes are:

- (i) The fixed-angle tool carriage subframe
- (ii) The variable-angle tool carriage subframe.

3.3.5.1 The Tool Carriage Mainframe

The tool carriage mainframe is essentially a rectangular framework. It is similar in shape and construction to the mainframe of the soil processing trolley (described in section 3.3.2). Bars of angle steel section (38 mm x 38 mm x 3.6 mm) were used in fabrication the mainframe.

3.3.5.2 The Axles and Suspension

These are similar to those of the soil processing trolley described earlier. The axles were cut from the same standard stock, and the suspension device is also similar to that of the soil processing trolley.

3.3.5.3 The Teflon Wheels and Bearing Housing

Four wheels were machined from Teflon industrial stock (in the form of thick rectangular cross-section bar). On one diameter face of each wheel is made a recess to accommodate the metallic bearing housing. The construction details are similar to that reported in section 3.3.3.

3.3.5.4 The Fixed-Angle Tool Carriage Subframe(s)

Three fixed angle tool carriage subframes were fabricated from standard stock angle steel bars of sectional dimensions 38 mm x 38 mm x 3.6 mm. The size lengths were cut to specification. Holes were also drilled to specification. On the members. The holes were used to fasten the subframes to the tool carriage as required. The three types of the subframes are designated by the angles they furnish:

- (i) $20^{\circ} - 70^{\circ} - 90^{\circ}$ subframe
- (ii) $30^{\circ} - 60^{\circ} - 90^{\circ}$ subframe
- (iii) $40^{\circ} - 50^{\circ} - 90^{\circ}$ subframe

3.3.5.5 The Variable-Angle Tool Carriage Subframe

The components of the subframe are:

- The tool holding bar
- The slider mechanism device
- The angle measuring device
- The suspension shaft

(a) The Tool Bar

This is essentially an angle iron bar. It was fabricated from angle iron bar of dimension 38 mm x 38 mm x 3.6 mm. Its purpose is to hold the tillage tool in position for operation. On one flange of the tool bar was cut an extended slot with a milling machine and the other flange had holes drilled at predetermined points.

The tool bar is installed in a slider mechanism device where its operating length control be adjusted and fixed.

(b) The Slider Mechanism Device

The slider mechanism device enabled the tool bar length to be adjusted or varied by means of sliding action on top of a bottom U-section plate. This plate has three holes drilled in it (equi-spaced) corresponding to the extended slot when the tool bar lapped the U-section plate.

The U-section plate was welded to a base support which in turn 'housed' the suspension shaft.

(c) The Angle Measuring Device

It consists of two semi-circular plates cut to specification. Holes, equispaced were drilled on each plate on a pitch circle diameter. An arc connecting two adjacent holes subtends an angle of 15° at the centre of the circle of which the arc is a part. A flange was welded to each plate for attaching it to the base of subframe. The flange which was fabricated from steel angle bars had three holes drilled into it (equispaced) for fastening by means of bolts and nuts to the base on which the flange rested.

(d) The Suspension Shaft

The suspension shaft is essentially a solid circular shaft of diameter 25 mm. The ends of the shaft were turned in a milling operation and threaded with the use of dies. The shaft served as a pivot about which the variable-angle subframe rotated to vary the rake angle of the tool. The ends of the shaft are bolted to the fixing and vertical adjustment device.

3.3.5.6 The Fixing and Vertical Adjustment Device

It consists essentially of a pair of U-shaped frameworks. They were fabricated from angle section bars cut and drilled to specifications. Holes were drilled on the vertical and horizontal members for the purpose of fastening of components by means of bolts and nuts. They are installed vertically inside the tool carriage mainframe by the use of bolts and nuts, and can thus be raised or lowered to adjust the implement or tool as the case may be.

3.3.6 Assembling of Parts

The techniques used to join parts into products are referred to assembling processes. By definition these are processes which temporarily or permanently join two or more parts into assemblers or products.

These methods of temporarily or permanently combining parts may be grouped under two major headings. These are mechanical assembly and bonding processes. The mechanical assembly process used in this equipment include screws, bolts, nails, staples, cotter pins. The fasteners grip or squeeze the parts and hold them in position. The other part which were not to be disassembled were assembled by the use of bonding technique or welding.

3.4 Instruments Used in This Study

The following instruments were used in this study to compliment the equipment for soil tillage dynamics.

3.4.1 The Power Transmission System

The power transmission system consisted essentially of electric motor pulley, intermediate driven pulley, intermediate driving pulley, final driven pulley and wire rope pulley. The Figure 22 shows the top view of the transmission system.

3.4.2 The Load Cell

The load cell is essentially a spring dynamometer capable of measuring force to the maximum of 1.96 kN (200 kgf). The load cell and its associated framework is shown in Figure 23 By this frame-work, the load cell could be mounted on top of the tool carriage from where it is linked by means of rope to the power transmission system.



Fig. 22 Top view of the power transmission system

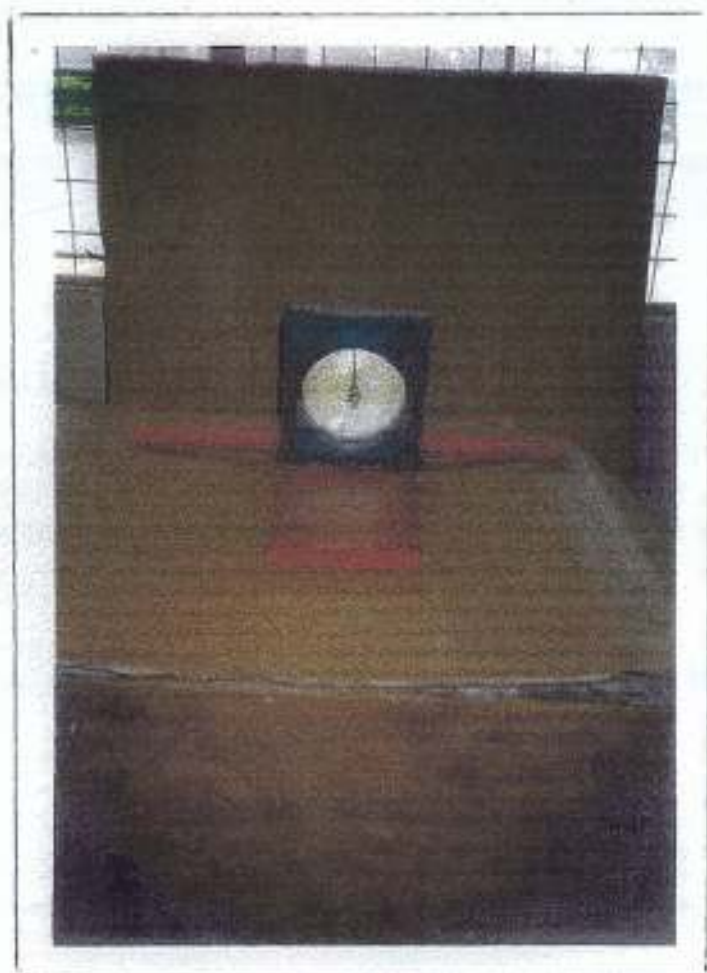


Fig: 23.: The load cell

3.4.3 Cone Penetrometer

A bush recoding cone penetrometer model CP20 (ultrasonic) was used. It was capable of indicating the values of cone index directly in units of pressure (kPa) on a digital display

3.4.4 Shear Vane Tester

A hand shear vane tester was used in this study to determine the shear strength or cohesion of agricultural soil. The type was equipped with two types of vanes: 19 mm vane for the range of 0 to 140 kPa; 33 mm vane for the range of 0 to 30 kPa pressure.

3.4.5 Universal Compression Machine

A Universal Testing Machine (SM100, Model No CPI-60) of 0.1kN calibrations was also used in this study for the compression of soil in moulds (Figure 24).

Further details of the operations of the machine are reported in chapter four.



Fig: 24. The Universal Testing Machine

3.4.6 Triaxial Test Machine

A tri-axial compression test machine was used also to determine the shear strength of agricultural soil in terms of cohesion and angle of internal friction.

3.4.7 Translational Shear Box

A simple test for finding the shear strength of a soil is the shear-box. A shearing force is applied to the sample such that the sample "shears" at a constant rate (constant rate of strain). Typical laboratory shear box measuring technique is discussed in chapter four.

3.4.8 Soil-Materials Friction Measuring Device

A soil-material friction measuring device was designed and fabricated for this study. The diagram of the apparatus is shown in Figure 25.





Fig.25 : The soil-material friction measuring device

3.4.9 Drying Oven

The drying oven used in this study is the Gallenkamp plus II oven model.

3.4.10 Speedy Moisture Meter

A laboratory speedy moisture meter was also used in this study to determine the moisture content of soil samples.

3.4.11 Other Apparati

The other apparati used in this study include:

- Soil core samplers
- Soil moulds
- Soil auger
- Soil trays with liners

3.5 Tools Used in This Study

The tools that were used in this study were classified mainly as Tines and Blades.

3.5.1 Tines

Some of the tines used in this study are illustrated as shown in Figure 26. Tine T1 is a very narrow tine of width, 1.0 cm. Tines T5 and T10 are narrow tines of widths 5.1 and 10.0 cm respectively. Tine T20 is a wide tine of width 20.0 cm. The tines were made of mild steel flat. The bevel angle of each tool was 15°.

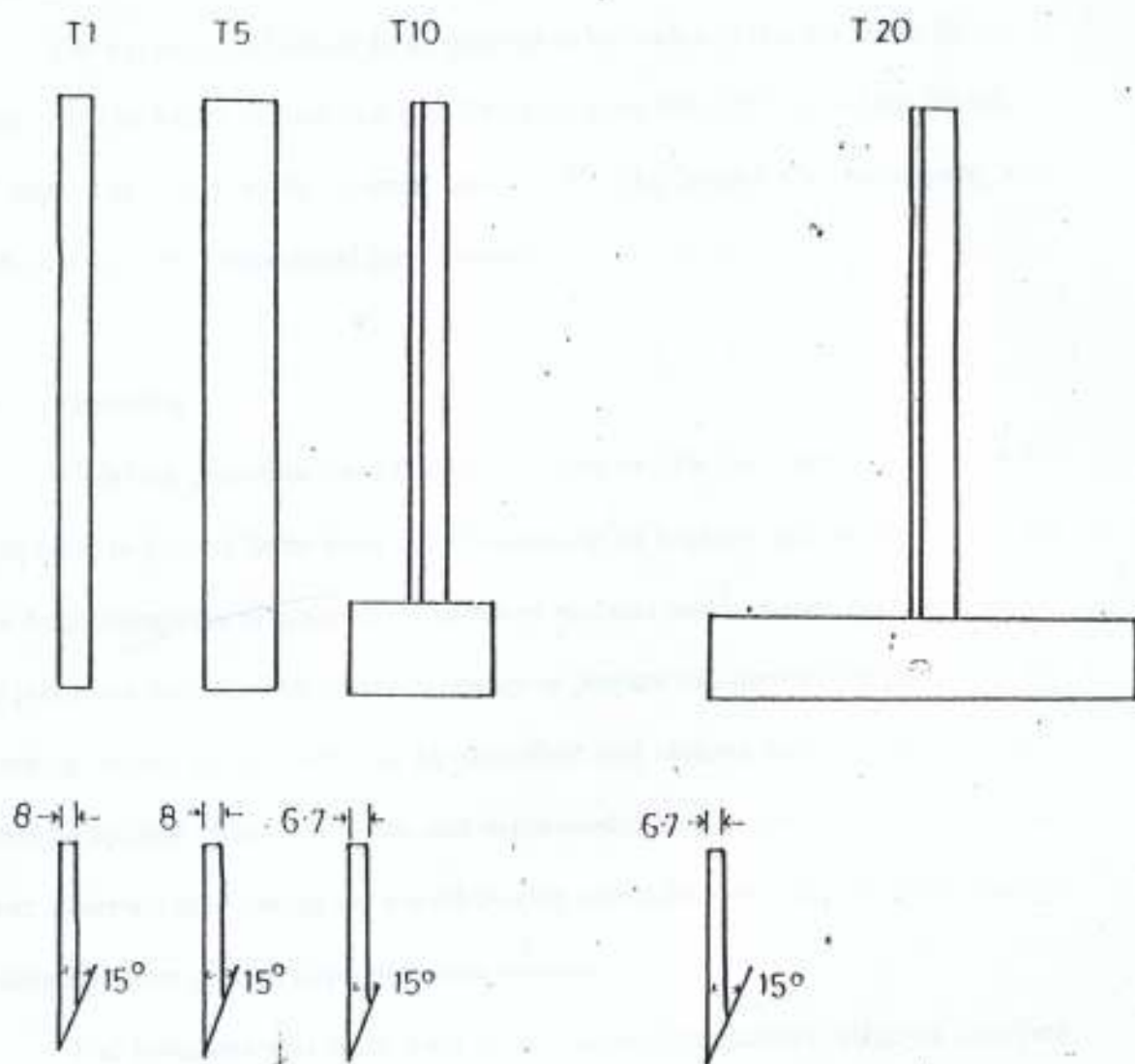


Fig. 26: Some of the experimental tines

3.5.2 Blades

The experimental tillage tools referred to as blades in this study are shown in Figure 27. The length of each tool was 20.0 mm, the width 7.27 cm and the thickness, 6.7 mm. The bevel angle of each tool is 15° . The shapes are: rectangles, vee, triangular, convex, concave and semi-circular.

3.6 Finishing

Finishing processes were designed to alter or treat the surface of parts of the equipment to protect them from the environment or improve appearance. These are two basic categories of processes. Converted surfaces and coatings. However, before the processes were applied, it was necessary to prepare two parts of the equipment for finishing. Many parts needed to be smoothed and cleaned before finish materials could be applied. Scratches, burrs, and dents needed to be removed. Oil, grease, and other materials used during the manufacturing processes were cleaned away. Surface oxides and other process impurities were removed.

The processes that were used in the material preparation stage of finishing were mechanical and chemical processes. The mechanical processes include abrasive cleaning with abrasive paper or cloth, brushing with wire and fibre brushes. For chemical process, flame cleaning used an oxy-acetylene flame for cleaning oxidation and scale from metal surface. The rapid heating caused the impurities to break off the surface.

The finishing process adopted in the development of the equipment was coatings, in which a layer of protective material (organic material) was applied to the product. The main organic coating used was paint. The methods that were used to apply the organic coating were brush coating, dip coating and spray coating.

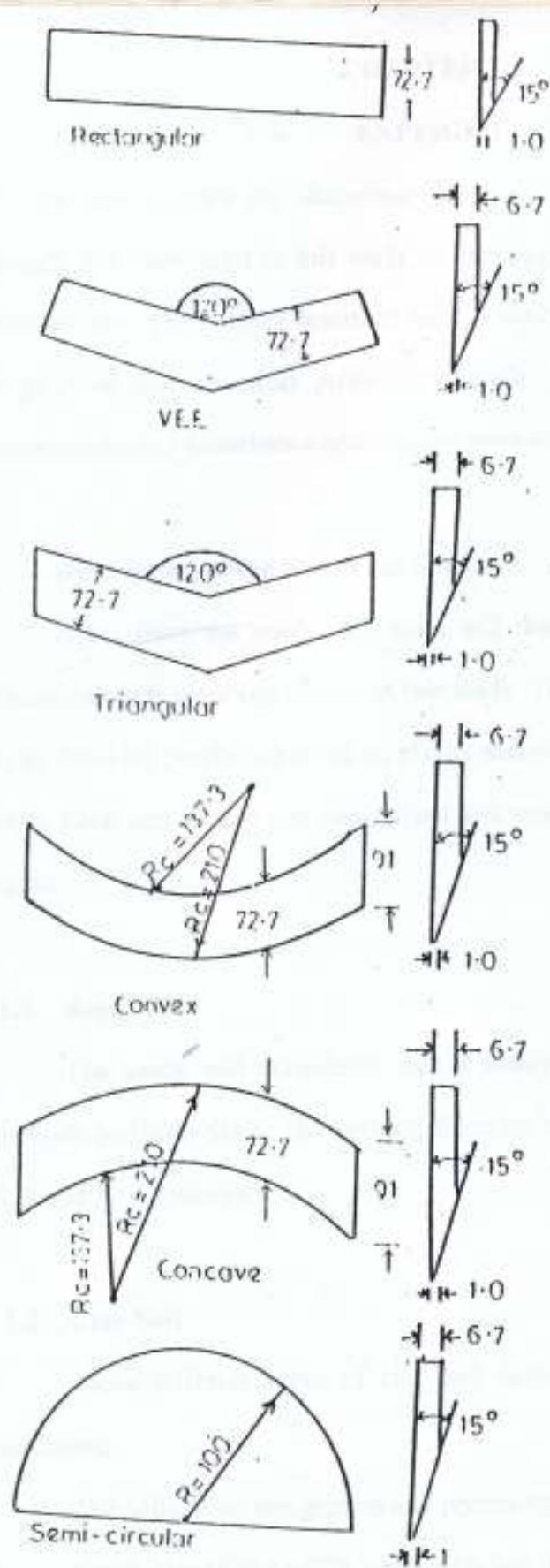


Fig. 27: Shapes and dimensions of experimental tillage tools (dimensions in mm)

4. EXPERIMENTATION

In this chapter are discussed the experimental methods, procedures and materials that were used in this study to generate or collect the relevant soil tillage parameter data. The chapter describes the soil studied, reports the determination of the soil physical and chemical properties. Finally, the effect of variation in tillage parameters on soil disturbance and draught were also reported.

4.1 Description of the Soil in the Study

Apart from the sandy clay loam soil that was put into the soil bin, other agricultural soils were considered in this study. The samples were taken from the top 40 cm, from the profile, air dried on plastic sheets and ground to pass through a 2 mm screen. Each soil texture was then mixed in a cement mixer to obtain a homogeneous sample.

4.1.1 Sandy Soil

The sandy soil considered was a loamy sand soil, designated IGLS, from Igbokoda in Ondo State. The textural fractions of percentage sand, silt and clay are 85, 3 and 12 respectively.

4.1.2 Clay Soil

Three different types of clay soil from different locations in Akure were considered.

The soils, their designation and percentage textural fractions were:

- (i) Sandy clay (EWA) 47% sand, 13% Silt, 40% clay.
- (ii) Clay (EO), 40% sand, 14% silt, 46% clay
- (iii) Clay (EC) 32% sand, 17% silt, 51% clay

4.1.3 Loamy Soil

Three different types of loamy sand soils were considered. These were also soils from Akure. The soils are:

- (i) Sandy loam (EWV), 77% sand, 13% Silt, 10% clay
- (ii) Sandy loam (EB1), 70% sand, 24% silt, 6% clay
- (iii) Sandy loam (EH3), 56% sand, 30% silt, 14% clay

4.1.4 Sandy Clay Loam

This soil was taken from one of the fallow agricultural land of the commercial farm of the Federal University of Technology, Akure, Nigeria (elevation 210m, 7° 15'N, 5° 15'E). The soil is Oxic Paleustalf (Alfisol) or Ferric Luvisol (FAO). The site was recovered from about three years of bush fallow. The site of the sample is presented in Figure 28.

The dimensions of the soil bin, that is, length and width were marked out on the field, and the soil was excavated to the equivalent depth of the soil bin about 42 cm. This equivalent depth which showed the soil profile of the pit in three distinct layers is shown in Figure 29. The thickness of the uppermost layer or top soil (layer 1) is 8.0 cm while the middle layer (layer 2) was about 15.0 cm. The third layer (layer 3) which was thickest was excavated to 150 cm. The quantities of soil samples that were removed according to the three layers were stock piled separately as shown in Figure 30.

The bin soil was characteristically sandy clay loam soil. The layers were analysed differently to determine their textural fractions:

- (i) Layer 1: Sandy clay loam (EBS1); 54% sand, 21% and 25% clay.
- (ii) Layer 2: Sandy clay loam (EBS2); 54% sand, 21% and 25% clay.
- (iii) Layer 3: Sandy clay loam (EBS3); 53% Sand, 17% silt and 31% clay.
- (iv) Mixed soil, M of the above layers samples, sandy clay loam (EBSM), 52%, 21% silt and 27% clay.



Fig.28 : Site of Experimental soil (bin soil)



Fig. 29 : The soil profile of pit and depth of excavate soil



Fig.30 : The heaps of layers of excavated soil

4.2 Determination of the Soil Properties

The physical and chemical properties of the soils considered are reported in this section.

4.2.1 Physical Properties

The physical properties of the soils determined were texture, water content, bulk density, hydraulic conductivity, clay ratio and clay plus silt. The soil samples were air-dried and sieved through 2 mm mesh.

4.2.1.1 Texture

Soil texture was described in terms of the percentage of clay (< 0.002 mm), silt ($0.002 - 0.6$ mm) and sand (0.06 and 2.0 mm). Soil samples were pretreated with hydrogen peroxide (30%v/v) and the size fractions were determined by the pipette method (Day, 1965) after treatment with calgon (sodium hexameta phosphate and sodium carbonate) and ultra sound.

4.2.1.2 Water Content

The soil water content was determined by using the speedy moisture meter and cross-checked by the gravimetric method using the Gallenkamp plus II model oven.

4.2.1.3 Bulk Density

Bulk density of soil both in the field and soil bin was determined using steel core sample method, (Black and Hartge, 1986). The steel core is of 8 cm diameter, 4 cm height similar to that used by Moreno et al. (1997).

4.2.1.4 Hydraulic Conductivity

(a) Laboratory Method

Saturated hydraulic conductivity of the soils were determined in the laboratory using the core permeameter (Klute and Dirksen, 1986). A constant head-core permeameter was used. The core permeameter measures the hydraulic conductivity by allowing one-dimensional water flow through a small column of saturated soil. A constant head of water over the sample is maintained during the measurement. The hydraulic conductivity is determined from the elapsed time and the corresponding volume of water that passed through the sample. The permeameter consists of undisturbed soil samples, 150 mm long polyvinyl chloride pipe of the same diameter as the core, 500 ml beaker, wire mesh, water supply tank and a bucket to collect overflow of water. The permeameter arrangement is shown schematically in Figure 31. In this study, a constant head of 100 mm was maintained all the time on the soil sample. Silicon gel was used to prevent any water leakage from the polyvinyl chloride pipe and the soil sample. Fine mesh of synthetic materials and tissue paper were used to prevent any soil washing out from the bottom of the sample. The wire mesh helped to hold the soil core above the beaker. Before the hydraulic conductivity tests, the soil samples were soaked in water for 24 hours to get the soil fully saturated. Special care was taken so that the soil did not fall out of the sample. The elapsed time for 100, 200, 300 and 400 mm depth of water flow through the soil sample was noted.

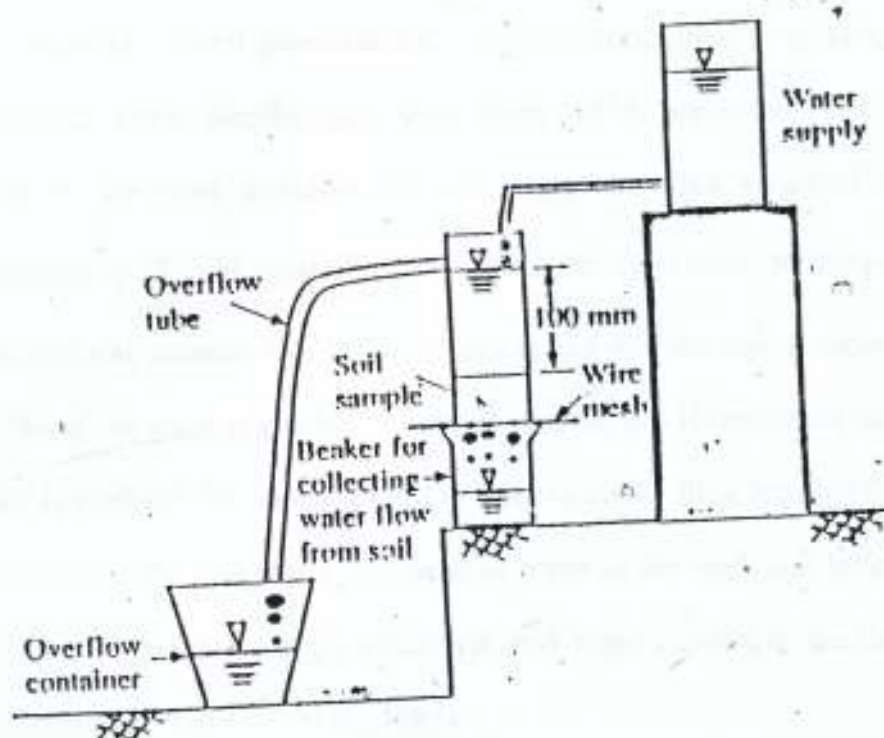


Fig. 31: Laboratory arrangement for measuring saturated hydraulic conductivity with the core permeameter

(b) **Field Method or Guelp Permeameter Method**

The Guelp permeameter (GP) method is one of a group of field procedures variously known as the "Constant head well permeameter", "bore hole permeameter", "well permeameter", "Inverse auger hole", "techniques (e.g. Boersma, 1965; Kessler and Oosterbaan, 1974; Reynolds, 1993). These methods are used primarily for measuring the field saturated hydraulic conductivity (K_{fs}) of unsaturated soil above the water table. In these methods, a cylindrical uncased hole or "well" is augered into the soil, a constant depth or "head" of water is ponded in the well and the soil is monitored until steady flow is attained. The time required to achieve steady flow depends (to varying degrees) on the well radius, the head of water in the well, soil hydraulic and physical properties, and the antecedent soil water content at the time of the measurement (Reynolds et al., 1985).

In the GP method, a Mariotte siphon system is used to pond the constant head of water in the well and measure the flow rate into the soil (Elrick and Reynolds, 1992). Once steady flow has been established, K_{fs} in mm/h can be determined using (Reynolds, 1993; Elrick et al., 1989).

$$K_{fs} = CQ_s / \left[2\pi H^2 + C\pi r^2 + (2\pi H / \alpha^*) \right] \quad (44)$$

where Q_s (mm^3/min) is the steady rate of water flow out of the GP reservoir and into the soil, H (mm) is the steady head of water in the well, a (mm) is the well radius, α^* (mm^{-1}) is a soil texture-structure parameter, and C is a dimensionless shape factor that depends primarily on the H/a ratio. The steady flow rate (Q_s) is usually determined using the relationship (soilmoisture Equipment Corp, 1987).

$$R_i = (\Delta L / \Delta t)_i = R_s = \text{constant}; \quad i \geq 4 \quad (45)$$

and

$$Q_s = R_s A \quad (46)$$

Where

R (mm/min) is the rate of fall of the water level in the GP reservoir (R_i = transient rate, R_s = Constrantrate) A (mm²) is the cross-sectional area of the reservoir, L (mm) is the water level in the reservoir, and t (min) is time. Normally R_i decrease with increasing time and approaches a constant value (R_s) when the flow rate becomes steady (Q_s). Steady flow is usually assumed when R_i is constant (R_s) over four ($i = 4$) consecutive time intervals (Δt) (Soilmoisture Equipment Corp., 1987). The α^* parameter is usually obtained from a table (Reynolds, 1993; Elrick et al., 1989) and the C factor from a graph (Reynolds, 1993; Soilmoisture Equipment Corp., 1987). In this study, $\alpha^* = 0.012/\text{mm}$ was used, which is the recommended value for structured soil (Reyholds, 1993).

4.2.15 Clay Ratio

It is an index for characterizing the strength of soil (Elbanna and Witney, 1986) and is given by the expression.

$$\text{clayratio} = \frac{\% \text{clay}}{\% \text{silt} + \% \text{sand}} \quad (47)$$

4.2.2 Chemical Properties

The chemical properties of the soil considered are: the hydrogen ion concentration (pH), organic carbon and organic matter, nitrogen, phisphorus, the macro-elements and cation exchange capacity.

4.2.2.1 Soil pH

Soil pH was determined in a slurry of 10g soil in a 25 ml deionised water, and in 1N potassium chloride (KCl)

4.2.2.2 Organic Carbon

Organic carbon was determined by wet oxidation using the Walkley-Black method (Walkley, 1947).

- Organic matter – Organic matter content was determined using the wet dichromate oxidation method.

4.2.2.3 Total Nitrogen

Total Nitrogen was determined using the Kjeldahl method.

4.2.2.4 Available Phosphorus

Available phosphorus was extracted by Bray-1 solution and determined using auto analyzer.

4.2.2.5 Macro-Elements (Exchangeable Bases)

Exchangeable bases, Ca, Mg, K and Na were determined by exchange using IM, pH 7, ammonium acetate extract and using atomic absorption (Ca and Mg) and flame emission (K and Na) spectrophotometry.

4.2.2.6 Cation Exchange Capacity

Effective cation exchange capacity was calculated as the sum of exchangeable basic and acidic cations and expressed in cmol/kg.

4.2.2.7 Loss on Ignition

Loss on ignition (LOI) was determined by the loss in mass after ignition at 450°C and expressed as a percentage of oven dry (105°C) soil mass. Donkin (1991) showed that LOI was strongly correlated with organic carbon and clay content, the latter indicating the influenced of structural water.

4.3 Measurement of Soil Parameters

This section reports the methods and materials that were used to measure the soil parameters in this study. The parameter are soil cohesion, cone index, soil compaction, angle of internal friction and angle of soil-interface friction.

4.3.1 Soil Cohesion

Soil cohesion, a parameter of shear strength of soil was measured in this study using three methods.

- (i) Direct shear method using the translational shear box. This involved controlling the shear plane of a small area of a soil and measuring the stresses on that plane (Figure 32). Maximum shear stress, $\tau_{\max}$ is measured for a number of normal stresses σ . These data can be plotted, $\tau_{\max}$ Versus σ , the C and ϕ determined from a straight line fitted to the data.
- (ii) Tri-axial Test methods. Here, known stresses are applied to a soil mass and failure is allowed to occur unrestrained (Figure 33). Two or more soil

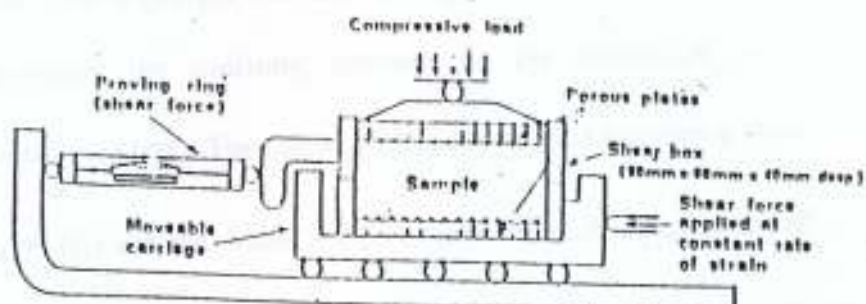


Fig-32: Shear box

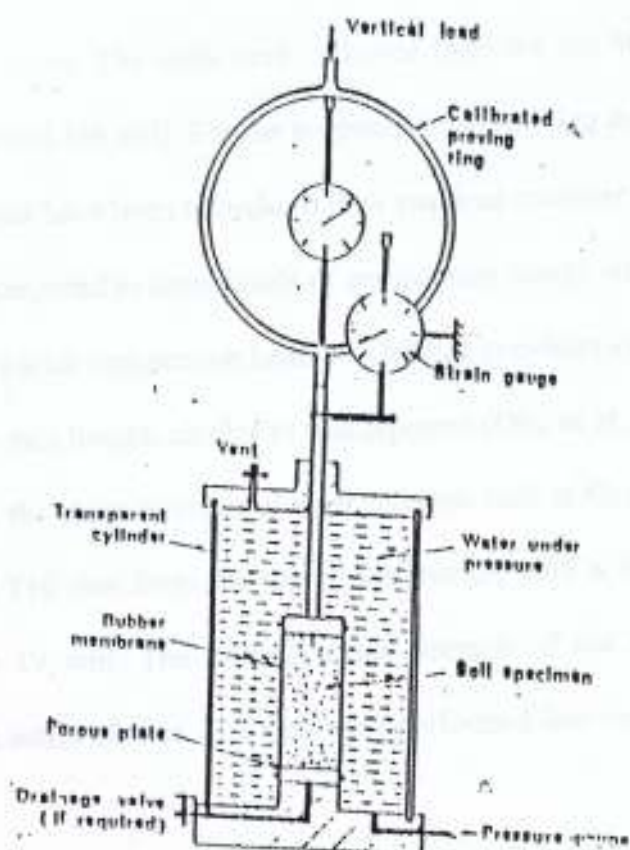


Fig-33: Tri-axial Compression Apparatus

specimens are sheared at different levels of the confining pressure (σ_3) and a series of Mohr's circles that represent two states of stress at failure are determined. C and ϕ are determined from a straight line drawn tangent to the circles. Usually, the test is began by increasing the confining pressure on the cylindrical soil sample to a prescribed stress (even (σ_2)). Then an axial force is applied to cause a shear component σ_1 , ($\sigma_1 > \sigma_2 = \sigma_3$) on the Mohr's circle. Several soil samples tested at various confining pressure (σ_3) must be used to determine the shear failure envelope.

- (iii) Shear Vane method. This is a very simple direct method of measuring cohesion of soil. It was used in the laboratory and insitu on the field.

Laboratory Use: Sample of the soil was brought to the laboratory, air dried and sieved through 2 mm mesh. The soils were collected from the top 40 cm of the soil profile (except for the soil bin soil). For the purpose of determining the strength of the soils after the soils must have been brought to their required moisture content, each of the soil sample was subjected to three levels of compaction energy using 5, 15 and 25 blows of a standard proctor compaction hammer (2.2 kg) in cylindrical moulds of 102 mm diameter by 116 mm height, similar to that reported (Olu et al., 1986). For each level of compaction, the shear strength of each soil was read at five different depths (27, 45, 72, 99 and 116 mm from the top of the mould) with a shear vane device whose vane size is 19 mm. The average shear strength of the soil column was calculated after each series of tests. The tests were performed four times on each soil.

Field Use. The shear vane was used in the field to measure the shear strength of agricultural soils insitu. Measurement were taken mostly at about optimum moisture content for tillage corresponding to friable consistency.

4.3.2 Soil Cone Index

A 30%-cone peetrometer with a base area of 1.28 cm^2 was used for measuring cone index. The penetrometer was a bush recording penetrometer model CP20. Cone insertion rate was between 2.6 – 6.7 mm/s (Tollner and Simonton, 1989). Several readings were recorded in the test field and in the laboratory including the soil bin conditions at each moisture level and mean values were obtained to determine the representative value of rated cone index.

4.3.3 Soil Compaction

The samples were air-dried and ground to pass through a 2 mm sieve. Each soil was wetted to a range of moisture content, consistent with tillage practices, for each sample approximately 2 kg of the air-dry soil was wetted with an atomiser and thoroughly mixed to bring the soil to the desired moisture content. The tray was then placed in a plastic bag and the sample was allowed to equilibrate for 48 hours.

After equillibration, soil samples at each moisture content were placed in an aluminum sleeves, 77 mm in diameter and 50 mm long. Similar to that used by Smith et al. (1997). The cylinders were then placed on a 5 mm pertorated metal base before the soil was added. The cylinders were gently tapped to allow setting of the soil particles. Soil samples in the cylinders were than subjected to applied pressures in the range of 17 kPa to 618 kPa including the static equivalent pressure corresponding to 5, 15 and 25 proctor compaction blows. This pressure was applied by an hydraulic press consisting of an hydraulic ram connected to a piston (Koolen, 1997). A hand pump was used to generate the required pressure on the soil (Figure 34).

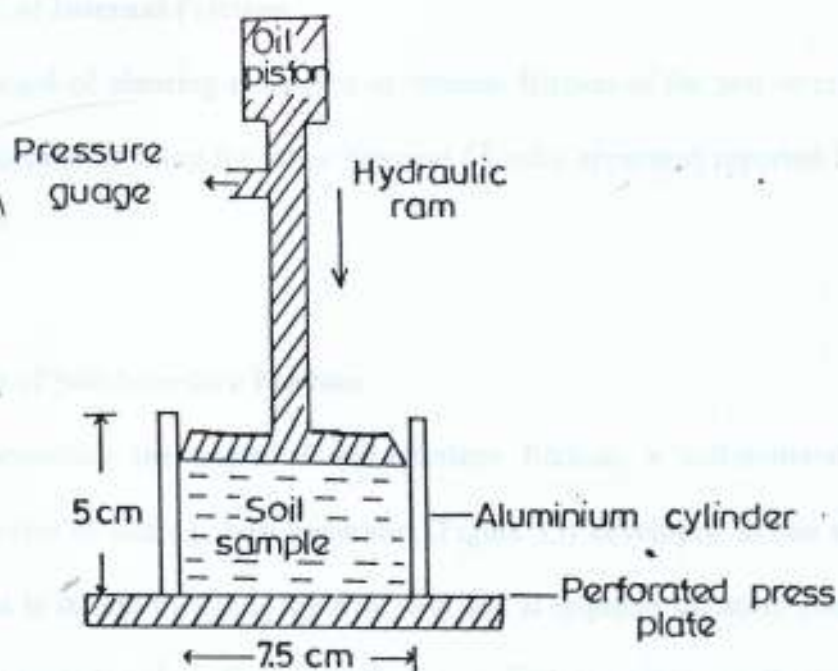


Fig. 34: Uni-axial compression apparatus

The pressure was maintained for a few seconds and then released. The samples were allowed to 'rebound' before final heights were measured. Water and air could escape around the piston and through fine perforations in the base plate. The depression in the soil surface from the rim of the cylinder was measured at three points around the core by using a vernier scale. These measurement were used later to calculate bulk density.

4.3.4 Angle of Internal Friction

The angel of shearing resistance or internal friction of the soil were obtained from the procedure of using the shear box and tri-axial apparatus reported in section 4.3.1 above.

4.3.5 Angle of Soil-Interface Friction

To determine the angle of soil-interface friction, a soil-material friction measuring device or sliding shear apparatus (Figure 35) developed in this study was used. The test is started by filling the tray with soil at required moisture content. The soil was compacted and surface smoothed out. Soil sample were then taken for moisture determination. The slider was then loaded and winched along and the spring balance reading recorded. The test was repeated using different normal loads noting the normal load used and the spring balance reading. Suggested normal loads were 250 g, 500 g, 750 g, 1000 g, 1250 g, the whole process was repeated for the slider with different linning surfaces.

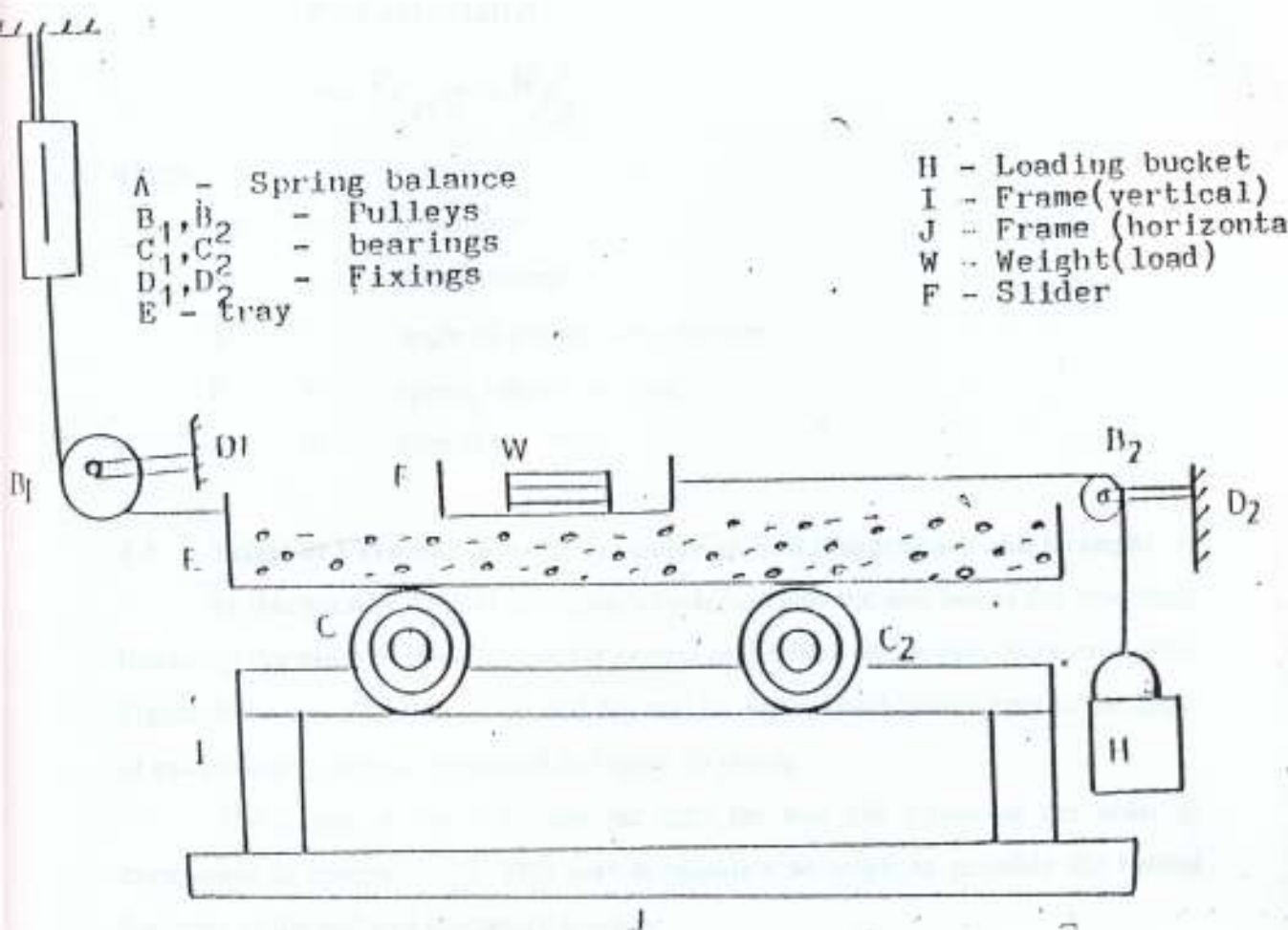


Fig-35 : Schematic diagram of soil-material friction device

A plot of tangential versus normal stress from this data gives the expression.

$$\tau' = Ca + \sigma \tan \delta \quad (48)$$

$$\tau' = F/A, \sigma = W/A \quad (49)$$

where

Ca	=	adhesion
σ	=	normal stress
δ	=	angle of soil interface friction
F	=	spring balance reading
A	=	area of the slider.

4.4 Effect of Variation in Soil Parameter on Soil Disturbance and Draught

In this section the soil had been transferred into the soil bin in the laboratory following the order of the horizons (or layers) in the field where they were excavated. Figure 36 shows a section of the soil bin and its depth which correspond to the depth of excavation of the soil presented in Figure 29 above.

The heaps of the soil were put into the soil bin following the order of excavation in reverse order. This was to simulate as much as possible the natural horizons of the soil in a laboratory soil bin.

After the whole soil have been put into the soil bin, the soil as a whole was allowed to equilibrate for about three days. This was to allow for the normal depth on the field to be achieved as much as possible. It was also wetted to near saturation and also allowed to equilibrate for another three days before any test was carried out on it.

4.4.1 Effect of Moisture Content

Effect of moisture content variation on soil disturbance and draught was studied. Two methods were used to vary the moisture content: by wetting the soil to field capacity and working from there towards drier conditions; secondly by applying sufficient water as may be required for the type of condition envisaged. For each soil preparation for test, time was always given for soil, to equilibrate and the conditions (moisture content, bulk density or cone index) were always taken. In this test, the moisture content of the soil was varied from about 10% (db) to about 22.5% (db).



Fig.36 : Section of the soil bin showing the depth

The tools tested are T1, T5 and T20 whose dimension have been stated in section 3.5.1. There were two sets of tests (or treatments). Two rake angles 45° and 90° were used. The forward speed was held constant at 1.0 m/s, depth was also held constant at 150 mm. The average penetration resistance of the soil was about 680 kPa. At least three replicates were made for each test run, and the mean values obtained. The draught for these tines were observed. The soil disturbance and the parameter of it were also observed and recorded. Draught was measured by a spring dynamometer or load cell earlier mentioned in section 3.4.2. The soil disturbance was observed by a profilometer and a steel rule. The results are discussed in section 5.5.1. Time of travel and distance were measured by stop watch and tape respectively and speed was calculated.

4.4.2 Effect of Compaction

Effect of compaction was produced in terms of the penetration resistance of the soil (or cone index). The increase in compaction or cone index was generated by the number of passes of the compaction roller on the surface of the soil bin. Two sets of tests were performed. The same tools T1, T5 and T20 were used. Rake angles used were 45° and 90° , speed was held constant at 1.0 m/s, depth was also held constant at 150 mm. The cone index ranged between 220 to 810 kPa. The moisture content was about 11.5% (db). Draught measurements were taken and soil disturbance observed and measured.

The results are presented and discussed in section 5.5.2. Figure 37 shows author measuring penetration resistance of soil in the soil bin with a bush recording penetrometer.



Fig.37 : Measuring penetration resistance of bin soil
with bush recording penetrometer

4.5 Effect of Variation in Implement Parameters on Soil Disturbance and Draught

In this section, test were carried out to see the effect of variation in implement parameters on soil disturbance and draught. The implement parameters are dimension, shape, surface finish and cutting edge thickness. The implements considered in there test were tines, varying from very narrow tines, 10 mm to wide tines, 200 mm and blades discussed in section 3.5.2.

In each case the implement was attached to the tool bar and the latter to the tool carriage subframe of the tool carriage. During the test the whole arrangement was winched along the soil bin

4.5.1 Effect of Dimension of Implement

The implement used in these tests were mainly tines (very narrow tines to wide tines). Two sets of tests were carried out to study the effect of variation in implement dimension on soil disturbance and draught. In each of the two sets of tests, depth was held constant at 35 mm and the 70 mm. Speed was varied at three levels, V_1 , V_2 and V_3 which were 0.28, 1.0 and 2.5 ms respectively. The widths of the tines tested were 10, 20, 31, 40, 51, 88, 126, 163 and 200 mm. The penetration resistance (cone index) of the soil ranged from 400 to 600 kPa. Observation were made of draught of the tools. Soil disturbance was also observed and measured. The result of these test were analysed and presented in section 5.6.1.

4.5.2 Effect of Shape of Implement

Tests were carried out to study the effect of variation in shape of implement on soil disturbance and draught. The shapes tested are wide tine. (TWT), and the flowing

blades: concave (BCC), semi circular (BSC), convex (BCV), triangular (BTR) and Vee (BVE) earlier discussed in section 3.5.2. All the blades or implements in the tests have the same width, 200 mm. An experimental set up for the BVE tool is presented in Figure 38.

Four sets of tests (treatment) were carried out. In all the tests, the mean moisture content was about 11.5% (db), the rake angle was held constant at 45° , the cone index ranged from 500 to 700 kPa. The four levels of depth tested were 35, 70, 150 and 250 mm. Speed was varied from about 0.14 m/s to 2.5 m/s. Draught was observed for tillage tools and soil disturbance was also observed. The results are presented in section 5.6.2.

4.5.3 Effect of Surface Finish of Implement

In this tests the effect of surface finish on soil disturbance and draught were studied. There were two sets of tests carried out. The surface finishes were clean steel surface (SCS), rusted steel surface (SRC) and Teflon coated steel surface (STS). The implements used here were tines of dimension 100 x 73. For the STS, Teflon sheet was used as a liner on the tine bonded to it by an adhesive material (JB weld). Depth of operation was held constant at 35 and 70 mm. Rate angle was held constant at 45° for each test. The draught of the implement was observed as the speed was varied from 0.14 m/s to 2.5 m/s. The soil disturbance were also monitored and measured. The results are presented in section 5.6.3.



Fig. 38 : Tool carriage set up for measuring draught of tillage tools

4.5.4 Effect of Cutting Edge Thickness of Implement

Tines of the dimensions of T1, T5 and T20 were prepared for these tests. Each group of tine has the following cutting edge thicknesses: 1, 3, 5, 7 and 8 mm. Two treatments (sets of tests) were carried out to study soil disturbance and draught. In each of the two sets of tests, the depth of operation was made constant at 150 mm. The rake angle was also made held constant at 45° . The speed was varied at two levels: that is, 1 m/s in one and 2.5 m/s. The range of penetration resistance was 500 to 700 kPa. Draught of tools was observed with variation in cutting edge thickness. Soil disturbance was also studied. The results are presented in section 5.6.4.

4.6 Effect of Variation in Operational Parameters on Soil Disturbance and Draught

In this section tests were carried out to study the effect of operational parameters (Depth, forward speed and rake angle) on soil disturbance and draught of tools. The implements used in these were tines (T1, T5 and T20).

4.6.1 Effect of Depth of Operation

Three sets of tests were conducted in this section in which the depth of operation was varied from 35 to 250 mm. Three levels of speed were tested, that is V_1 (0.28 m/s), V_2 (1.0 m/s) and V_3 2.5 m/s). The implements tested were tines, that is, T1 T5 and T20. Values of draught were observed as the implements moved or worked through the soil. Soil disturbance pattern was also observed and measured. The results were analysed and presented in section 5.7.1

4.6.2 Effect of Forward Speed

Two sets of tests were conducted to study the effect of forward speed on soil disturbance and draught. The implements tested were tines T1, T5 and T20. Moisture content was averaged 11.5% db. Depth was held constant at 150 mm in each case of the sets of tests. The rake angle was held 45° for one set and 90° for the other set of tests. The penetration resistance averaged about 600 kPa. Draught was observed with each tool as the forward speed increased from 0.14 to 2.5 m/s. Soil disturbance was also observed and studied. The results were analysed presented and discussed in section 5.7

4.6.3 Effect of Rake Angle

Three sets of test were carried out to supply the effect of rake angle on soil disturbance and draught. For each set of tests depth was held constant. The constant depths of operation were 50, 100 and 200 mm. The implements tested were tines, that is, T1, T5 and T20. The average moisture content during the experiments was 11.5% (db). Penetration resistance of the soil ranged from 500 to 700 kPa with a mean of about 650 kPa.

Draught was observed from each tool as the rake angle varied in the tests from 30° to 90° . The soil disturbance were also observed and studied. The data collected were analysed, presented and discussed in section 5.7.3.

5. RESULTS AND DISCUSSION

The results of this research project arising from chapters three and four of this thesis are hereby presented and discussed in this chapter.

5.1 Performance of Soil Bin and Equipment

The performance of the soil bin and equipment has been assessed for about two years for which they have been put to use.

5.1.1 Performance of Soil Bin

The soil bin developed for this study is shown in Figure 39. Its full length is 9.0 m. The minimum length of processed soil for each test is dependent upon the forward speed. A length of between 2.5 and 3.0 m has been found satisfactory for speeds up to 1.6 m/s. Additional lengths of bin wall are required for running the tool carriage up to speed and holding section for the soil prior to re-processing.

With a bin width of 0.85 m and manually preparing a 2.5 m section of sandy clay loam to a depth of about 0.3 m, one man can perform 30 test/day with soil in the uncompacted state, that is, light digging of disturbed soil and leveling. For more compact conditions, that is, soil re-processing, leveling and moderate compaction, a 2 – man team can conduct tests and reprocess soil four times in an 8-hour working day.

With the width of this bin, multiple tests (with narrow tines) can be conducted for each soil preparation. Similarly two 200 mm wide blades tests may be achieved with the 0.85 m spacing between the walls.

In the last two years of use of the soil bin, the structure remained functional without any misalignment, sagging of railings nor buckling of side walls. The wooden wall were also in good functional condition.

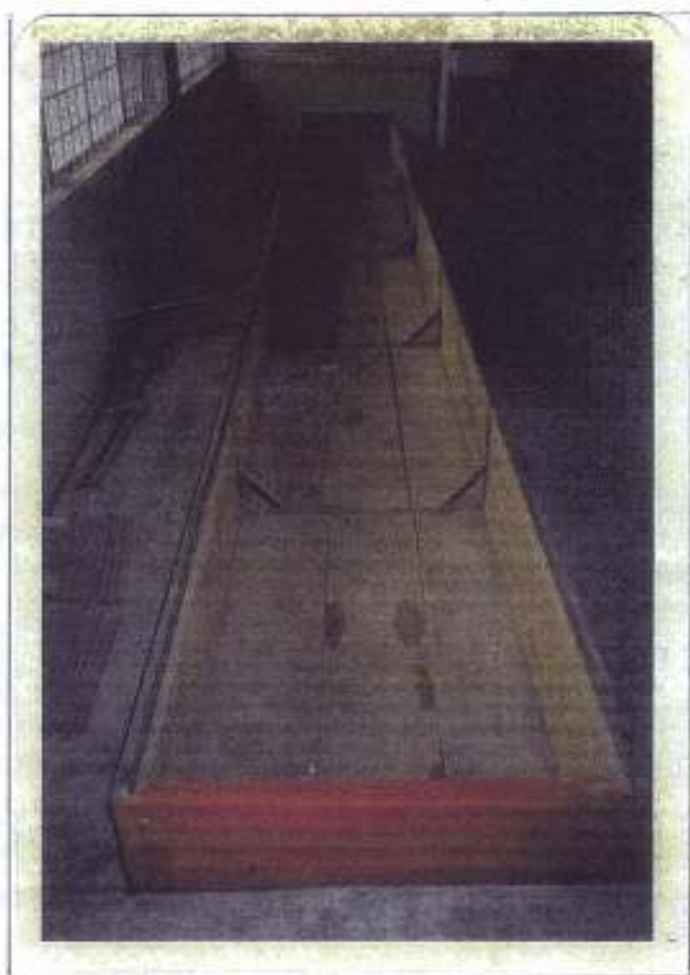


Fig.39 ; The full length soil bin

5.1.2 Performance of Equipment

The performance of equipment for soil tillage dynamics is presented in this section. The equipment consists of:

- The soil processing trolley-compaction roller and leveling board
- The tool carriage
- The tool bar
- The fixed-angle tool carriage subframe

5.1.2.1 The Soil Processing Trolley

The soil processing trolley consisting of the trolley mainframe, the compaction roller and levelling board is shown in Figure 40. After about two years of use the soil processing trolley continued to be functional. No parts were damaged, repaired nor replaced. With the empty compaction roller drum of 16 kg weight and 16 ballast rods (equal to 59 kg), the roller is able to furnish a compaction load of 150 kg/m. This is a standard roller weight and it agrees with that reported by Aboaba (1969). The ease of assembling and dismantling makes its maintenance very easy and troubles-free. During compaction process, the levelling board is raised and its weight is supported by the mainframe of the soil processing roller thereby not affecting the weight of the compaction roller.



Fig. 40 : The processing trolley, compaction roller and levelling board

5.1.2.2 The Tool Carriage

The tool carriage is also a product developed for this study. It is shown in Figure 41. It has been versatile, rugged and trouble-free. It is easy to assemble and disassemble. In the two years of use, it has not malfunctioned nor broken down. It is almost maintenance-free. The noise level of the Teflon wheels on steel rails was low and therefore not irritating. The Teflon wheel which run on flat rails appears to be an improved design over that where the soil processing trolley and tool carriage trolley were mounted on "V"-groove pulleys the type reported by Soomro et al. (1982) and Guptya and Surrendranath (1989).

5.1.2.3 The Tool Bar

The tool bar is a device that holds the tool by fastening with bolts and nuts. It is shown in Figure 42, with the semi-circular blade fastened to it. The design of the tool bar is such that it is made functional with the variable-angle tool carriage subframe and also with the fixed-angle tool carriage subframe. The tool bar was fabricated from angle iron bar. It is maintenance free and portable. It has a mate which it will lap in order to function with the variable-angle tool carriage subframe, and can then be rotated in the vertical plant. However, when it worked with the fixed-angle tool carriage subframe, it had to be in upright position always.

5.1.2.4 The Fixed-Angle Tool Carriage Subframe

The fixed-angle tool carriage subframes are shown in Figure 43. They are also some of the items of equipment of this project. They are versatile, rugged, portable and almost maintenance free. They are not heavy 1.5 to 2.0 kg, yet very strong to perform its functions. They can be used to generate rake angle ranging from acute angle to obtuse angle.



Fig. 41 : The tool carriage with some accessories .



Fig. 42 : The tool bar



Fig. 43 : The fixed-angle tool carriage subframes

5.1.2.5 The Soil Tillage Dynamics Equipment

The soil tillage dynamics equipment discussed above are presented in a working condition or arrangement as shown in Figure 44. In this plate, the soil processing trolley and its accessories, the tool carriage and accessories (including the load meter) are all set inside the soil bin. The soil processing trolley has behind the tool carriage. The rope for hauling the equipment is also visible on top of the soil in the soil bin.

Judging from about two years of operation of these items of equipment, it can be said that the performance has been very satisfactory. Also, hope has been raised that subsequent development would lead us to larger soil bin facilities where full size implement could be tested and/or evaluated for their performance.

5.2 Physical Properties of the Soils

The physical properties of the soils in this study are presented in Table 10. The sandy soil (coarse textured soil) tested was a loamy sand soil. Its mean bulk density was 1.56 Mg/m^3 with a standard deviation of 0.1 Mg/m^3 . Its clay ratio and saturate hydraulic conductivity are 13.6 and 5.3 mm/min respectively.

The clay soil tested are sandy clay (EWA), clay (EO) and another clay (EC). Their bulk densities are not significantly different at 5% level of significance. Similarly the bulk densities of the sandy loam soils are not significantly different, although their clay ratios differ numerically.

The properties of the three horizons of the sandy clay loam (bin soil) are also presented in Table 10. The textural fractions of the first two horizons (or layers) are the same numerically. Although not shown on the Table, the thickness of the first and second layer were 8 and 15 cm respectively. The third and lowest layer had the largest thickness but only 15 cm of it was cut to provide the necessary depth inside the soil bin. The mean bulk densities of the three layers were not significantly different of 5% level of significance. The saturated hydraulic conductivity of the bottom layer was smaller (0.85 mm/min) than for the other two layers above it. This is probably due to its higher value of clay ratio, that is 44.

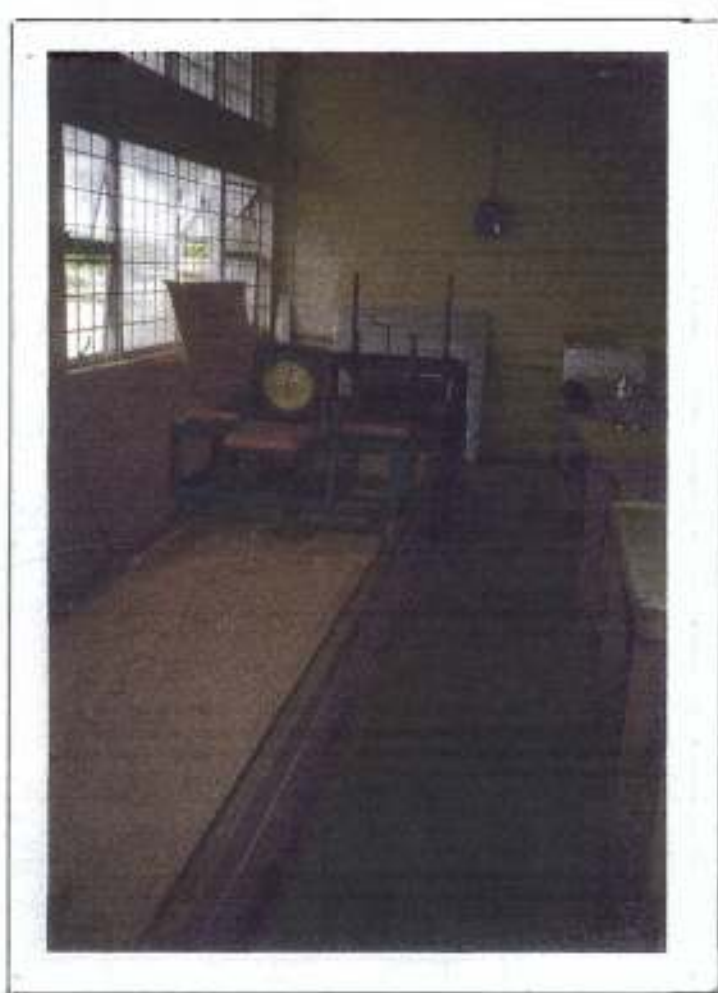


Fig. 44 : The soil tillage dynamics equipment

Table 10: Physical Properties of the Soils

Soil type	Texture			Bulk density Mg/m ³	Sat. hyd. Cond. mm/min	Clay ratio %	Clay + silt %	LOI %
	Sand %	Silt %	Clay %					
Loamy Sand (IGLS)	85	3	12	1.56	5.3	13.6	15	1.12
Sandy Clay (EWA)	47	13	40	1.2	0.02	66.7	53	1.78
Clay (E O)	40	14	46	1.09	0.015	85.2	60	2.22
Clay (EC)	32	17	51	1.03	0.012	104.0	68	2.43
Sandy Loam (EWV)	77	13	10	1.42	0.92	11.1	23	2.91
Sandry Loam (EBI)	70	24	6	1.35	0.47	6.4	30	3.87
Sandy Loam (EH3)	56	30	14	0.38	0.38	16.2	44	4.31
Sandy clay loam (EBS1)	54	21	25	1.43	1.21	33.3	46	3.98
Sandy clay loam (EBS2)	54	21	25	1.55	1.22	33.3	46	3.12
Sandy loam (EBS3)	52	17	31	1.39	0.85	44.9	48	3.58

5.3 Chemical Properties of the Soils

The chemical properties of the soil in this research project are presented in Table 11. Value of organic carbon ranged from 0.13 to 2.1% w/w. It was highest in the sandy loams and least in the clay soils. The value of organic carbon decreased from 1.4 in the top layer to 0.87% w/w in the bottom layer of the soil bin soil of sandy clay loam.

Table 11: Chemical Properties of the Soil

Soil type	PH	Chemical composition meg/100g				Organic carbon % w/w	N %l w/w	Available P (ppm)	CEC mg/100g
		Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺				
Loamy Sand (IGLS)	6.1	1.1	1.3	0.35	0.19	0.7	0.12	4.21	2.81
Sandy Clay (EWA)	6.1	1.3	1.1	0.31	0.20	0.5	0.16	3.62	4.67
Clay (E O)	6.3	2.1	1.3	0.29	0.23	0.3	0.13	4.63	4.25
Clay (EC)	6.7	1.6	1.2	0.37	0.18	0.4	0.15	3.92	3.23
Sandy Loan (EWV)	5.9	1.7	1.1	0.24	0.22	1.6	0.21	2.96	3.41
Sandry Loam (EBI)	6.1	0.9	1.4	0.31	0.17	1.4	0.19	3.12	4.22
Sandy Loam (EH3)	6.4	1.4	1.0	0.29	0.19	2.1	0.31	5.17	5.72
Sandy clay loam (EBS1)	6.12	1.90	0.80	0.11	0.08	1.41	0.14	2.54	3.98
Sandy clay loam (EBS2)	6.37	1.30	1.00	0.08	0.07	1.22	0.15	1.70	3.12
Sandy clay loam (EBS3)	6.56	1.00	1.00	0.05	0.07	0.87	0.13	0.85	3.53

5.4 Soil Parameters

The results of the measured values of the soil parameters are presented in this section.

5.4.1 Soil Cohesion

Cohesion, a measure of the shear strength of soils has been measured using the direct shear box and triaxial test apparatus. Mean values and standard deviations for the soils in this study are presented in Table 12. From these values, it is seen that the two methods given comparable values of cohesion for loamy sand, clay soils, sandy loams and sandy clay loams. Moreover, cohesion values are greatest in clay soils and lowest in loamy sand. This is expected since cohesion increase with the amount of clay fractions in the soil (Johunson et al., 1987; Chen et al., 1998). The purpose, need and use of shear measurement data must be kept in mind when choosing a method and apparatus for shear measurement in agricultural soil. All direct shear apparatus involve soil-machine interaction and so the shear response measured is at best on soil-machine relationship that is dependent on both the soil and the apparatus. The range of cohesion for the sandy clay loam bin soil in this study is 23.0 to 30.06 kPa. These values agree well with those reported for similar soils by Stafford (1979, 1984).

Table 12: Mean Values obtained for Cohesion of Experimental Soils

Soil Type	Moisture content (% db)	Dry density (Mg/m ³)	Cohesion	
			Direct Shear (kPa)	Triaxial (kPa)
Loamy Sand (IGLS)	4.5 (0.3)	1.56 (0.1)	1.67 (0.2)	1.62 (0.3)
Sandy Clay (EWA)	18.3 (0.3)	1.21 (0.09)	35.2 (1.21)	36.6 (1.2)
Clay (E O)	19.5 (0.1)	1.09 (0.7)	38.6 (1.21)	39.2 (1.3)
Clay (EC)	20.1 (0.3)	1.03 (0.08)	44.2 (0.96)	43.6 (0.9)
Sandy Loam (EWV)	9.2 (0.1)	1.42 (0.15)	11.6 (1.1)	10. (1.3)
Sandry Loam (EBI)	10.4 (0.2)	1.35 (0.19)	12.7 (0.9)	13.2 (0.9)
Sandy Loam (EH3)	14.6 (0.2)	1.39 (0.20)	14.3 (0.7)	15.6 (1.0)
Sandy clay loam (EBS1)	11.5 (0.7)	1.43 (0.13)	23.6 (1.5)	23.0 (1.3)
Sandy clay loam (EBS2)	11.6 (0.8)	1.55 (0.19)	24.5 (1.3)	25.6 (1.0)
Sandy clay loam (EBS3)	11.6 (0.9)	1.39 (0.200)	29.7 (1.2)	30.6 (1.2)

() Value in parenthesis is standard error.

5.4.2 Soil Cone Index

Mean soil penetration resistance or cone index of the experimental soils are presented in Table 13. These values are representative values from the field with their corresponding bulk densities and corresponding moisture contents in the range of friable consistency.

This data shows that cone index is highest in fine textured soils like loamy sand. The values cone indices reported here agree well with those reported by Perumpral (1987) under similar conditions.

Table 13: Mean Values Obtained for Cone Index of Experimental Soils.

Soil Type	Moisture contents, (%, db)	Dry density (Mg/m ³)	Cone Index (kPa)
Loamy Sand (IGLS)	4.5 (0.3)	1.56 (0.1)	130 (12)
Sandy Clay (EWA)	18.3 (0.3)	1.21 (0.00)	870 (30)
Clay (E O)	19.5 (0.1)	1.09 (0.07)	930 (27)
Clay (EC)	20.1 (0.3)	1.03 (0.08)	1340 (43)
Sandy Loan (EWV)	9.2 (0.1)	1.42 (0.15)	752 (13)
Sandry Loam (EBI)	10.4 (0.1)	1.35 (0.19)	833 (16)
Sandy Loam (EH3)	14.6 (0.2)	1.39 (0.20)	870 (17)

() values in parenthesis are standard errors

5.4.3 Compaction of Agricultural Soil

The effect of soil compaction on crop productivity cannot be over-emphasized. To this end relevant information or data are desired to be able to assess the compaction behaviour of soil under load. In this section are reported

- Effect of applied pressured, moisture content on soil compaction of the soils in this study
- Effect of applied pressure on bulk density of the soils.
- The effect of compaction on cohesion and cone index of the soils

It should be noted that the applied pressures of 175, 404 and 618 kPa were calibrated to be statically equivalent to 5, 15 and 25 proctor hammer blows. It is also note worthy that this agrees with the calibration reported by Ohu et al. (1986) for the same applied pressures.

5.4.3.1 Effect of Moisture Content and Applied Pressure on Compaction of Sandy Soil

The sandy soil reported here is the loamy sand (IGLS). Figure 45 shows the effect of the applied pressure, moisture content on soil compaction of loamy sand. The figure is presented in 3-dimension. Three moisture regimes were considered, that is, dry, moist and wet. The percentage increase in compaction was defined as increase in bulk density over initial bulk density (Smith et al., 1985). The moisture content corresponding to the dry, moist and wet conditions were 0.01, 1.6 and 10.4% (db). The analysis show that loamy sand achieves higher bulk densities when it is approaching saturation, but this is a feature of the unique particle rearrangement of sands with changing water content rather than the effect of an applied pressure at intermediate water contents. Panayiotopoulos and Mullins (1985) found that air dry and nearly saturated sands always packed more closely under a given load than at intermediate water content and suggested this was related to annular bridges being formed between sand particles which act like elastic bonds when the soil is moist but are lost when the soil is saturated or air-dry and hence the soil at these two extremes collapses.



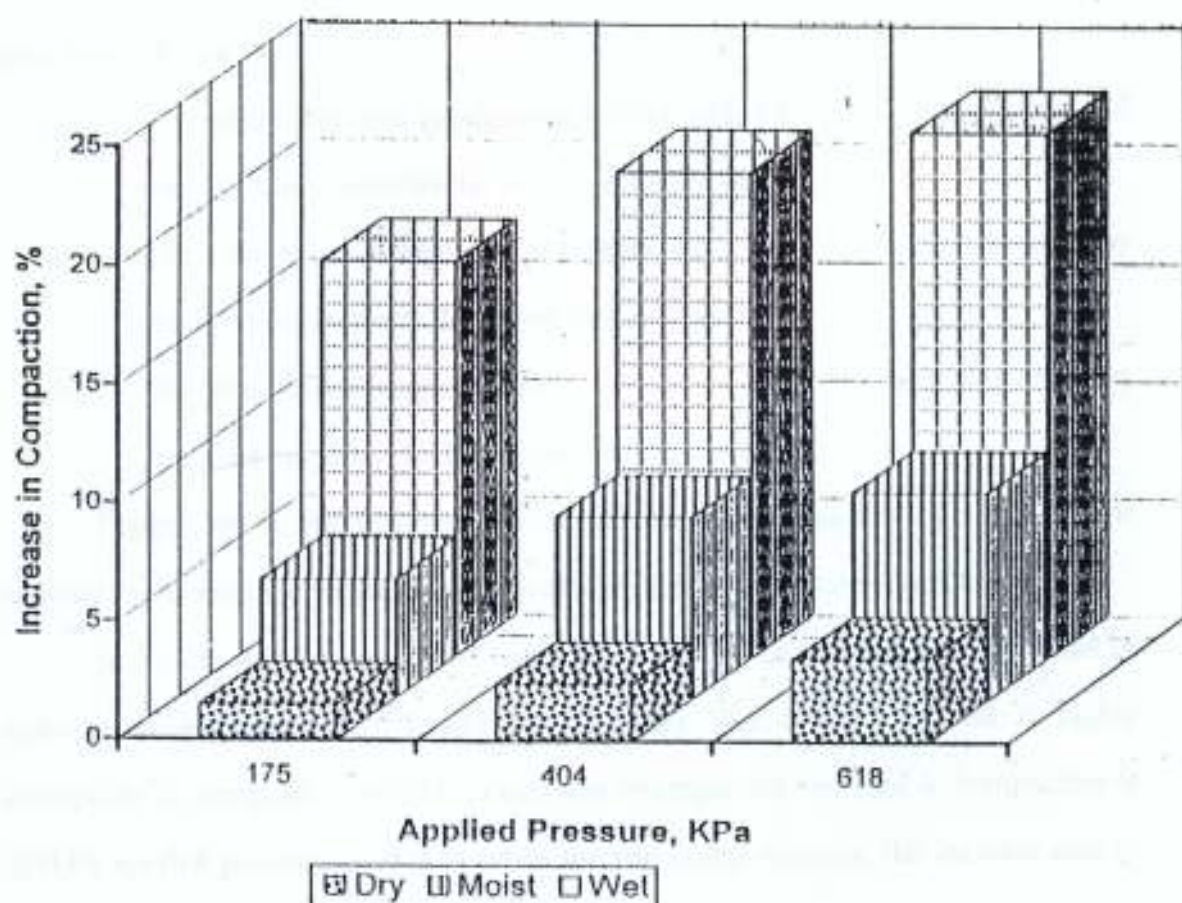


Fig.45:Effect of applied pressure, moisture content on soil compaction for loamy sand soil (85, 03, 12)

5.4.3.2 Effect of Moisture Content and Applied Pressure on Compaction of Clay Soil

Effect of moisture content and applied pressure on compaction were tested for three types of clay soils:

- (i) The sandy clay soil (designated EWA) with 47, 13, 40 % sand, silt and clay fractions respectively, shown in Figure 46.
- (ii) The clay soil (designated EO) with 40, 14, 45 % sand, silt and clay fractions respectively. It is presented in Figure 47.
- (iii) The clay soil (designated EC) with 32, 17, 51 % sand, silt and clay fractions respectively. It is shown in Figure 48.

Figures 46 to 48 therefore show increase in compaction of clay (or fine textured) soils with the variation of applied pressure and moisture content.

In Figure 46, the dry, moist and wet conditions of the clay soil, in terms of moisture content are 2.1, 5.2 and 10.1 % (db). The sandy clay soil is highly susceptible to compaction when it is wet. For example, the increase in compaction at 404kPa applied pressure is 18.3 % when the soil is dry whereas, the increase rose to about 84% when wet at the same pressure.

In Figure 47, the clay soil conditions of dry, moist and wet correspond to 1.3, 6.8 and 10.6% (db) of moisture content. This soil is also highly susceptible to compaction. For example applying a pressure of 400 kPa when the soil dry, moist and wet result in an increase in compaction of 18.2, 50.5 and 83.9 % respectively.

In Figure 48, the dry, moist and wet conditions of the clay soil in terms of moisture content are 3.7, 5.7 and 12.8 % (db). The soil is also highly susceptible to compaction. For example at an applied pressure of about 404 kPa, the increase in compaction in the dry, moist and wet conditions are 33.3, 41.3 and 93.8 % respectively.

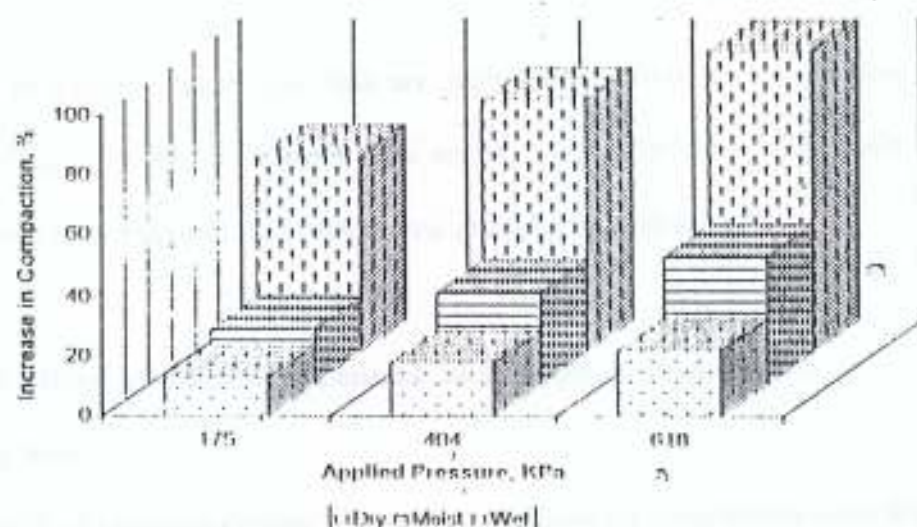


Fig 46 Effect of applied pressure, moisture content on soil compaction for Sandy Clay soil (47, 13, 40)

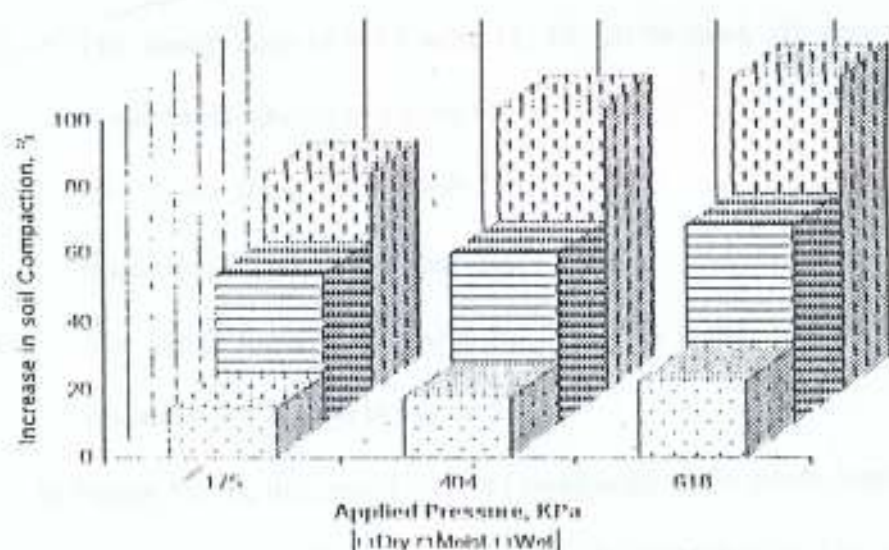


Fig 47 Effect of applied pressure, moisture content on soil compaction for Clay Soil (40, 14, 46)

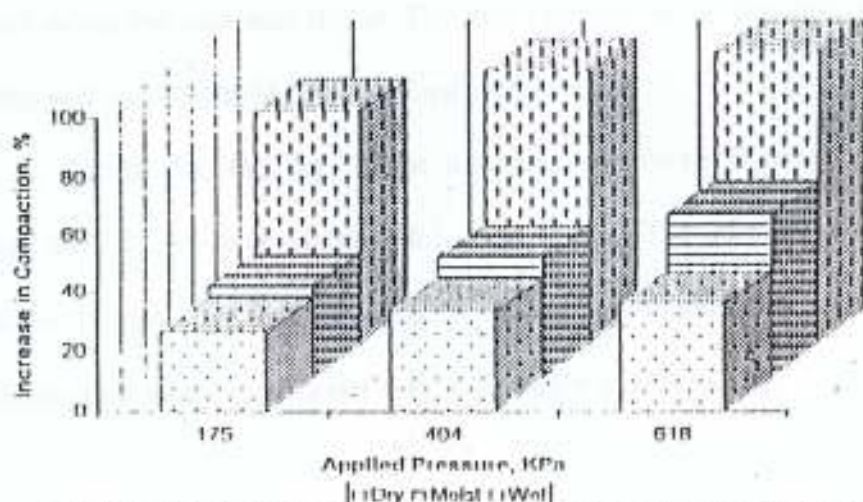


Fig 48 Effect of applied pressure, moisture content on soil compaction for Clay Soil (32, 17, 51)

In general, these clay soil are highly susceptible to compaction especially when their consistency changes from moist to wet. Therefore clay soils should be trafficked in dry periods and with as low ground pressure as possible.

5.4.3.3 Effect of Moisture Content and Applied Pressure on Compaction of Loamy Soil

Effect of moisture content and applied pressure on compaction were tested for the three types of sandy loam soils.

- (i) The sandy loam (EWV) with 77, 13, 10 % sand, silt and clay fractions respectively, shown in Figure 49
- (ii) The sandy loam (EB1) with 70, 24, 6 % sand, silt and clay fractions respectively, shown in Figure 50.
- (iii) The sandy loam (EH3) with 56, 30 14 % (sand, silt and clay fractions respectively), shown in Figure 51.

In Figure 49, the dry, moist and wet conditions of the sandy loam soil, interms of moisture content are 2.0, 5.6 and 10.6% (db) repectively. The minimum and maximum increase in compaction are 4.8 and 37.4 % respectively. The minimum occurred when the soil was dry at 175 kPa pressure while the maximum occurred when the soil was wet at 681 kPa applied pressure.

In Figure 50, the dry, moist and wet conditions correspond to moisture contents of 2.0, 5.0 and 10.0% (db) respectively. The minimum and maximum increase in compaction corresponding to dry and wet conditions are 8.8 and 50.0 %. This means that sandy loam is not very susceptible to compaction.

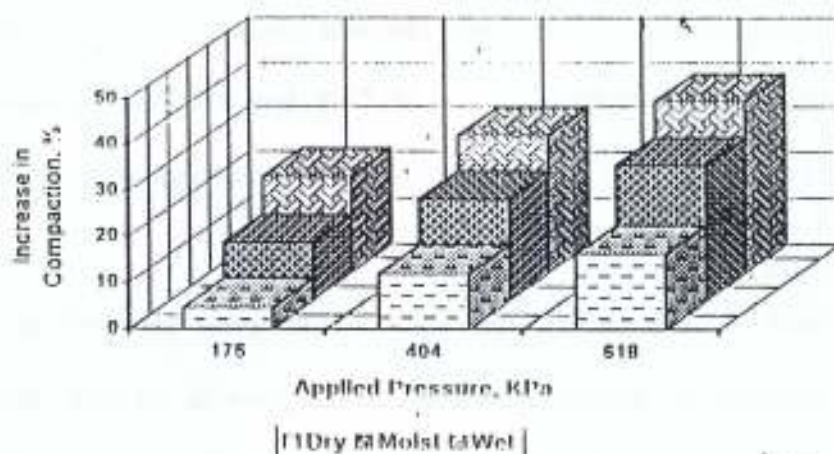


Fig49 Effect of applied pressure, moisture content on soil compaction for sandy loam soil (77, 13, 10)

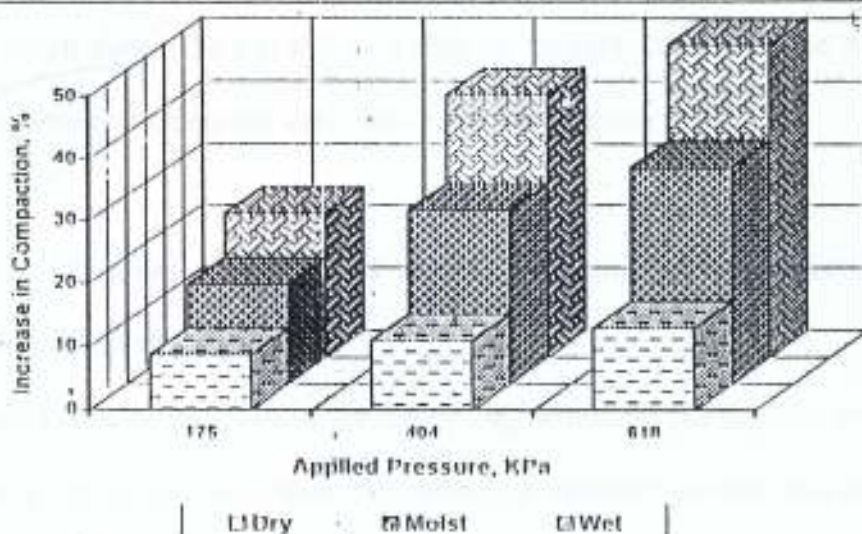


Fig50 Effect of applied pressure, moisture content on soil compaction for sandy loam soil (70, 24, 6)

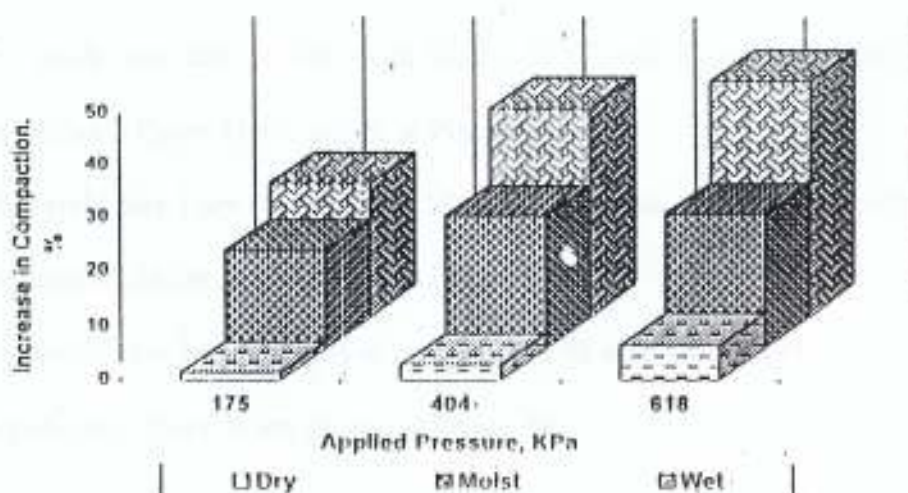


Fig51 Effect of applied pressure, moisture content on soil compaction for sandy loam soil (56, 30, 14)

In Figure 51, the dry, moist and wet conditions of the soil correspond to moisture contents of 2.2, 4.9 and 10.7 % (db) respectively. The minimum and maximum increase in compaction corresponding to dry and wet conditions are 1.5 and 44.0 %.

Generally, from the compaction characteristics of these sandy loam soils, it can be said that; increase in compaction are less dependent on moisture content. Increase in soil compaction are almost entirely due to applied pressure through these are not high neither. Therefore as sandy loam are water content, insensitive, there is unlikely to be much danger as a result of traffic on agricultural soil of the type of sandy loam. The observation agrees well with the report of Smith (1997).

5.4.3.4 Effect of Moisture Content and Applied Pressure on Compaction of Sandy Clay Loam (Soil Bin Soil)

The three layers or horizons of the sandy clay loam soil put into the soil bin were subjected to uni-axial compaction. The effect of moisture content and applied pressure on the compaction of the three samples of the layers are presented in this section.

- (i) The sandy clay loam (EBS1) with 54, 21, 25 % sand, silt and clay fractions respectively (layer 1) are shown in Figure 52.
- (ii) The sandy clay loam (EBS2) with 54, 21, 25 % sand, silt and clay fractions respectively (layer 2) are shown in Figure 53
- (iii) The sandy clay loam (EBS3) with 52, 17, 31 % sand, silt and clay fractions respectively (layer 3) are shown in Figure 54

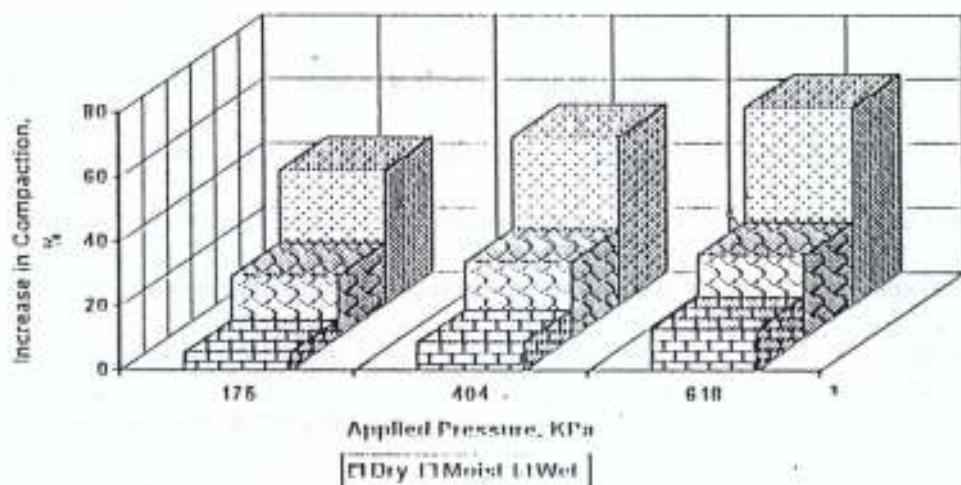


Fig52: Effect of applied pressure and moisture content on soil compaction for sandy clay loam soil (54, 21, 25)

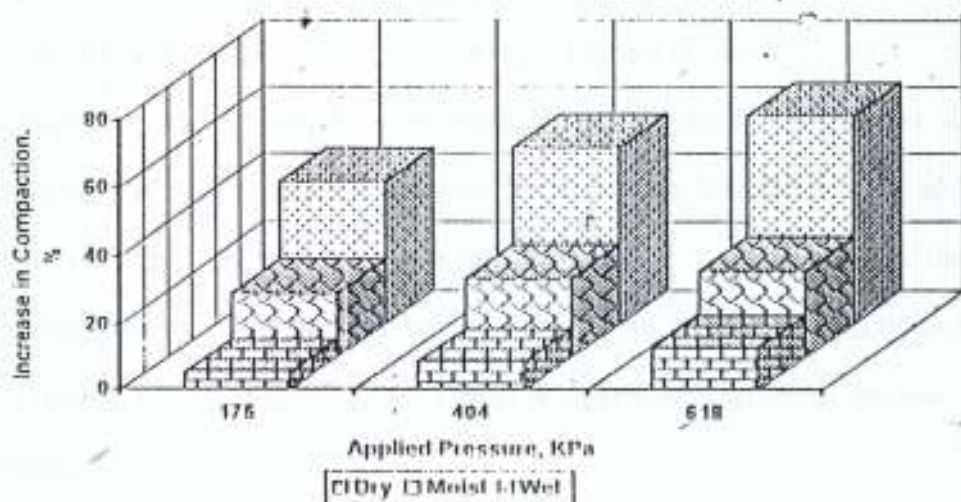


Fig53 Effect of applied pressure and moisture content on soil compaction for sandy clay loam soil (54, 21, 25)

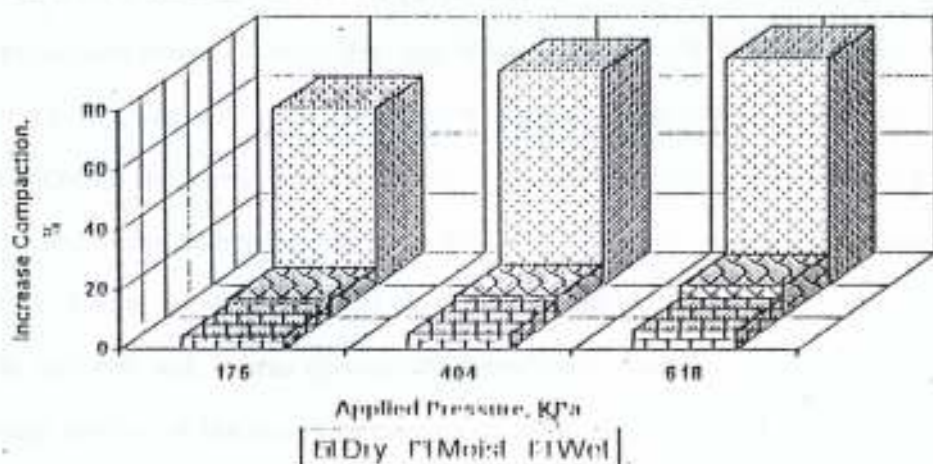


Fig-54 Effect of applied pressure, moisture content on soil compaction for sandy clay loam soil (52, 17, 31)

In Figure 52, the dry, moist and wet conditions correspond to moisture contents of 1.6, 4.7 and 10.4 % (db) respectively. The minimum and maximum increase in compaction are 5.5 and 61.5 % respectively. The minimum occurred when the soil was in dry condition and at applied pressure of 175 kPa. The maximum occurred when the soil was wet and applied pressure of 618 kPa. When the soil was moist (at moisture content, 4.7% (db) and applied pressure of 404 kPa, the increase in compaction was 23.6%. the soil seems to be very sensitive to water content at the time of compaction. The effect or influence of pressure on compaction was not too high.

In Figure 53, the dry, moist and wet conditions correspond to moisture contents of 2.2, 5.1 and 10.2 % (db) respectively. The minimum and maximum increase in compaction are 3.9 and 53.6 % respectively. The minimum increase in compaction was for soil in dry condition whereas the maximum increase was for soil in the wet condition. When the soil was moist and at applied pressure of 404 kPa, the increase in compaction was 25.0 %. This analysis also shows that the compaction of the soil in this layer is water sensitive and to a large extent less sensitive to influence of applied pressure.

In Figure 54, the dry, moist and wet conditions correspond to moisture contents of 2.3, 5.5 and 12.9 % (db) respectively. The minimum and maximum increase in compaction achieved with this soil were 4.5 and 76.9 %. The minimum occurred when the soil was in dry condition and at applied pressure of 175 kPa, while the maximum occurred in the wet condition and at applied pressure of 618 kPa. In the moist condition and under an applied pressure of 404 kPa, the increase in compaction was only 7.2 %. From the foregoing of the compaction of the soil of the three horizons of the soil bin soil, it was obvious that sandy clay loam soils are extremely sensitive to water content at the time of compaction. The Figures 52 to 54 show that the percentage increase in soil compaction for the sandy clay loam is related more to changes in water content than to applied pressure. Scheduling tillage operations on

these soil to drier periods will have greatest benefit in lowering soil compaction, notwithstanding changes in ground pressure.

5.4.3.5 Effect of Applied Pressure on Bulk Density of Sandy Clay Loam (Soil Bin Soil)

It is also important to understand in sufficient detail the variation of bulk density with applied pressure at specific moisture content. If this is done and models are proposed, it will enable us to apply bulk density into the mechanics of soil-tool interaction for Nigeria soils. Curves were produced for the three different layers of the sandy clay loam. Equations describing the curves were also proposed. These equations could be referred to as compaction behaviour equations. The equations are sufficiently generalized, so that parameters are available to represent the difference in shapes for the various soils.

The compaction behaviour equations or models that are found best suited for the soils are in the following general forms.

$$(i) \quad \text{Linear fit} \quad y = b + mx \quad (50)$$

$$(ii) \quad \text{Logarithmic fit} \quad y = b + m \ln x \quad (51)$$

$$(iii) \quad \text{Exponential fit} \quad y = be^{mx} \text{ or } \ln y = \ln b + mx \quad (52)$$

$$(iv) \quad \text{Power fit} \quad y = bx^m \text{ or } \ln y = m \ln x \quad (53)$$

The range of applied pressure to which the soil samples were subject to was 17.5 to 618 kPa. This range covers all the ground pressures that can possibly be applied in the field.

Figure 55 shows the effect of applied pressure on bulk density of sandy clay loam (EBS1), layer 1. The percentage textural fractions of sand, silt and clay for the soil were 54, 21, 25 respectively. The best fit curves are shown at their respective moisture content, and R^2 values are also given for the respective curves.

Figure 56 shows the effect of applied pressure on bulk density of sandy clay loam (EBS2), layer 2. The percentage textural fractions of sand, silt and clay were 54, 21, 25 respectively. The best fit curve for each moisture content level was plotted. R^2 values were also given for the curves.

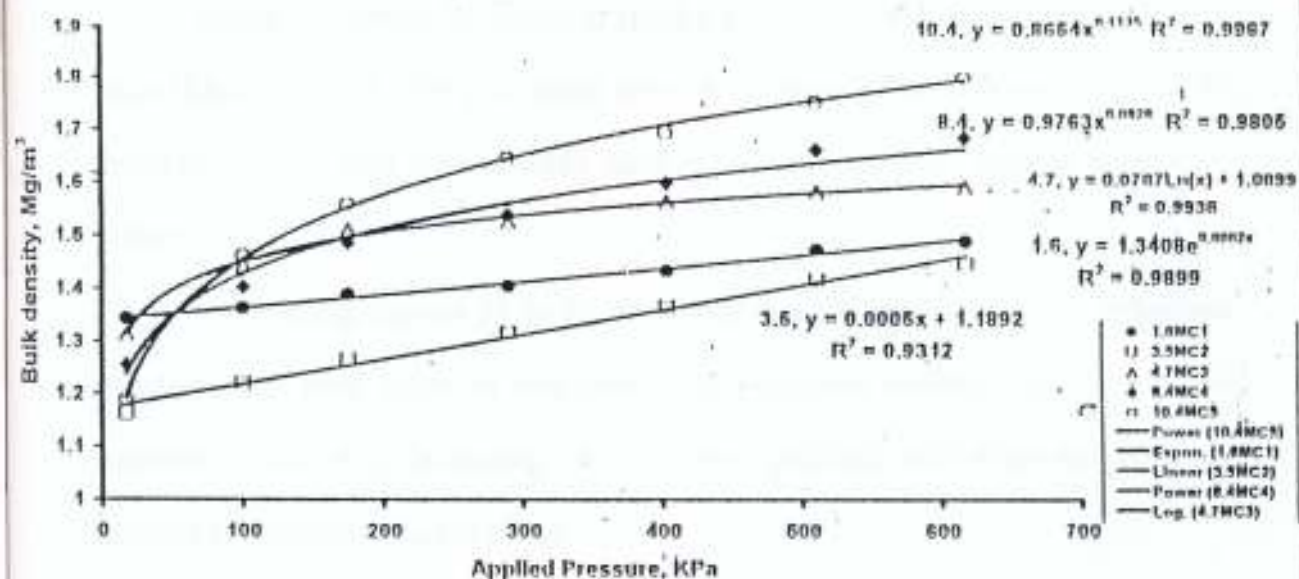


Fig 55 Effect of applied pressure on bulk density of sandy clay loam soil, (CBS1), Layer1 (54, 21, 25)

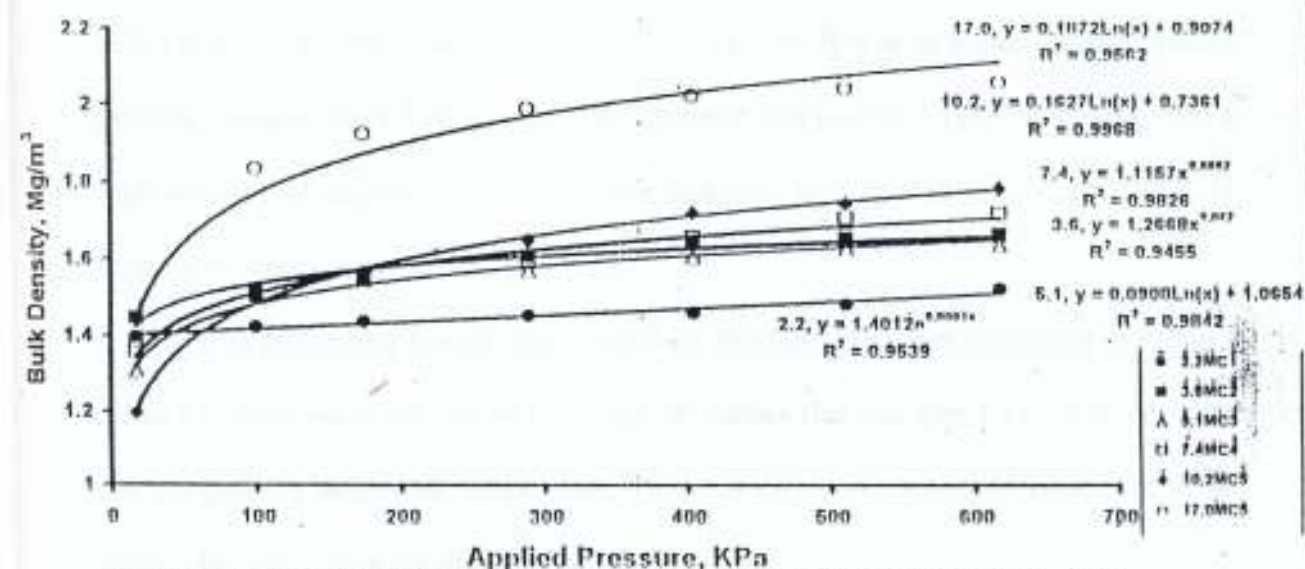


Fig 56 Effect of applied pressure on bulk density of sandy clay loam soil, (EBS2), Layer2 (54, 21, 25)

Figure 57 presents the effect of applied pressure on bulk density of sandy clay loam (EBS3), layer 3. The percentage textural fractions for the soil were: 52, 17, 31 respectively. The best fit and other models for each moisture content level were plotted.

Considering Figures 55 to 57, it is seen that the best compaction behaviour equation vary from linear to non-linear. For non-linear models, the bulk density increase initially at a decreasing rate, and then gradually with some and reaching towards asymptotic values in others.

Comparing the compaction behaviour of the soil samples in the three horizons, it was observed or seen that the effect of pressure on bulk density was highest in soil of layer 3 and lowest in layer 1. The reason is probably due to higher organic matter content found in layer 1. It was reported (Koolen and Kuipers, 1983) that soils with a high content of organic matter are more resistant to compaction than soils low in organic matter content.

It is interesting to note that apart from the best fit curves presented in Figures 55 to 57, there are other curves with high R^2 values that can also be used to describe the compaction behaviour of the soils. The models, contents and R^2 values for these sandy clay loam soils are presented in Tables 14, 15 and 16.

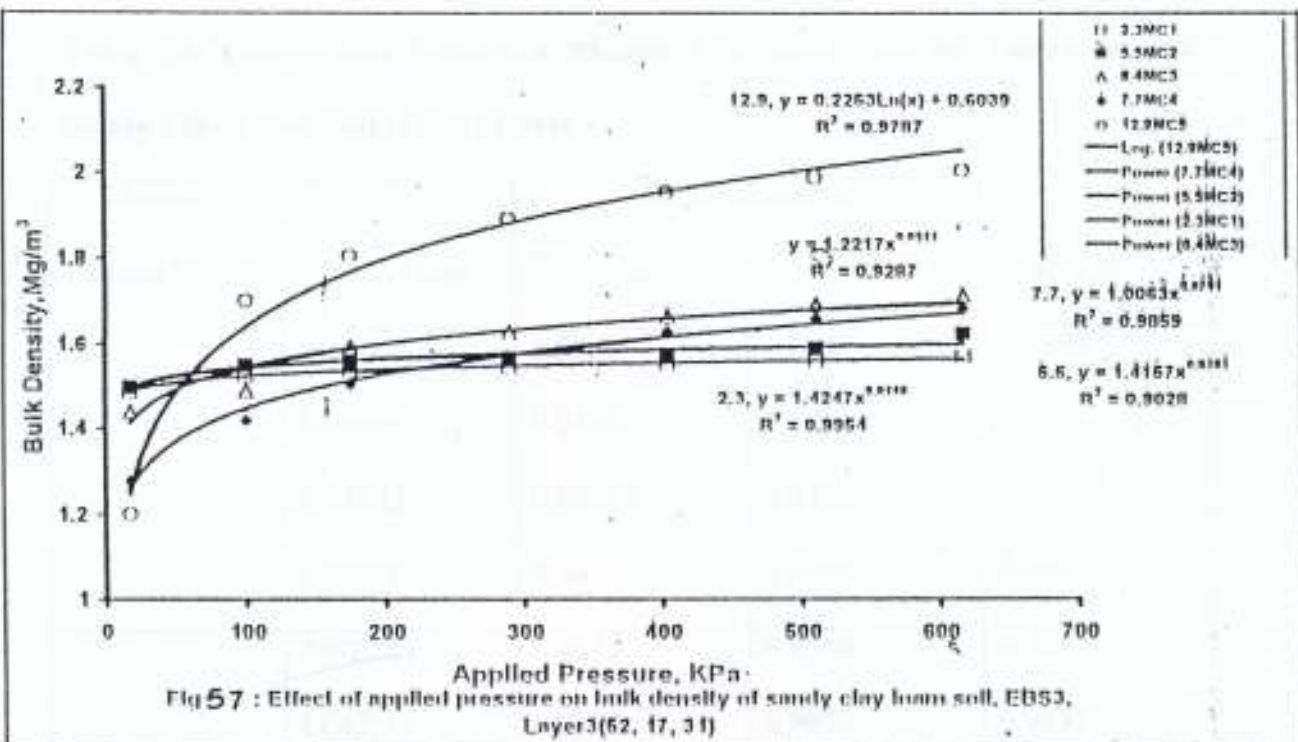


Table 14: Compaction Behaviour Models, Constants, and R^2 Values for the Sandy Clay Loam Soil (EBS1) Layer 1

Moisture content % (db)	Model type	Model constants		R^2 values
		m	b	
1.6	PWRFIT	0.0279	1.2192	0.8099
	LOGFIT	0.0393	1.2063	0.7996
	EXPFIT	0.00017	1.3412	0.9899*
	LINFIT	0.0002	1.3396	0.9898
3.5	PWRFIT	0.0615	0.9554	0.9259
	LOGFIT	0.0794	0.9059	0.9135
	EXPFIT	0.0003	1.1914	0.9171
	LINFIT	0.00045	1.1878	0.9312*
4.7	PWRFIT	0.0542	1.1284	0.9931
	LOGFIT	0.0786	1.0899	0.9938*
	EXPFIT	0.0003	1.3858	0.7668
	LINFIT	0.0004	1.3865	0.7883
8.4	PWRFIT	0.0800	0.9859	0.9805*
	LOGFIT	0.1206	0.8821	0.966
	EXPFIT	0.0004	1.3222	0.8921
	LINFIT	0.0007	1.3193	0.9178
10.4	PWRFIT	0.1136	0.864	0.9967*
	LOGFIT	0.1667	0.7075	0.9966
	EXPFIT	0.0006	1.3293	0.7774
	LINFIT	0.0009	1.331	0.8248

* Best fit model at the given moisture content

Table 15: Compaction Behaviour Models, Constants and R² Values for the Sandy Clay Loam Soil (EBS2) Layer 2

Moisture content % (db)	Model type	Model constants			R ² values
		m	B	...	
2.2	PWRFIT	0.0202	1.3074		0.8074
	LOGFIT	0.0293	1.3004		0.7959
	EXPFIT	0.0001	1.4012		0.9539*
	LINFIT	0.0002	1.400		0.9522
3.6	PWRFIT	0.042	1.2668		0.9455*
	LOGFIT	0.0002	1.4753		0.9380
	EXPFIT	0.0002	1.4753		0.8961
	LINFIT	0.0004	1.4745		0.9046
5.1	PWRFIT	0.0617	1.1124		0.9767
	LOGFIT	0.0908	1.0654		0.9842*
	EXPFIT	0.0003	1.4109		0.6921
	LINFIT	0.0004	1.413		0.7201
7.4	PWRFIT	0.0662	1.1157		0.9916*
	LOGFIT	0.1013	1.0518		0.9729
	EXPFIT	0.0004	1.4231		0.8743
	LINFIT	0.0005	1.4216		0.8974
10.2	PWRFIT	0.1105	0.8831		0.9916
	LOGFIT	0.1627	0.7361		0.9968*
	EXPFIT	0.0005	1.3454		0.7458
	LINFIT	0.0008	1.3487		0.7944
17.0	PWRFIT	0.0662	1.1157		0.9367
	LOGFIT	0.1013	1.0518		0.9562*
	EXPFIT	0.0004	1.4231		0.5789
	LINFIT	0.005	1.4216		0.6191

* Best fit model at the given moisture content

Table 16: Compaction Behaviour Models, Constants And R^2 Values For The Sandy Clay Loam Soil (EBS3) Layer 3

Moisture content % (db)	Model type	Model constants		R^2 values
		m	b	
2.3	PWRFIT	0.0148	1.4247	0.9954*
	LOGFIT	0.0266	1.4214	0.9946
	EXPFIT	0.00005	1.5054	0.8303
	LINFIT	0.0001	1.5054	0.8364
5.5	PWRFIT	0.0191	1.4157	0.9028*
	LOGFIT	0.297	1.4097	0.8954
	EXPFIT	0.0001	1.5172	0.8651
	LINFIT	0.0002	1.5169	0.8701
6.4	PWRFIT	0.0511	1.2217	0.9287*
	LOGFIT	0.0801	1.1803	0.9226
	EXPFIT	0.0003	1.4702	0.887
	LINFIT	0.0004	1.469	0.9012
7.7	PWRFIT	0.0791	1.0063	0.9859*
	LOGFIT	0.1163	0.9201	0.9756
	EXPFIT	0.0004	1.3467	0.8716
	LINFIT	0.0006	1.3449	0.8966
12.9	PWRFIT	0.1425	0.8347	0.95653
	LOGFIT	0.2253	0.6039	0.9787*
	EXPFIT	0.0006	1.4572	0.6229
	LINFIT	0.0011	1.4749	0.6803

* Best fit model at the given moisture content

5.4.3.6 Effect of Moisture Content and Compaction on Strength Properties of Soil

Shear strength and cone index have been considered as two soil strength parameters used to evaluate the strength of the sandy clay loam soils under different moisture contents and compaction levels. The compaction levels were those of proctor hammer blows: 5, 15 and 25 blows.

(i) Shear Strength

The effect of moisture content and compaction on the shear strength of sandy clay loam soil (bin soil) is presented in Figures 58 and 59 for layer 1 and layer 3 respectively. The layer 2 was not considered here because the properties were characteristically the same with soil in layer 1. In all the soils higher levels of compaction resulted in higher shear strength, irrespective of the moisture contents of the soil. This was because of the higher density of the soil at higher compaction levels (Ohu, et al., 1985). Further, the shear strength was found to first increase with moisture content up to a maximum and then decrease with higher moisture contents. At low moisture contents, the shear strength of the soils increased with increasing moisture content because the addition of moisture created greater pore water pressures when stresses were applied.

(ii) Cone Index

The effects of soil compactness on cone index of sandy clay loam soils, EBS1 and EBS3 (layer 1 and layer 3 respectively) are illustrated in Figures 60 and 61. In all the soils, higher level of compaction resulted in higher cone index irrespective of the moisture contents of the soils. The behaviour of the cone index was very similar to that shown by the shear strength versus moisture content and compaction except that the values were very different.

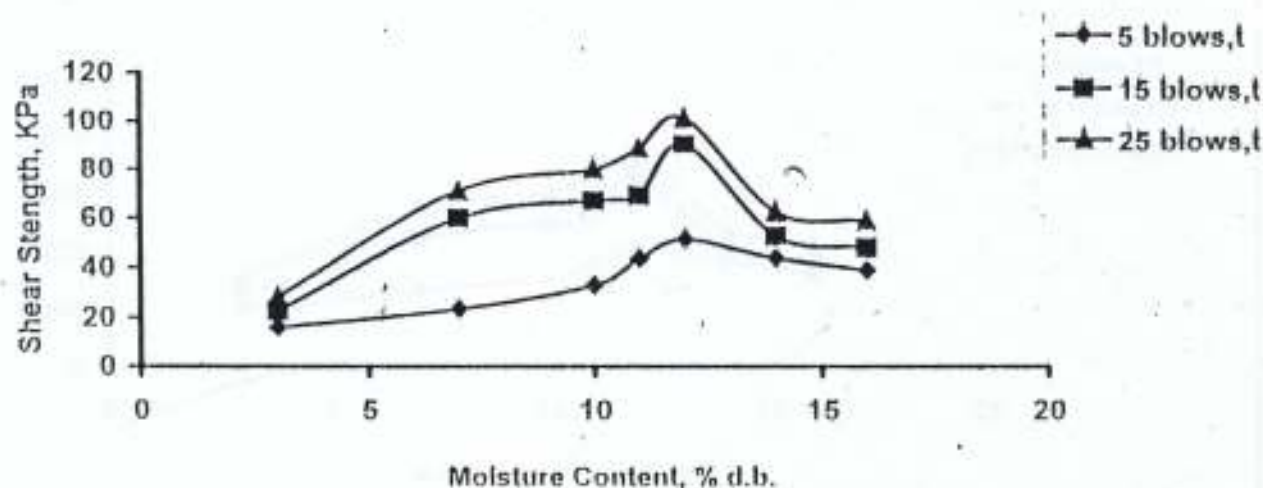


Fig58: Shear Strength Vs moisture content of sandy clay loam soil (EBS1), Layer1, at different compaction levels

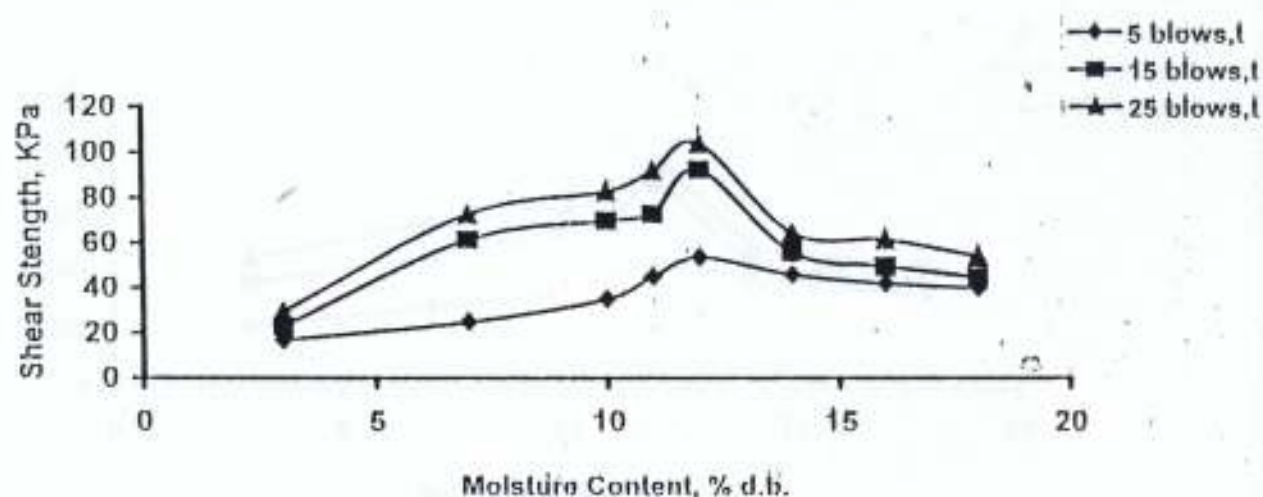


Fig59 Shear Strength Vs moisture content of sandy clay loam soil (EBS3), Layer3, at different compaction levels

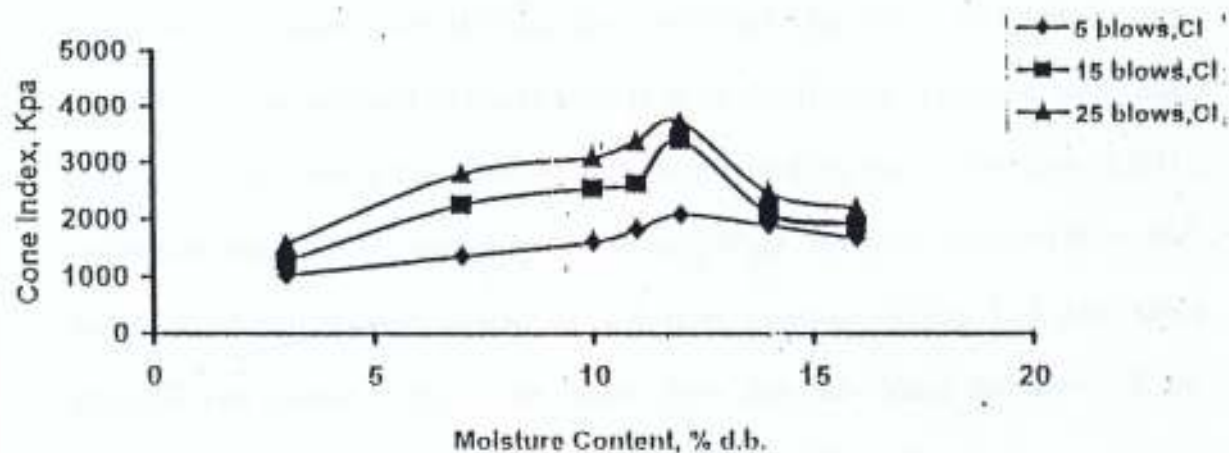


Fig 60: Cone Index VS moisture content of sandy clay loam soil (EBS1), Layer1, at different compaction levels

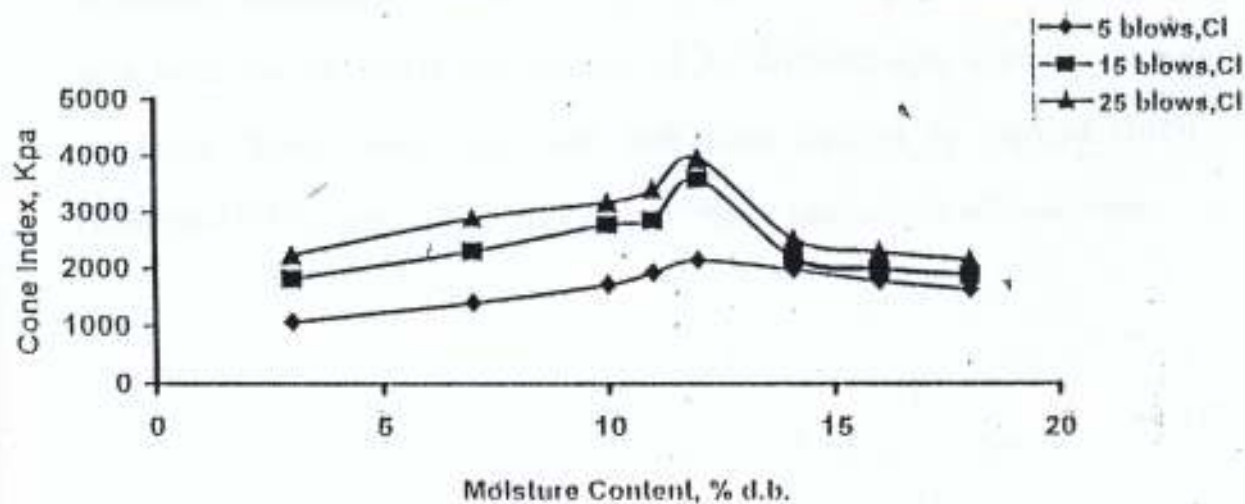


Fig- 61 : Cone Index VS moisture content of sandy clay loam soil (EBS3), Layer3, at different compaction levels

5.4.4 Angle of Internal Friction of Soil

The angle of shearing resistance or internal friction of the experimental soils are presented in Table 17. Four classes of soils have been identified in the Table: coarse textured soil represented by loamy sand (IGLS); fine textured soils, represented by sandy clay (EWA), clay (EO) and clay (EC); moderately coarse textured soils, represented by sandy loam (EWV), sandy loam (EBI) and sandy loam (EH3); and moderately fine textured soils represented by sandy clay loam (EBS1), sandy clay loam (EBS2) and sandy clay loam (EBS3). The value obtained show that, angle of internal friction depend on soil type, moisture content and pore space (Koolen and Kuipers, 1983). The results show that the values increase with the amount of coarse particles in the soil and with increase in bulk density.

The corresponding values for the two methods of measurement are not significantly different at 5% level of significance. The range of moisture contents were those for the friable consistencies of the different soils optimum for soil cultivation. These values agree well with those reported by Stafford (1979), Perumpral (1987), Ayers (1987) and Fielke (1996) for similar soils and conditions.

Table 17: Values Obtained for Angle of Internal Friction of Experimental Soils

Soil Type	Moisture content (% db)	Dry density (Mg/m ³)	Angle of Interface friction	
			Direct Shear (kPa)	Triaxial (kPa)
Loamy Sand (IGLS)	4.5 (0.3)	1.56 (0.1)	39.6 (1.3)	40.2
Sandy Clay (EWA)	18.3 (0.3)	1.21 (0.09)	30.1 (1.1)	31.0 (1.0)
Clay (E O)	19.5 (0.1)	1.09 (0.7)	28.4 (0.9)	27.9 (0.9)
Clay (EC)	20.1 (0.3)	1.03 (0.08)	25.2 (1.2)	25.7 (1.1)
Sandy Loan (EWV)	9.2 (0.1)	1.42 (0.15)	32.1 (2.0)	32.9 (1.1)
Sandry Loam (EBI)	10.4 (0.2)	1.35 (0.19)	30.2 (2.1)	30.8 (1.0)
Sandy Loam (EHB)	14.6 (0.2)	1.39 (0.20)	29.6 (0.9)	30.2 (0.9)
Sandy clay loam (EBS1)	11.5 (0.7)	1.43 (0.13)	32.6 (1.3)	33.0 (0.9)
Sandy clay loam (EBS2)	11.6 (0.8)	1.55 (0.19)	31.9 (1.4)	31.0 (0.8)
Sandy clay loam (EBS3)	11.6 (0.9)	1.39 (0.200)	30.7 (1.2)	30.9 (1.0)

() value in parenthesis, is standard deviation

5.4.5 Angle of Soil-Interface Friction

The results of soil-interface friction was illustrated in Figures 62 to 68. The results show the effect of moisture content on coefficient of soil-interface friction. The coefficient of soil-interface friction was given as the tangent of the angle of soil-interface friction expressed in Equation (17). Four groups of soils have been considered that is sandy soil, clay soils, loamy soils and sandy clay loam soils. The surfaces considered were rubber (RUB). Smooth steel (SST), galvanized steel (GAS) and Teflon coated surface (TEF).

Generally, in the dry phase, soil-interface friction remains almost constant as the moisture content increase. In the adhesion phase the values of the coefficient of soil-interface friction increase until the lubrication phase where it peaked before it started to decrease rapidly. In the lubrication phase enough moisture was present to cause a low moisture tension and a free water surface to lubricate the soil-material surface and reduce total adhesion.

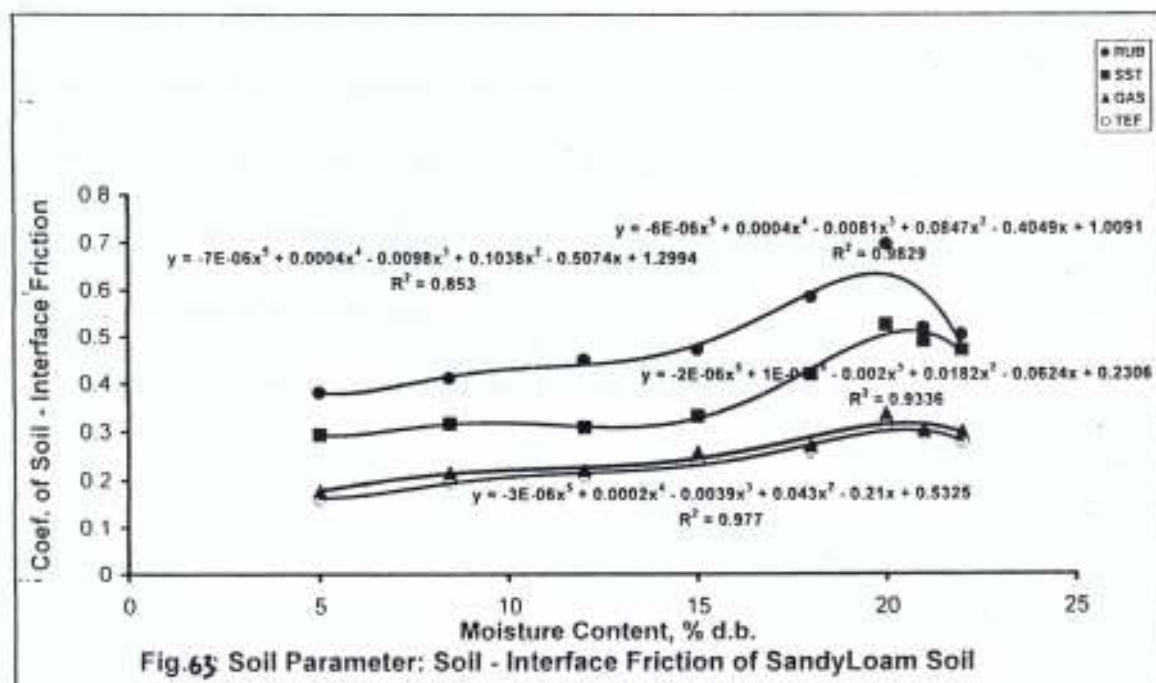
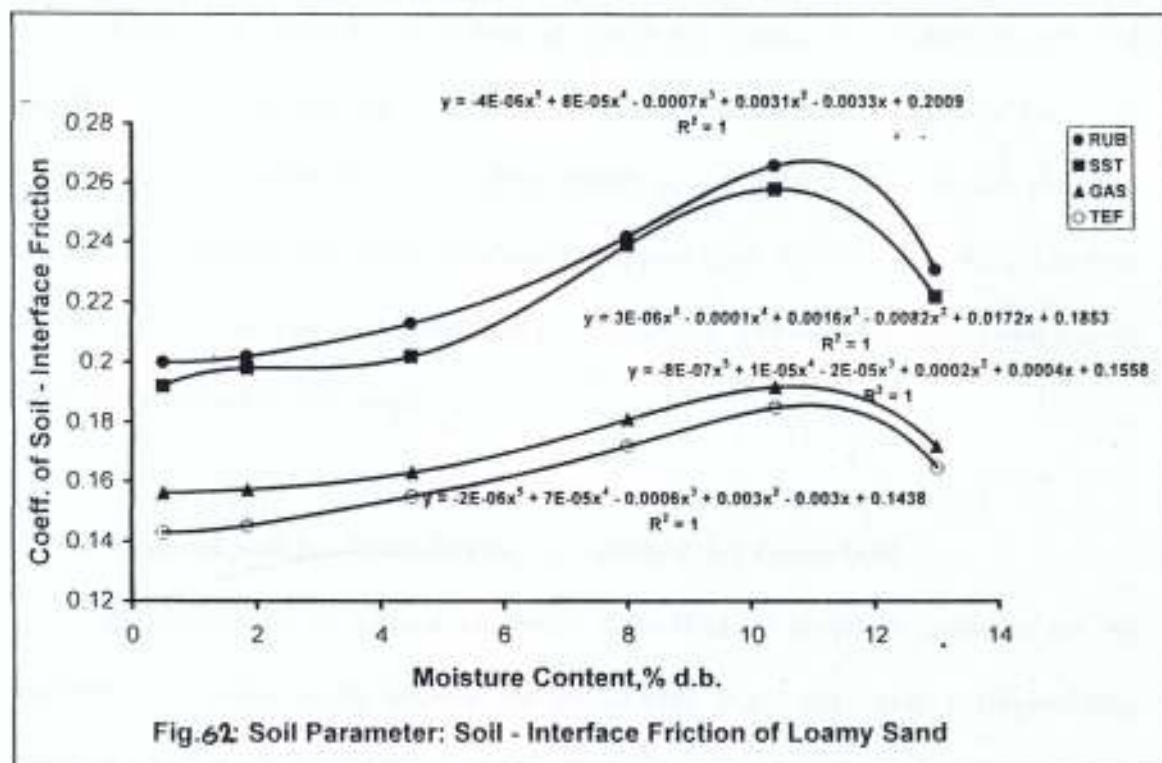
The curve were best fitted with polynomial equations. Generally, the coefficient of soil-interface friction was highest with rubber, followed by smooth steel, then galvanized steel and lastly Teflon. This is expected because Teflon (polytetrafluoroethylene) has non-wetting characteristics and therefore reduced adhesion (Koolen and Kuipers, 1983; Quian et al., 1999; Ren et al., 2001).

5.4.5.1 Angle of Soil-Interface Friction of Sandy Soil

Figure 62 shows the effect of moisture content on the coefficient of soil-interface friction of loamy sand (IGLS). The result shows that rubber and smooth steel are similar in their soil-interface friction characteristics. Also galvanized steel and Teflon have similar characteristics. It is also noteworthy that the values of the coefficient of soil-interface friction peaked when the moisture content was about 10.0% (db).

5.4.5.2 Angle of Soil-Interface Friction in Sandy Loam Soil

In Figure 63 is presented the effect of moisture content on coefficient of soil-interface friction for sandy loam (EH3). The peak values for the different materials occurred when the moisture content was about 18.0% (db). With this soil, it is seen that rubber has higher values of soil-interface friction than smooth steel and that the values for GAS and TEF are in a very close range.



5.4.5.3 Angle of Soil-Interface Friction in Clay Soil

Figure 64 presents the effect of moisture content on coefficient of soil interface friction of clay soil. It is seen here that soil adhesion was increased as the proportion of clay particles in the soil increased. It was highest when the soil moisture content was between the plastic limit and the liquid limit. (Ren et al., 2001). The clay soil in this test was that designated (EC) in this study. The best fit polynomial curves were also written for the curves.

5.4.5.4 Angle of Soil-Interface Friction in Sandy Clay Loam Soil

In Figures 65 to 68 are presented the effect of moisture contents on the coefficient of soil-interface friction for sandy clay loam soil, layer 1 (Figure 48), sandy clay loam soil, layer 2 (Figure 66)

Sandy clay loam soil, layer 3 (Figure 67) and sandy clay loam soil, mixed soil (Figure 68). It would be recalled that the soil designated M was the mixture of the three layers in the proportion of their horizons thicknesses.

The trend of interface friction has been very similar in the soils, the soil bin soil not an exception. The trend in layer 1 and layer 2 (Figures 65 and 66 respectively) is very similar. This is expected because the soils themselves have the same textural fractions. The coefficients of the soil-interface friction are relatively higher (especially in the adhesion phase) in soil of layer 3 because of the relatively higher value of clay particles in the layer.

From this study of soil-interface friction, it can be said that

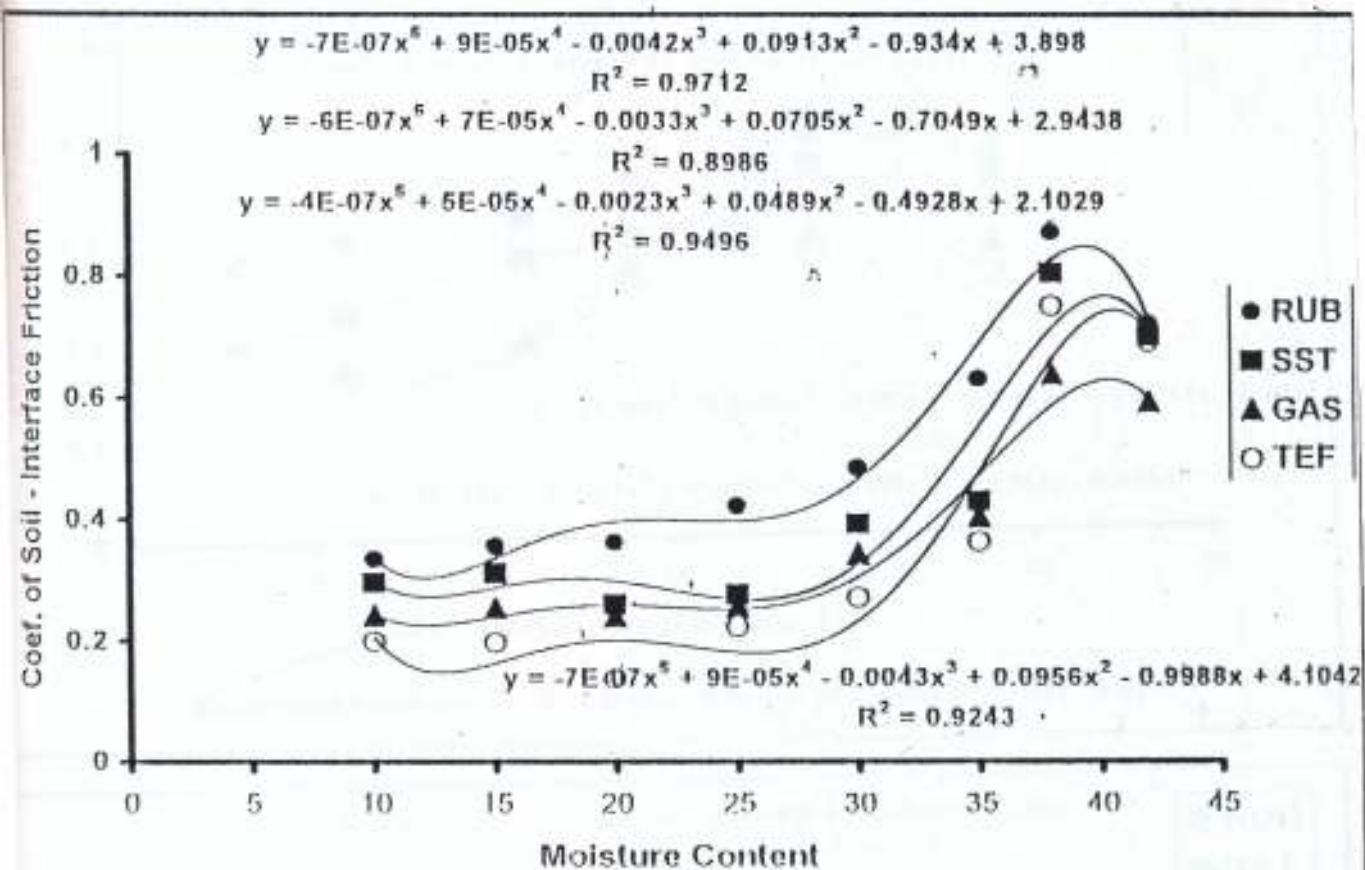


Fig-64: Soil Parameter: Soil - Interface Friction of Clay Soil

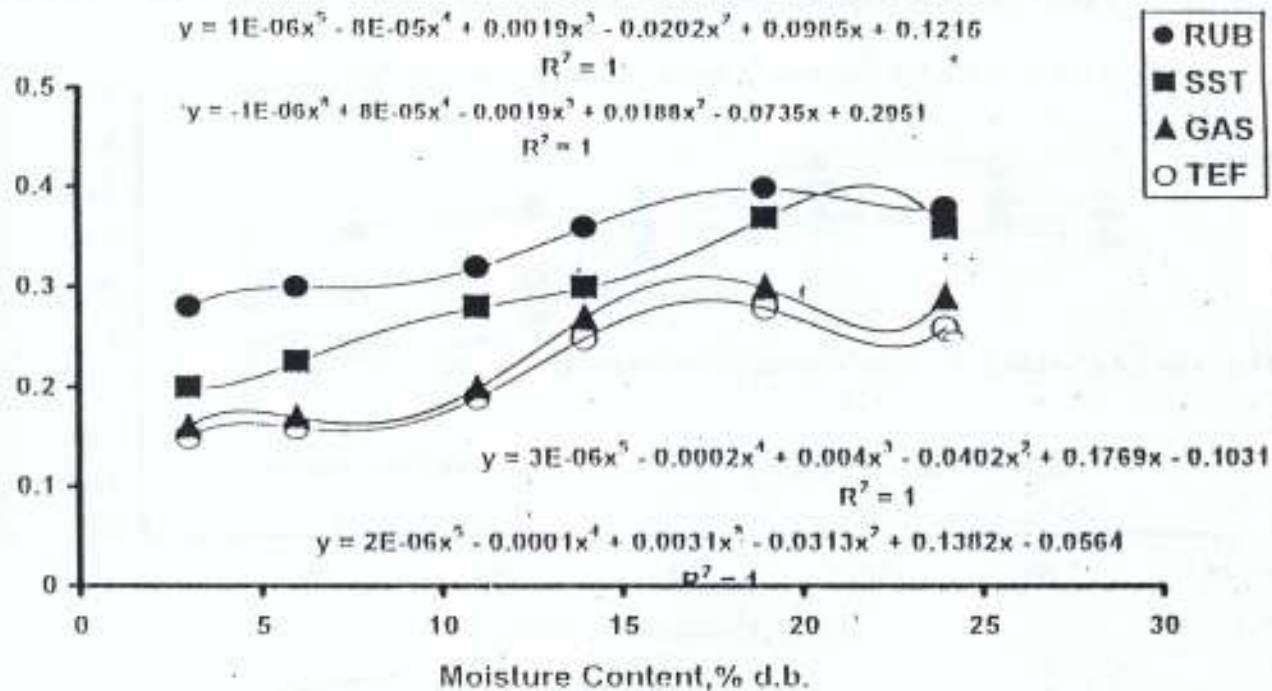


Fig.65 Soil Parameter: Soil - Interface Friction of Sandy Clay Loam 1-Layer 1

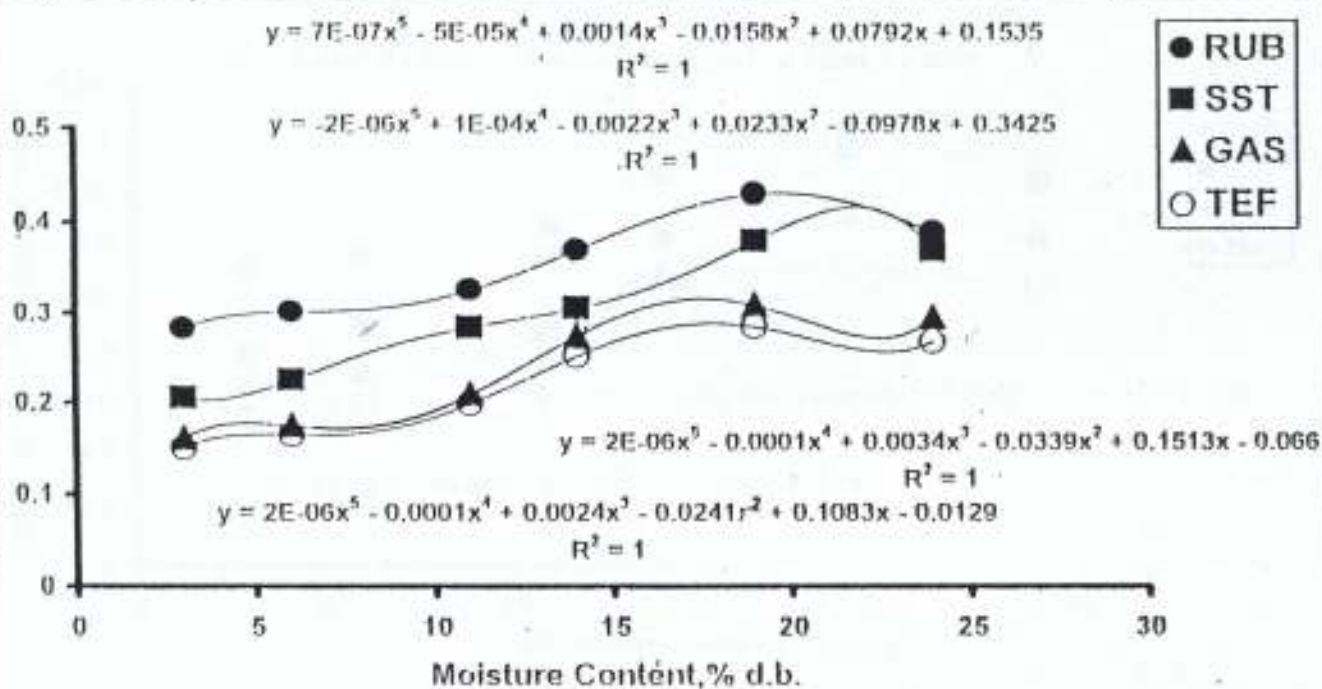


Fig.66 Soil Parameter: Soil - Interface Friction of Sandy Clay Loam Layer 2

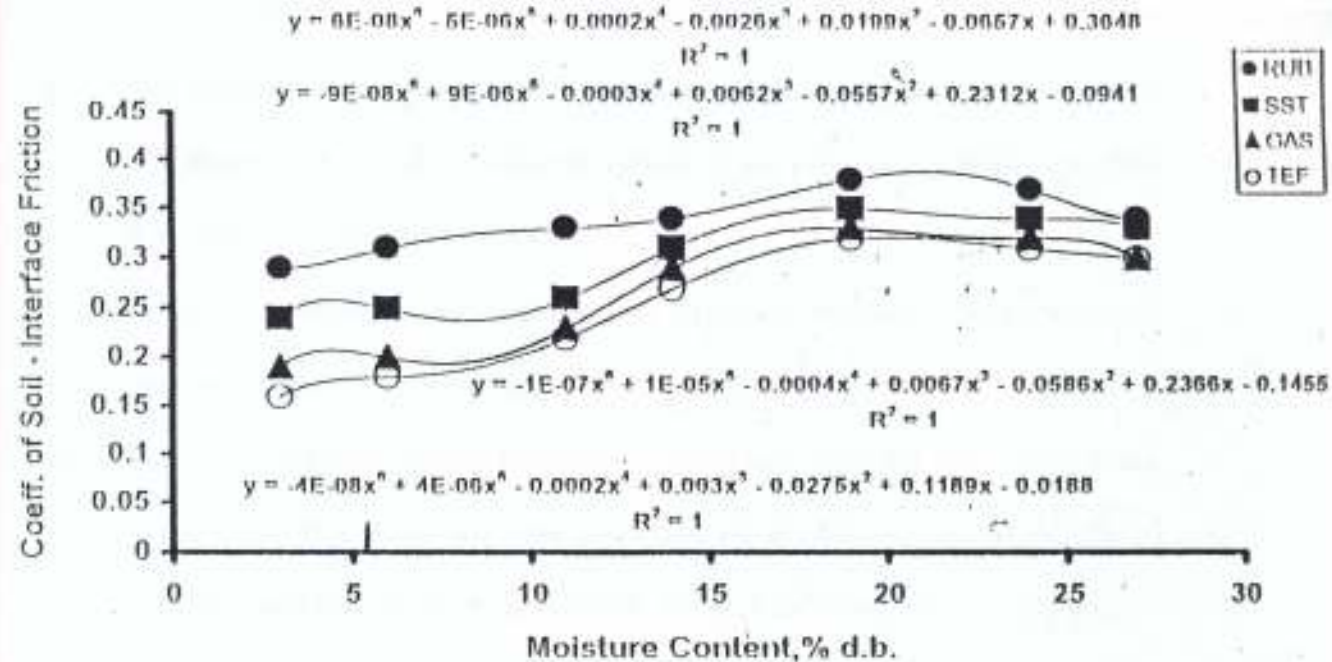


Fig-67: Soil Parameter: Soil - Interface Friction of SandyClayLoam 3

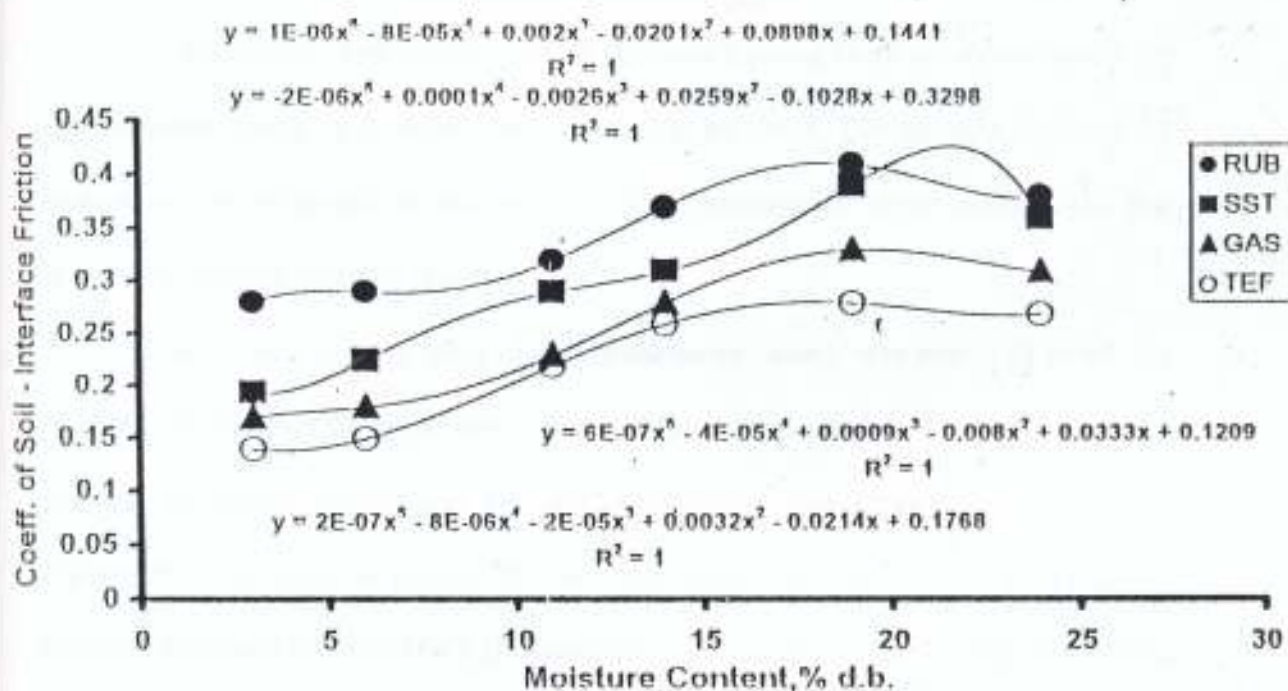


Fig-68: Soil Parameter: Soil - Interface Friction of SandyClayLoam M

- (i) Soil-interface angle remains fairly constant with soil in the dry phase, increase at a decreasing rate in the adhesion phase of the soil until it peaks and then decrease in the lubrication phase.
- (ii) By reducing adhesion and soil-interface angle, the slidding resistance of soil engaging implements can be reduced.
- (iii) Teflon is a suitable coating material to reduce soil adhesion and soil interface friction, and that by its use with soil-engaging implements, the resistance or draught could be reduced by about 20 to 30 % of the value with smooth steel.

5.5 Effect of Variation in Soil Parameters on Soil Disturbance and Draught

In this section and further, soil disturbance (arising from the operation of the experimental tillage tools inside the soil bin) is assessed. The draught force of the tools that were measured are also reported. The performance of the model tools, that is, specific draught and also reported.

There was a general form of soil disturbance, which was observed in all test runs, irrespective of the experimental tool. This is presented in Figure 69. For the purpose of further studies and analysis, a schematic and approximate version of Figure 69 is presented in Figure 70. The parameters of the soil disturbance include: the total disturbed width (TDW); the width of furrow at the surface (WFS), this is also the same as width of crescent(WC); the ridge – to – ridge disturbance (RRD); the height of the ridge (h_r); the after furrow depth (d_f) and the tool width (W).

Another parameter of the soil disturbance (not shown in the Figure 70) is rupture distance, f . These parameters have been used to assess soil disturbance of tillage implements by researchers (Godwin and Spoor, 1977; Willat and Willis, 1965).

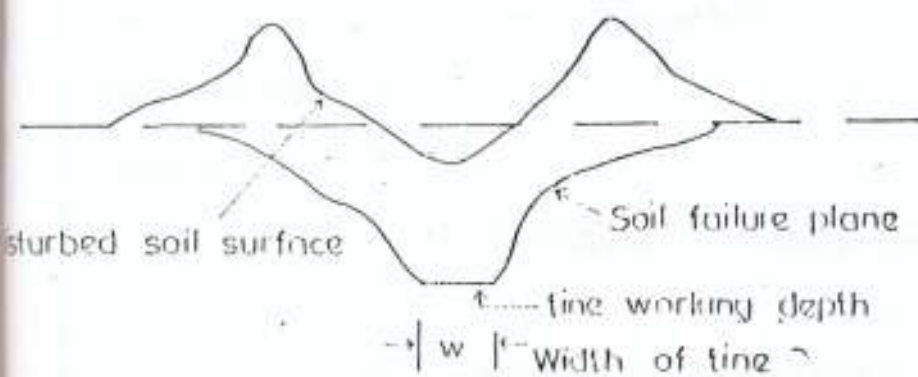
Spoor and Godwin, 1978; Spoor and Fry, 1983; Wheeler and Godwin, 1996; Taniguchi et al., 1999).

5.5.1 Effect of Moisture Content

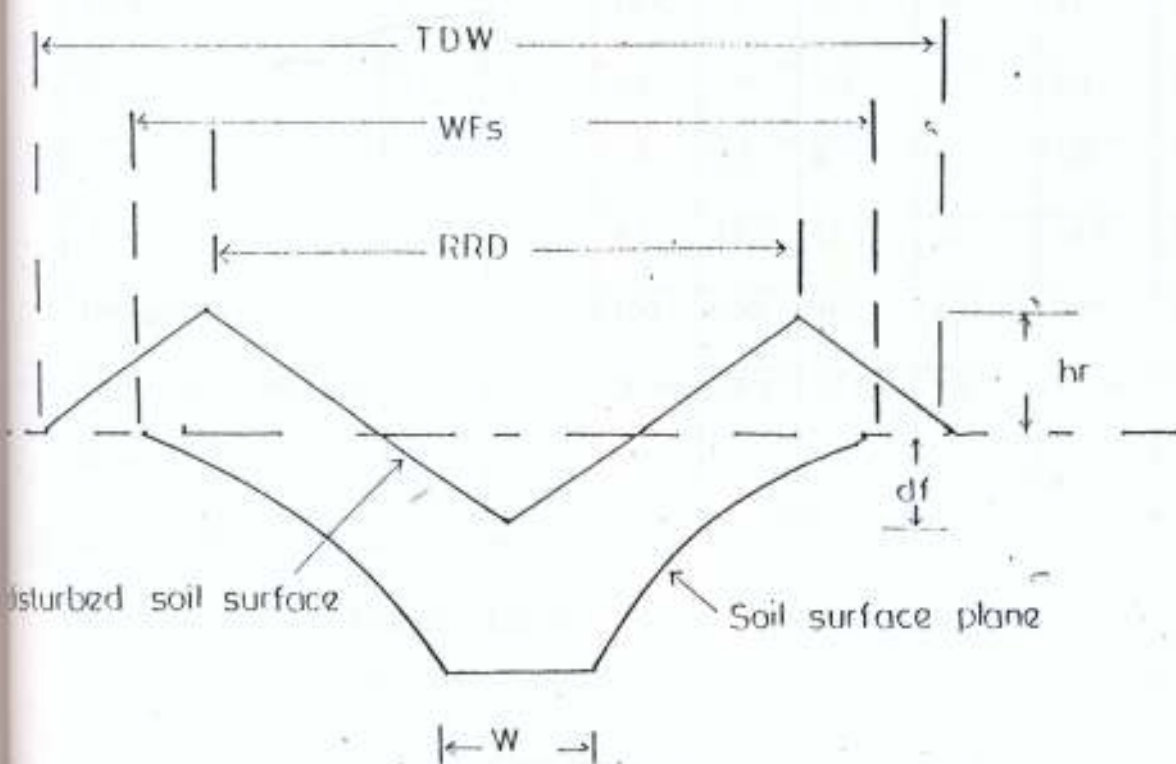
(a) On soil disturbance

Effect of soil moisture content on soil disturbance is presented in Table 18.

The tools tested are tines of width 1.0 cm, 5.1cm and 20.0cm designated as T1, T5 and T20 respectively.



69: Typical profile of soil disturbance of a single tine working through the soil



70: Schematic analysis of soil disturbance of a single tine working through the soil

Table 18: Effect of Moisture Content on Soil Disturbance

Parameters of Soil Disturbance (cm)	T1			T5			T20		
	Moisture Content (%)			Moisture Content (%)			Moisture Content (%)		
	6.0	11.5	17.5	6.0	11.5	17.5	6.0	11.5	17.5
RRD	10.5	8	7.0	18	15	14.5	28.5	28	27
WC (WFS)	10.0	8.5	8.0	22	17	16	31	33	35
TDW	12.5	11	10.5	29	27.5	26	41	40	39
d_r	4.3	4.5	5.1	5.0	5.3	5.5	2.1	2.5	3.1
h_r	1.0	1.5	1.8	2.5	4.5	5	3.8	3.0	4.3
f	7.0	8	8.5	15.0	15.5	16	16.5	17	18.5
Draught, N	100	150	160	400	460	470	700	750	770
*Specific Draught, N/cm	10	17.64	20.0	18.8	27.05	29.37	22.58	22.73	22.0
$\alpha = 90^\circ$ $d = 7.0$ cm $V = 1.5$ m/s * specific draught = Draught / disturbed width									

The parameters of soil disturbance represented in Figure 70 are presented in Table 18. It is observed that f decreased as moisture content decreased. Also at rake angle 90° , the width of crescent tends to be greater than rupture distance. The ridge - to ridge distance increase with decrease in moisture content and compactness of soil

(b) On Draught

Effect of moisture content on draught of tines resented in Figures 71 and 72.

Draught increased at a decreasing rate as the soil moisture content increased from 1 to 22.5%. However, the increase in draught is higher with 90° -rake angle. Polynomial equations were fitted to the curve with their R^2 values noted. The values of draught increased as the tine width increased but not in the ratio or proportion of the tine. The depth of operation in this test was 15. cm for both tests.

5.5. Effect of Compaction

(a) On soil disturbance

Effect of soil compaction on soil disturbance is presented in Table 19.

Table 19: Effect of Soil Compaction on Soil Disturbance

Parameters of Soil Disturbance (cm)	T1			T5			T20		
	Cone index (kPa)			Cone index (kPa)			Cone index (kPa)		
	200	400	800	200	400	800	200	400	800
RRD	9	9.5	11	11.5	13.5	18	24	29	32
WC (WFS)	9.5	10	12	18	20	21	25	32	33
TDW	11	12.5	14	22	27.5	29	30	43.5	46
d_f	6	7.5	8	4	5.5	7	2	3.5	5
h_f	2	1.5	0.5	4	3.5	2.0	3.5	3.0	2.0
f	9	11	12	17	18	19.5	21	23	27
Draught, N	120	150	280	300	400	600	590	610	920
Specific Draught, N/cm	12.63	15.00	23.33	16.67	20.00	28.57	23.6	19.06	27.87
$\alpha = 90^\circ$ $V = 1.0 \text{ m/s}$ $d = 10 \text{ cm}$ $mc = 11.5 (\% \text{ db})$									

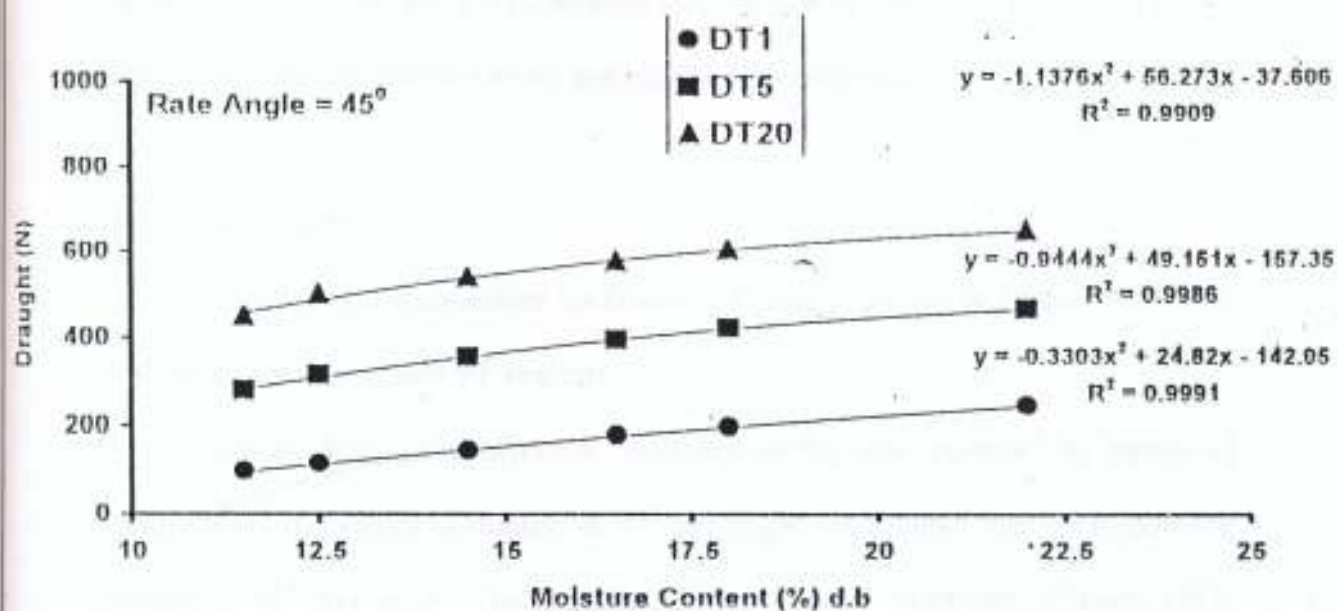


Fig.71: Effect of Moisture Content on Draught of Tines

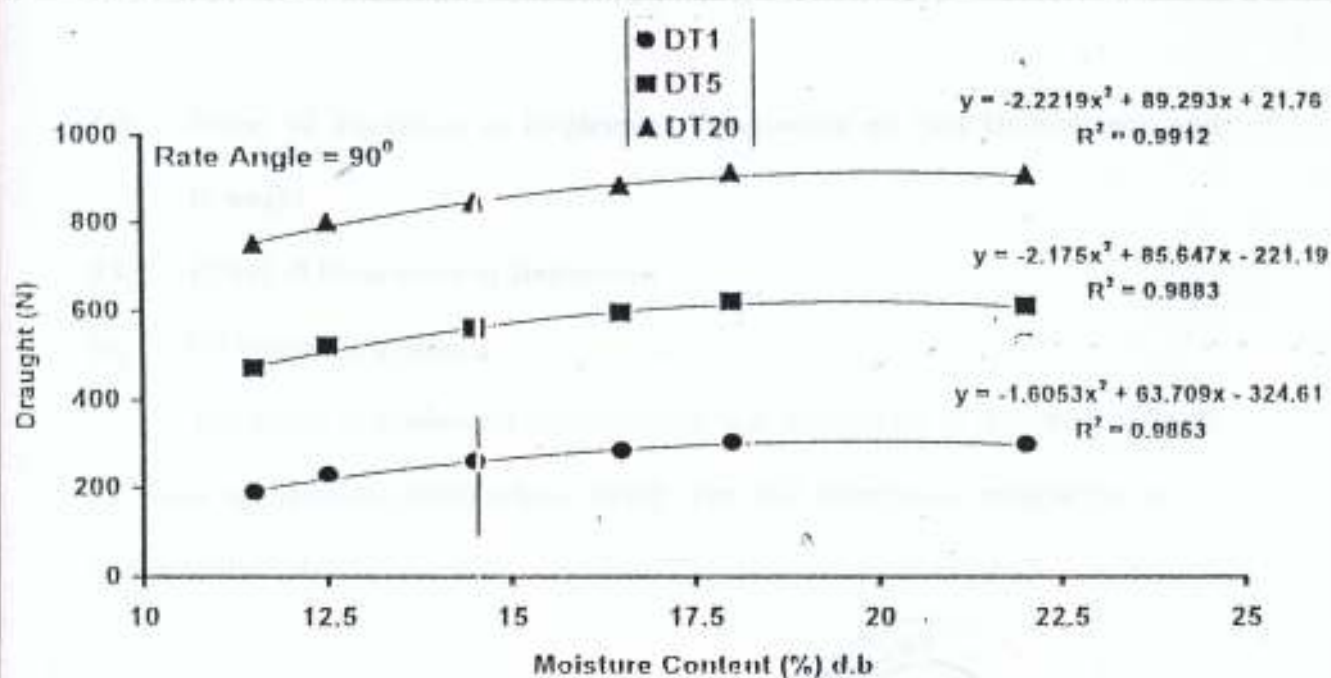


Fig.72: Effect of Moisture Content on Draught of Tines

The index of soil compaction was cone index. Three levels of compaction corresponding to cone indices of 200, 400 and 900 kPa were generated. The measured values of the soil disturbance parameters are reported in Table 19. The Table shows that the parameters increased as the soil compactness increased.

(b) On Draught

Effect of soil compaction on draught of tines is shown in Figures 73 and 74 with rake angle as 45° and 90° respectively.

Draught force of penetration resistance of the soil increased by means of compaction. The values of draught at 90° -rake angle were higher than corresponding draught at 45° rake angle. This angles with the work of researchers (Spoor, 1969; Gupta et al., 1989). Polynomial equations of second order degree best fit the curves. These will enable prediction where necessary.

5.6 Effect of Variation in Implement Parameters on Soil Disturbance and Draught

5.6.1 Effect of Dimension of Implement

(a) On the soil disturbance

The effect of implement dimension on soil disturbance is presented in Table 20. Four implements (tines) were tested. The soil disturbance parameters are as shown in the Table 20.



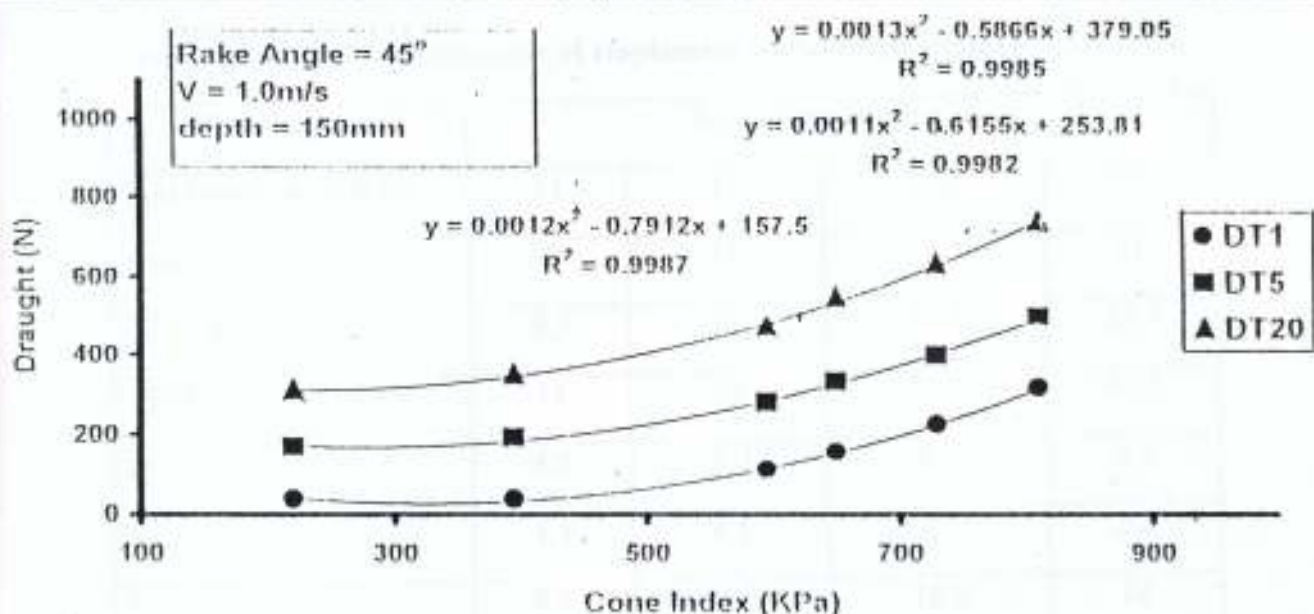


Fig.73: Effect of soil Compaction on draught of Tines

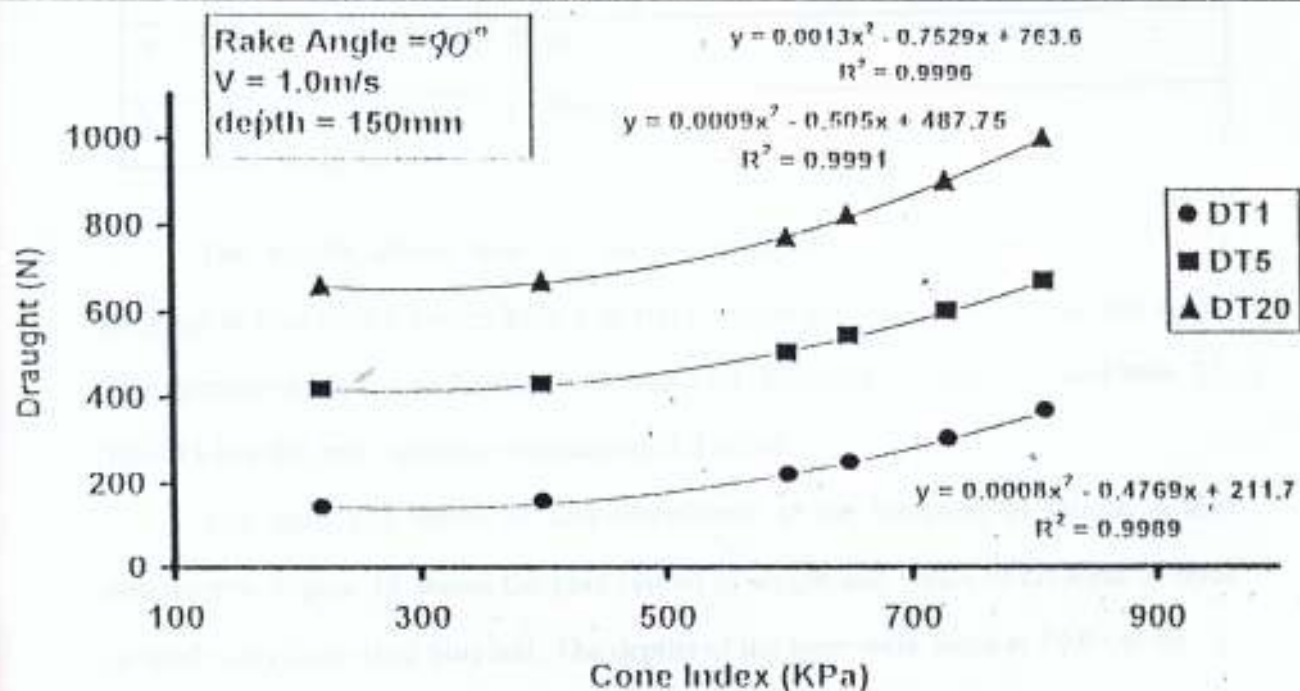


Fig.74: Effect of soil Compaction on draught of Tines

Table 20: Effect of Dimension of Implement on Soil Disturbance

Parameters of	Implement Dimension			
Soil Disturbance (cm)	T1	T5	T10	T20
RRD	8	15	22.5	31
WC (WFS)	8.5	17	19.5	23.5
TDW	11	29	34.5	42.5
d_r	4.5	5.0	4.5	3.5
h_r	1.5	4.5	3.0	2.8
f	8.0	15.5	18.0	21
Draught, N	44.2	105.4	165	250
Specific Draught, N/cm	5.2	6.18	8.46	10.63
$\alpha = 90^\circ$ $d = 7.0$ cm				
$V = 1.0$ m/s $mc = 11.5\%$ db				

The results shows that the parameter of soil disturbance increased with increase in tine width, except height of ridge which did not show any specific trend. The specific draught was highest with tine T20, followed by tine T10, and then T5. Tine T1 has the least specific resistance of 5.2 N/cm.

The limit and nature of soil disturbance at the incipient of failure is also noteworthy. Figure 75 shows the plan (view) of length and width of crescent of tines in sandy clay loam (soil bin) soil. The depths of the tines were fixed at 10.0 cm for the operations. It is clear from Figure 75 that for sandy clay loam soil, the distance in the direction of travel from the line of emergence of the tine to the limit of crescent increases more rapidly as the rake angle of the tine became more acute. A knowledge of this relationship may be of direct value to designers, for instance in avoiding the loading of the disturbed area by parts as depth wheels, which would thus increase draught unnecessarily.

$\gamma = 1.0$

$\gamma = 5.1$

$\gamma = 10.0$

$\gamma = 20$

$\alpha = 30^\circ$

45°

60°

90°

Limit of crescent
Tine

Fig. 75: Plan view of length and width of crescent of tines in sandy clay 10.8m soil.

The width of the crescent and hence of the disturbed area, must be of direct importance in assessing the usefulness of a tine (or tool) at disruption to increase air and permeability. Where this is important the draught per unit width (specific draught) of disturbance is therefore a measure of efficiency (Payne and Tanner, 1959).

(b) On Draught

Effect of implement dimension on draught is shown in Figures 76 and 77. In Figure 76, it was draught versus width of tine at constant depth, 3.5 cm while in figure 60, it was draught versus width of tine at constant depth, 7.0 cm. In these two figures (59 and 60), draught increased at a decreasing rate with tine width. The increase is also affected by the forward speed since higher draught values were obtained at higher speed. The forward speed V_1 , V_2 and V_3 were 0.28, 1.0 and 2.5 m/s, respectively. Quadratic models were used to fit the data points with their R^2 values. These relationship agree well with the work reported by Hettiaratchi and Reece (1974), O' Callaghan and Farrelly (1964).

5.6.2 Effect of Shape of Implement

(a) On Soil Disturbance

The effect of shape of implement on soil disturbance is presented in Table 21.

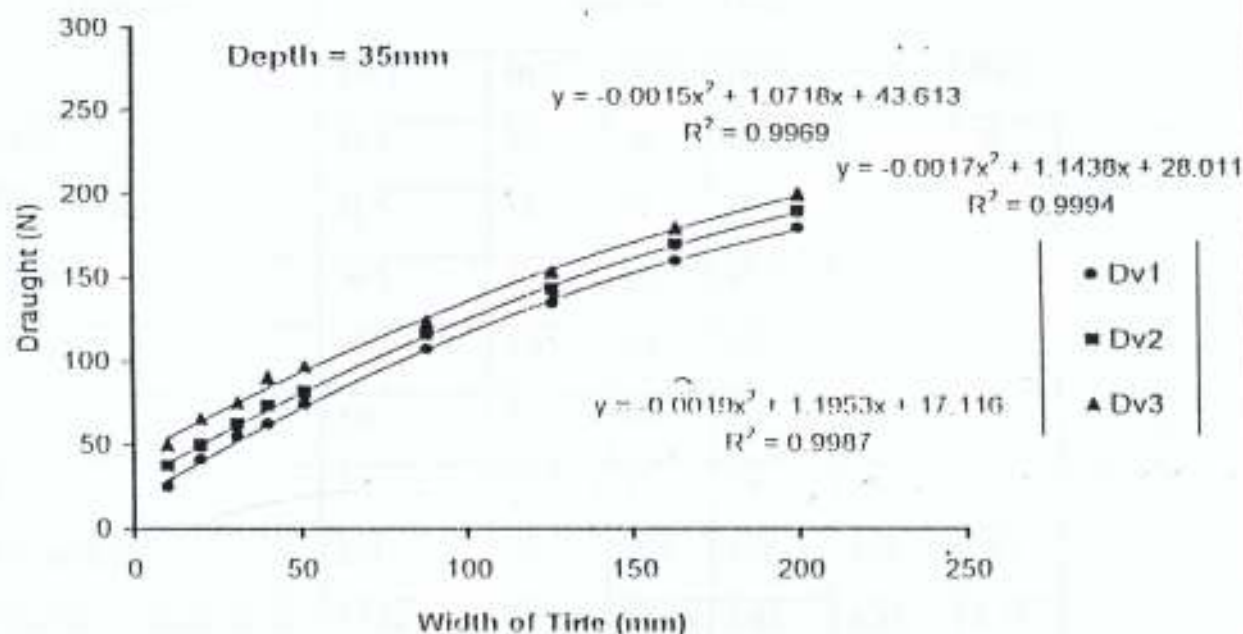


Fig-76 Effect of Dimension of implement on Draught

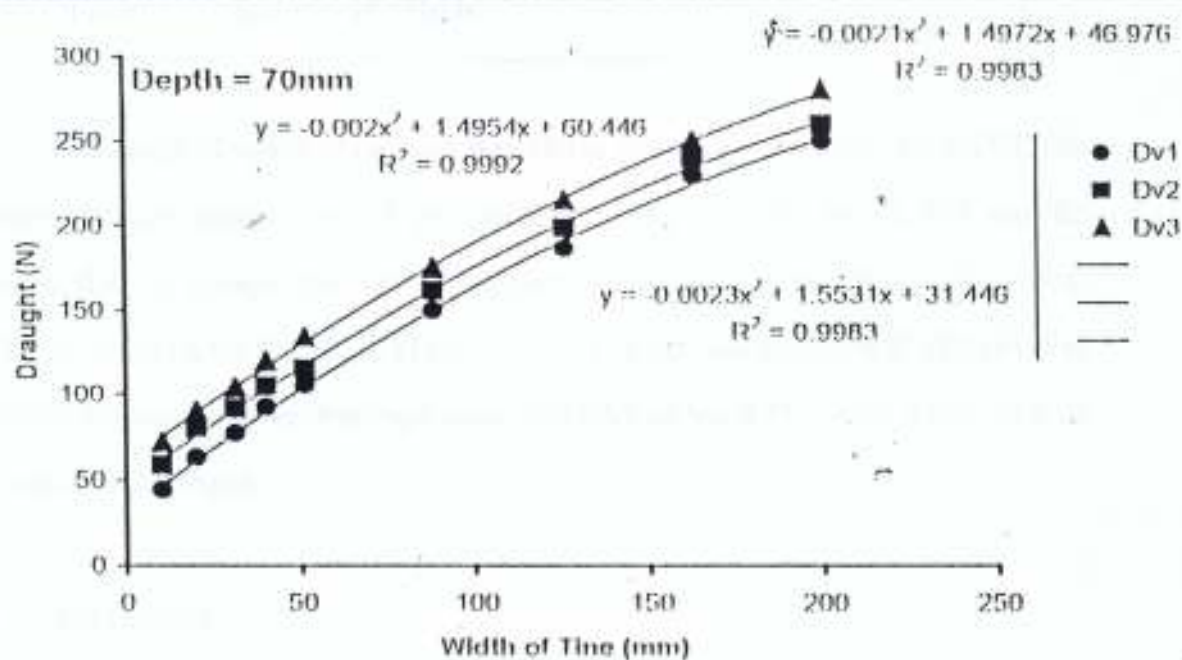


Fig-77 Effect of Dimension of implement on Draught

Table 21: Effect of Shape of Implement on Soil Disturbance

Parameters of Soil Disturbance	Implement Shape					
	TWT	BCC	BSC	BCV	BTR	BVE
RRD	27.5	30	26	28.5	27	26
WC (WFS)	21.5	18	18.5	24	19	20.5
TDW	36.5	39	46	47.5	36	35
d_r	35	3.8	40	40	39	37
h_r	3.0	3.0	4.0	3.3	3.5	3.2
f	2.1	17.5	19	25	18	21
Draught, N	274	242	205	167	128	105
Specific Draught, N/cm	12.74	13.44	11.08	6.95	6.73	5.12
$\alpha = 45^\circ$ $d = 7.0 \text{ cm}$ $V = 1.4 \text{ m/s}$ $mc = 11.5\% \text{ d.b}$						

The range of width of crescent was 18 cm (for BCC) to 24 cm (for BCV). The rupture distance ranged from 18 cm (for BTR) to 25 cm (for BCV). The specific draught, that is, draught per unit of crescent in increasing order of magnitude are: BVE (5.12); BTR (6.73); BSC (11.08); TWT (12.74) and lastly BCC (13.44). For practical reasons therefore; the implement with BVE shape BVE best while BCC is the least efficient blade.

(a) On Draught

Figures 78 through to 81 show the effect of shape of implement on draught of blades. All the blades have the same width, that is 20.0 cm. The depth, moisture contents were kept constant at 15.0cm and 11.5% (db) respectively.

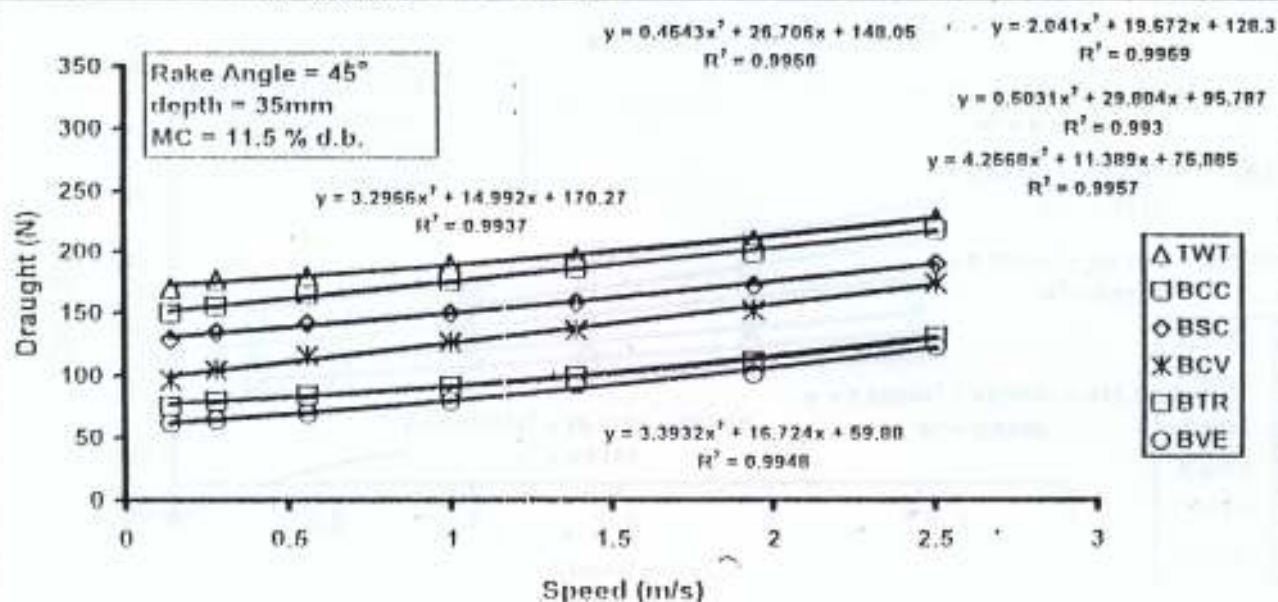


Fig.78 Effect of Shape on Draught of Blades

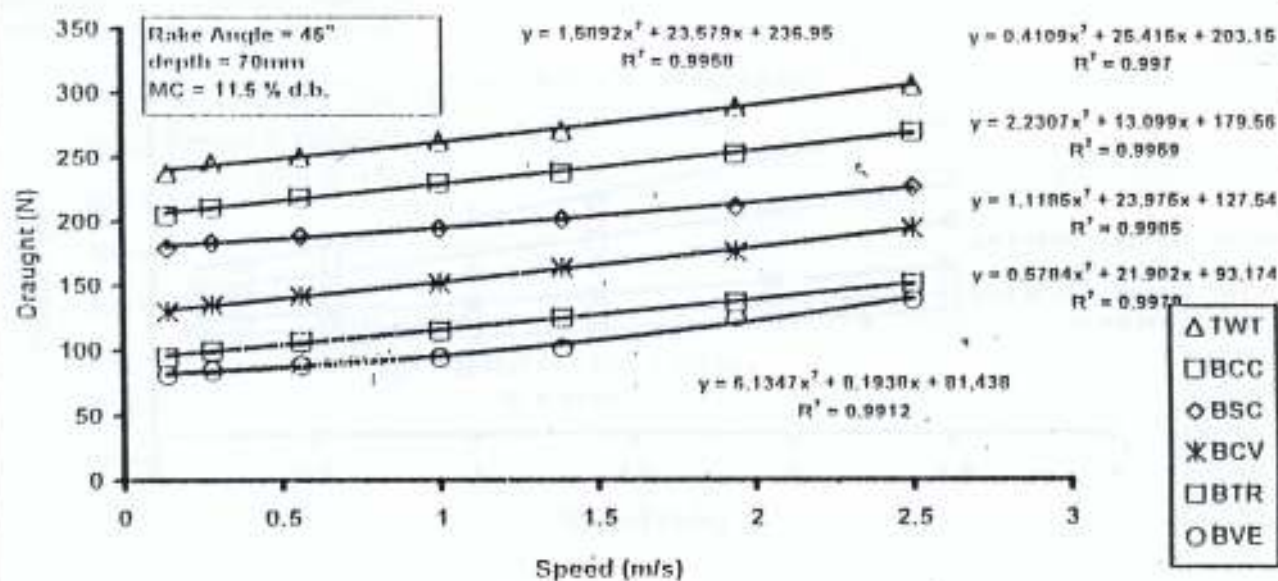


Fig.79:Effect of Shape on Draught of Blades

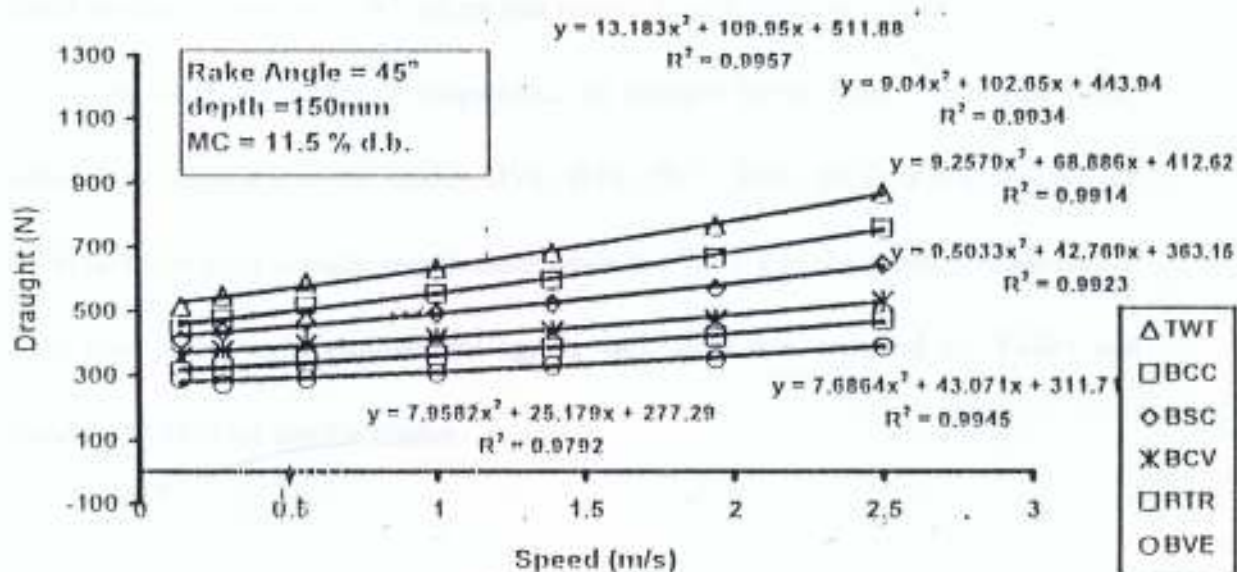


Fig 80: Effect of Shape on Draught of Blades

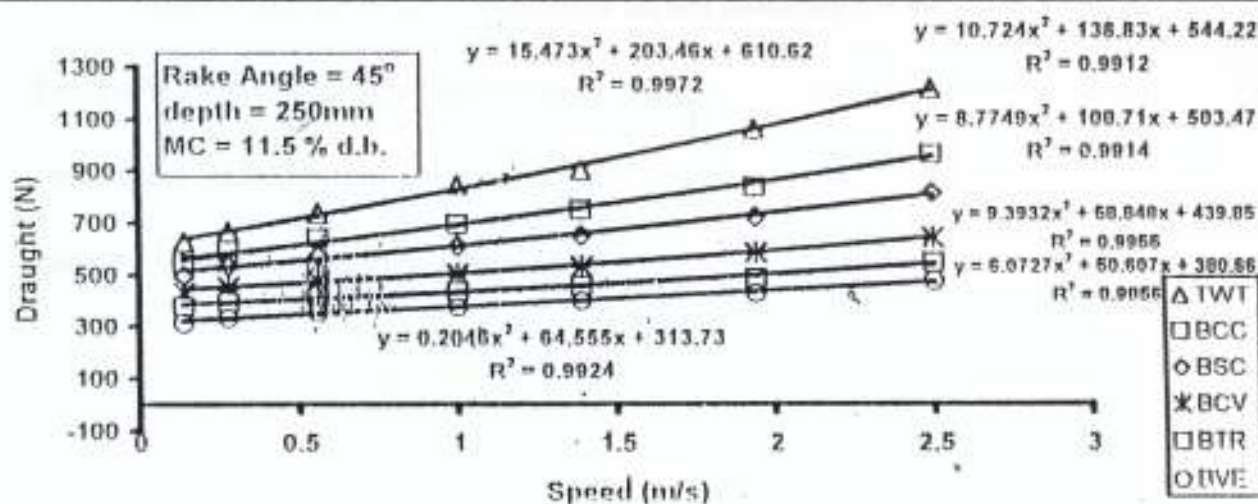


Fig 81: Effect of Shape on Draught of Blades

In all the figures and for all the blades, draught force increased gradually at an increasing rate with forward speed. Polynomial equations of second order degree best fitted the data points, with R^2 values that ranged from 0.9792 to 0.9985.

In increasing order of magnitude, the draught of the blades increased in the order of arrangement of the blades: BVE; BTR; BCV; BSC; BCC; TWT, that is, the BVE had the least draught requirement while the TWT had the greatest requirement. This trend of draught requirement agrees well with that reported by Yadav and Pandey (1984) for similar blades.

5.6.3 Effect of Surface Finish

(a) On soil Disturbance

Effect of surface finish of implement on soil disturbance is shown in Table 22. The surface considered were steel, clean surface (SCS); steel rusted (SRS) and the steel, Teflon coated surface (STS). It is clear from the table that Teflon coated surface gave the best parameters of soil disturbance.

Table. 22 Effect of Surface finish of Implement on Soil Disturbance

Parameters of soil disturbance (cm)	Surface finish of T 20		
	SCS	SRS	STS
RRD	31	32	30.5
WC (WFS)	18.5	20.5	18.5
TDW	42.5	43	42
d_f	3.5	3.7	3.2
h_f	2.8	3.0	2.5
f	21	22	20.5
Draught, N	271	325	224
Specific Draught, N/cm	14.65	15.85	12.10
$\alpha = 45^\circ$ $d = 7.0 \text{ cm}$ $V = 1.4 \text{ m/s}$ $mc = 11.5\%d.b$			

The specific draught, that is, draught per unit width of crescent are 12.10, 14.56 and 15.85 N/cm for Teflon coated surface (STS). Steel clean Surface (SCS) and steel rusted surface (SRS) respectively. This implies that Teflon, if used to prepare tillage tool surface would reduce draught requirement of the tool when compared with ordinary steel or rusted surface.

(b) On Draught

Effect of surface finish on draught of implement is presented in Figures 82 through to 84. Moisture content and rake angle were held constant in all the tests as

11.5% and 45° respectively but depth was varied at 3 levels: 3.5, 7.0 and 15.0 cm respectively with the figures. The three treatments of surfaces were SCS, SRS and STS. Draught was plotted versus forward speed. The trend in all the figure is that draught force increased gradually at an increasing rate with moisture content. Draught force requirement was highest for rusted tool surface and lowest with Teflon coated surface as shown in all the figures. Polynomial equations of second order (quadratic) were used to fit the curves.

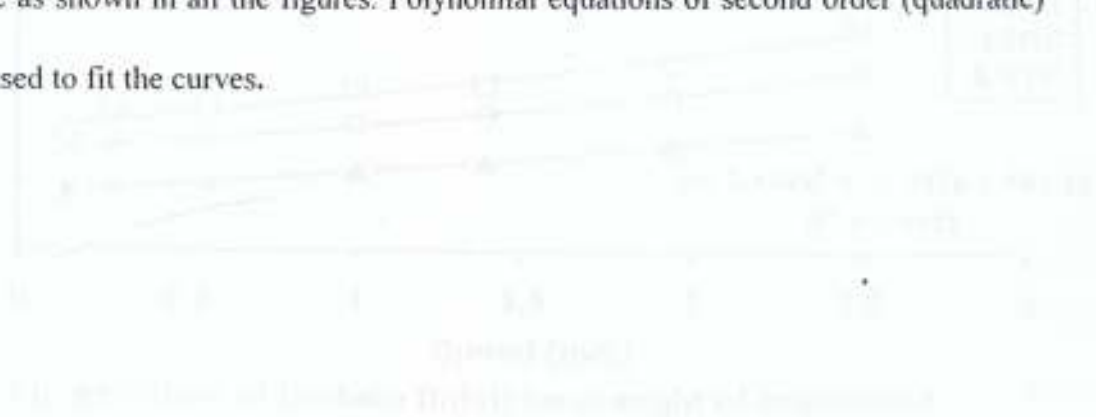


Figure 25: Effect of Surface (rusted) on draught force

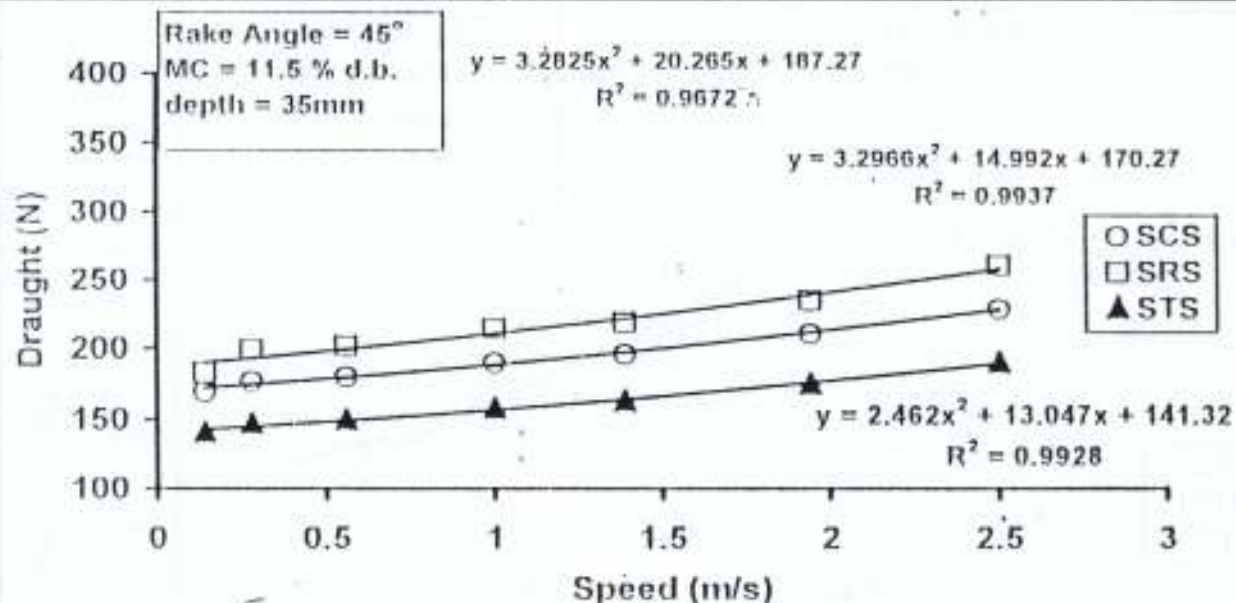


Fig.82: Effect of Surface finish on draught of implement

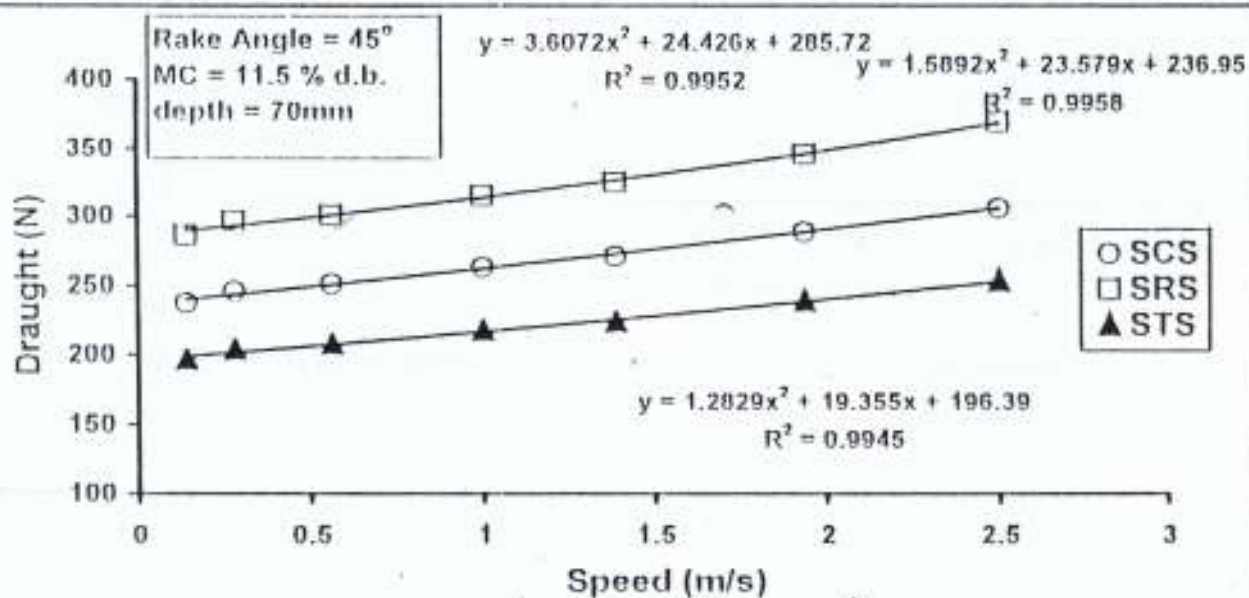


Fig.83: Effect of Surface finish on draught of implement

Rake Angle = 45°
MC = 11.5 % d.b.
depth = 150mm

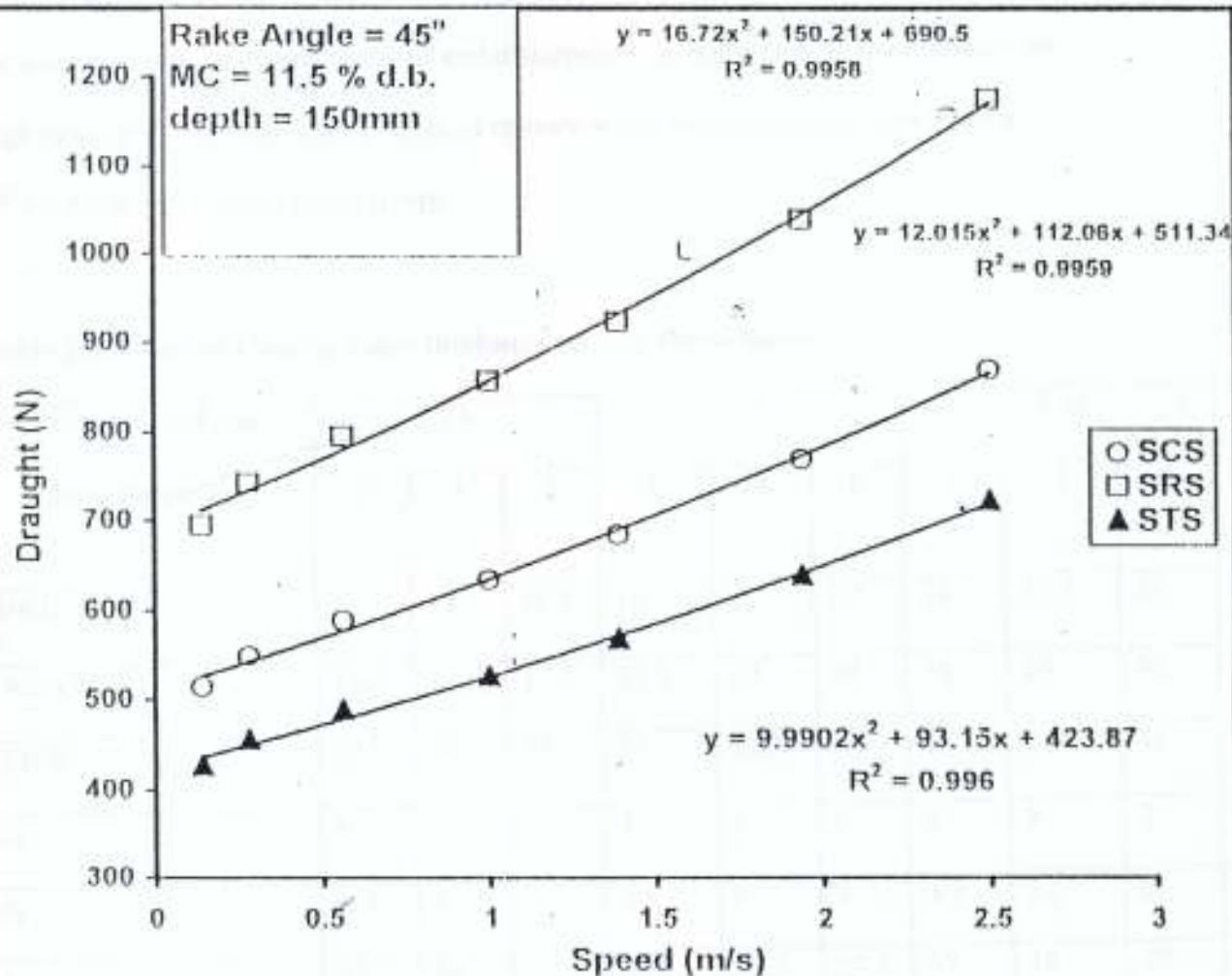


Fig 84: Effect of Surface finish on draught of implement

5.6.4 Effect of Cutting Edge Thickness

(a) On Soil Disturbance

Table 23 shows the effect of cutting edge thickness on soil disturbance.

For each tine type, the parameters of soil disturbance increased as the thickness of the edge increased. The rake angle, depth of operation and forward speed were fixed at 45° , 15.0 cm and 1.0 m/s respectively.

Table 23. Effect of Cutting Edge thickness on Soil Disturbance

Parameters of soil disturbance, cm	T1			T5			T20		
	1	4	8	1	4	8	1	4	8
RRD	10.5	13	16.5	18	22	27	33	37.5	39
WC (WFS)	12.5	13.9	17.5	21.5	24	28	36	39	40
TDW	14.5	19.5	23	31	32.5	36	45	47	48
d_r	5	6	7	4	5	6	3	5	7
h_r	2.5	3	4	5.5	6	7	3.5	4.5	6
f	12.5	14	17	20.5	23.5	27.5	37	38	39
Draught, N	100	119	148	314	389	494	752	900	1220
Specific Draught, N/cm	8.00	8.56	8.45	14.60	16.20	17.6	20.88	23.07	30.50
$\alpha = 45^\circ$ $d = 15 \text{ cm}$ $V = 1.0 \text{ m/s}$									

Increasing the cutting edge thickness from 1 to 8 mm increased the draught force by typical 48 to 62%. This increase compared well with 40 to 75% which Fielke (1996) reported for increased cutting edge thickens from 1 to 10 mm.

(a) On draught

The effect of cutting edge thickness on draught of implement in shown in Figures 85 and 86 where Draught force was plotted versus thickness of cutting edge of tines (T1, T5 and T20). In the two figures, depth, rake angle and moisture content were held constant at 15.0 cm, 45° and 11.0% db respectively. The forward speed was at two levels, that is, 1.0 and 2.5 m/s. At the levels of forward speeds, it was found out that an increase in draught. Moreover, the draught increased at an increasing rate with all the tines, however the rate curvature was greater with narrower tine. Second – order (quadratic) models were used to describe the relationship between draught and thickness of cutting edge. The R^2 values of the models ranged from 0.9937 to 0.9989.

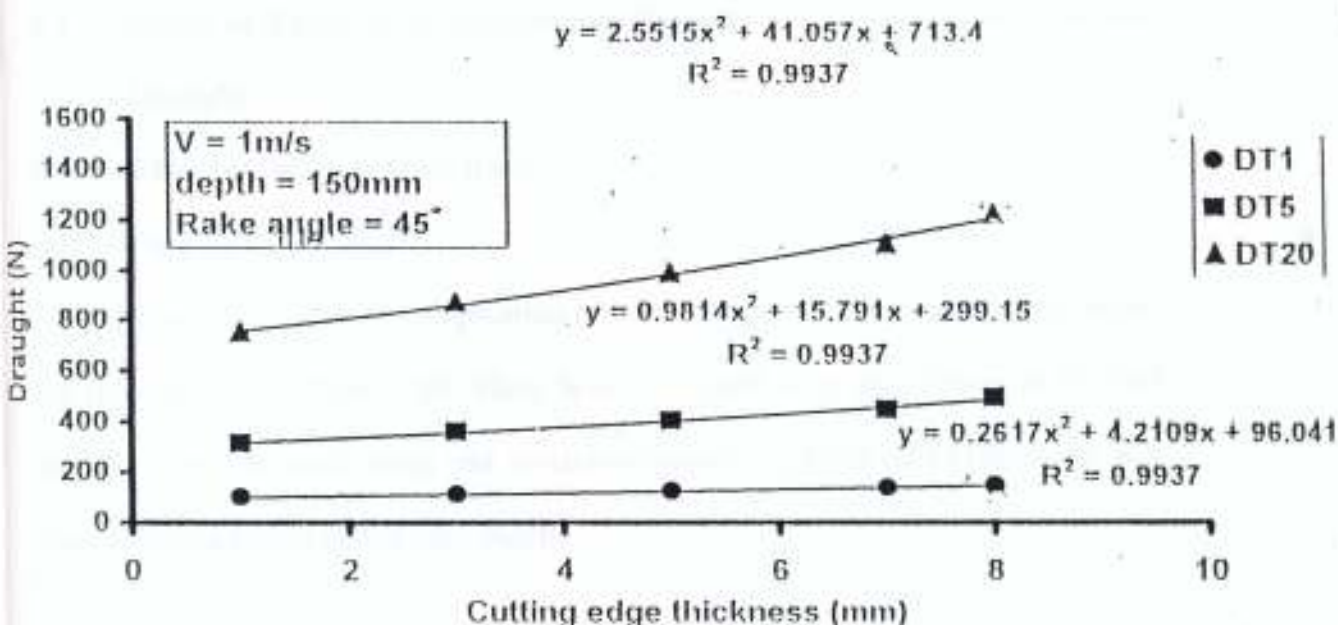


Fig.85: Effect of cutting edge thickness on draught of Tines

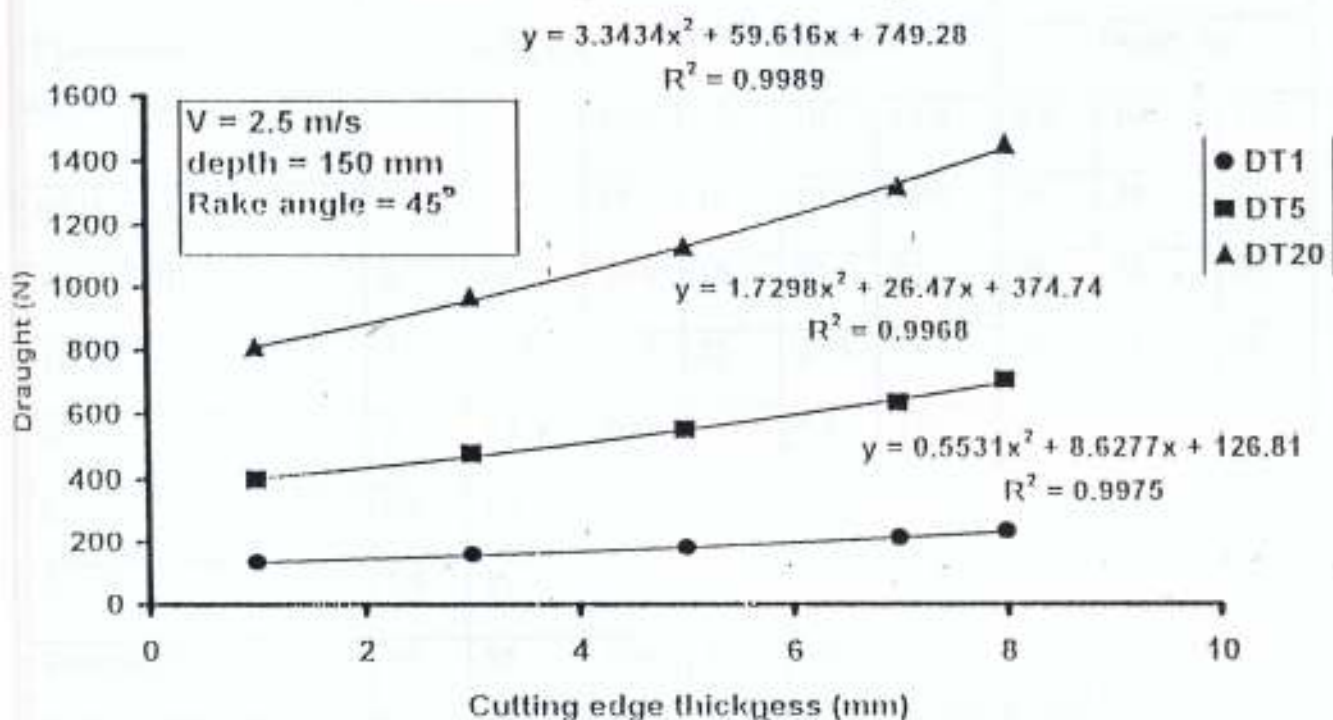


Fig.86: Effect of cutting edge thickness on draught of Tines

5.7 Effect of Variation in Operational Parameters on Soil Disturbance and Draught

5.7.1 Effect of Depth of Operation

(a) On Soil Disturbance

The effect of depth of operation of implement on soil disturbance was tested for three times T1, T5 and T20. Three levels of speed were also tested, at 90° -rake angle, 1.0 m/s forward speed and moisture content of 11.5% (db) (Table 24). It is clear from the results on the table that the

Table: 24 Effect of Depth of Operation on Soil Disturbance

Parameters of Soil Disturbance, cm	T1			T5			T20		
	Depth, cm			Depth, cm			Depth, cm		
	3.5	10	15.0	3.5	10	15.0	3.5	10	15.0
RRD	5	10	15	12	13.5	16.5	26	30	33
WC (WFS)	6	10	16.5	10.5	20	23	28	32	34
TDW	9.5	12.5	17.5	25	27.5	33	39	43.5	46
d_r	2	7.5	10.5	1.5	5.5	7.0	1.9	3.5	6.2
h_r	0.8	1.5	1.6	2.5	4.5	6.0	2.5	3.0	4.5
F	5.5	11	15	9.5	18	21	17.5	23	25
Draught, N	30	55	100	9.0	180	280	190	329	450
Specific Draught, N/cm	5.0	5.5	6.06	8.57	9.00	12.17	6.78	10.28	13.23
$\alpha = 90^\circ$ $V = 1.0$ m/s $mc = 11.5\%$ db									

The parameters of disturbance increased as the depth of operation of the tool increased. In the range of depth of operation tested, under this condition, the specific draught increased by about 21.2%, 42.0% and 92.18% for T2, T5 and T20 tines respectively.

(a) On Draught

The effect of depth of operation on draught of tines is presented in Figures 87 through to 89. In these figures, draught force was plotted versus depth of operation.

The three figures correspond to the three levels of forward speed V1, V2 and V3 whose numerical values were 0.28, 1.0 and 2.5 n/s respectively. The tines tested were T1, T5 and T20. It is clear from these figures that the relationship between draught force and depth of operation is a curvilinear one, not a straight line. Draught increased with increased depth of operation at an increasing rate. By regression analysis, exponential modes best suited the relationship with R^2 values ranging from 0.9784 to 0.9975. It was expected that draught of tine 20.0 cm (T20) be greatest while that of (T1) smallest.

The relationship between draught and depth of operation was similar to that report by Al – Suhaibami and Al – Janobi (1997), Grisso et al. (1996), Nicholson et al (1984). An increase in specific draught was observed with an increase in tillage depth and speed for all the implements tested. This also agrees well with the work reported by Al – Suhaibani and Al – Janobi (1997), Agbetoye et al. (1998). By comparing the three tools in this test, the draught requirements of the tines are in increasing order of magnitude: DT1, DT5 and DT20.

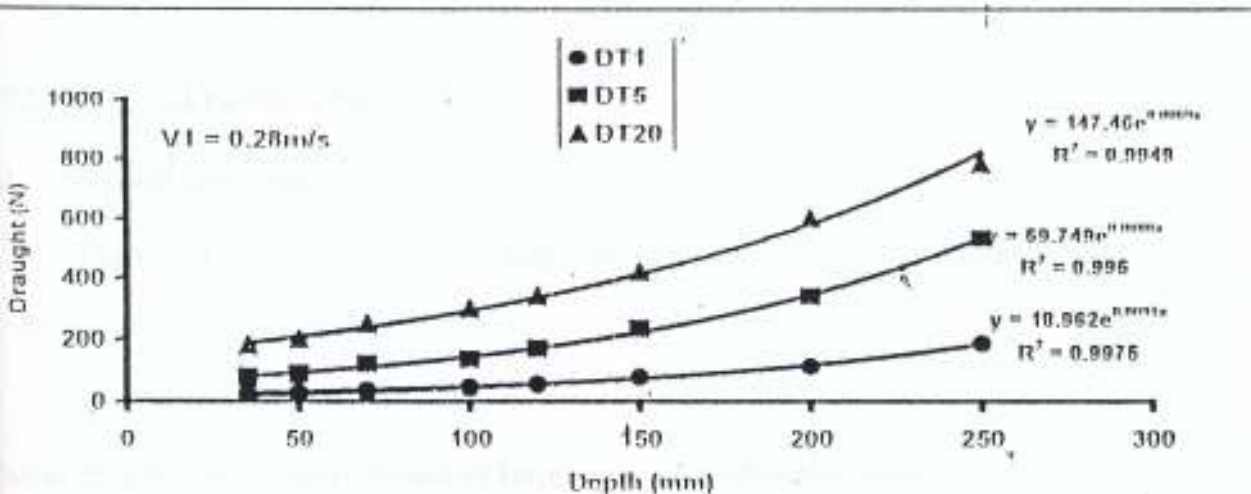


Fig87:Effect of Depth on draught of Tines

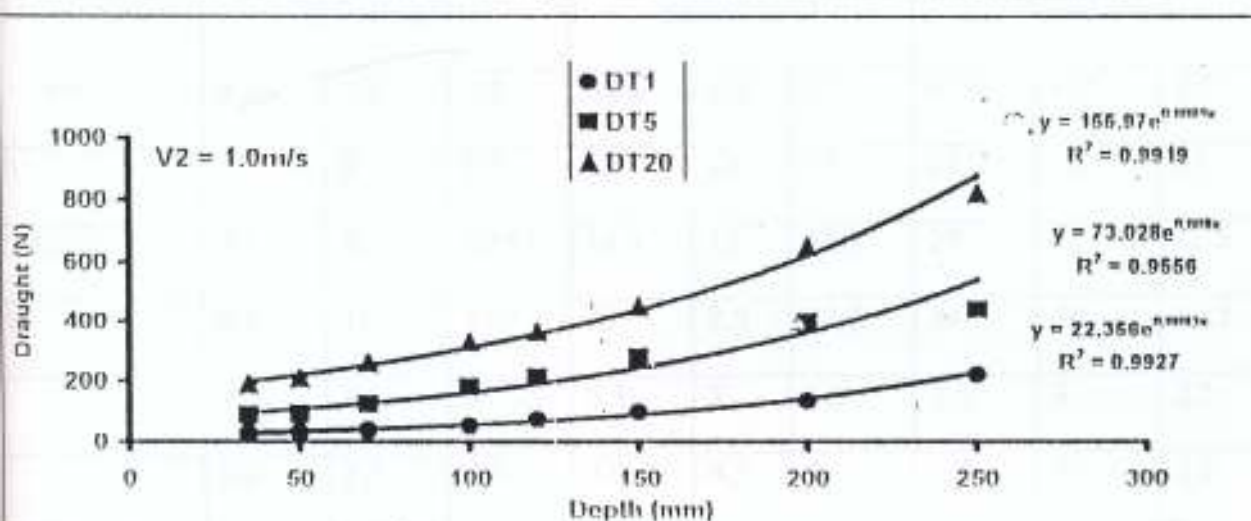


Fig88:Effect of Depth on draught of Tines

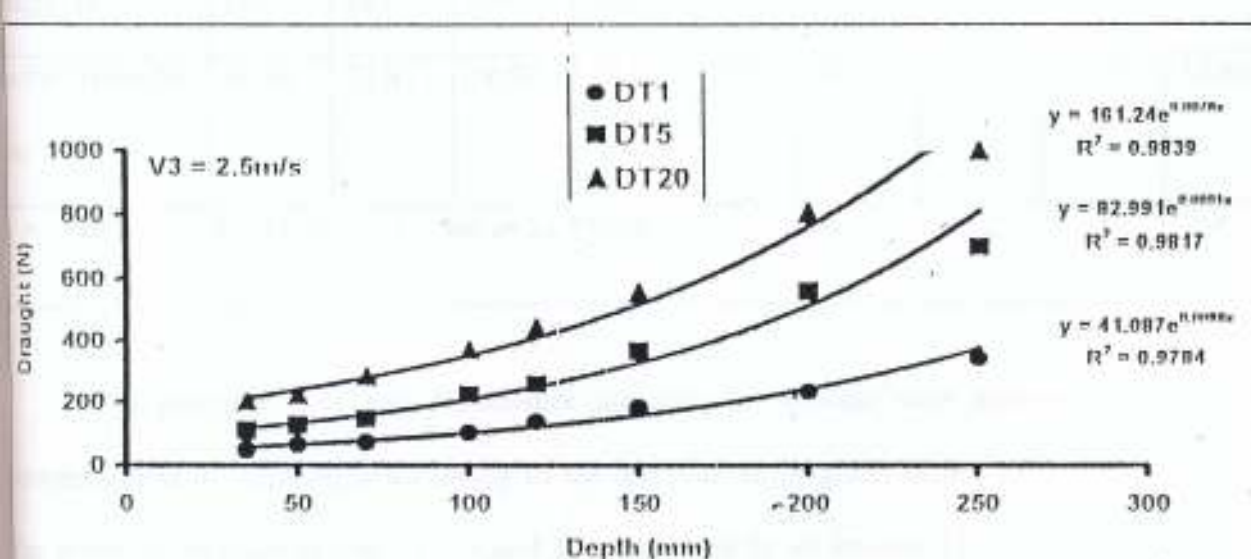


Fig89:Effect of Depth on draught of Tines

5.7.2 Effect of Forward Speed

(a) On Soil Disturbance

The effect of forward speed of implement on soil disturbance of experiment tines is presented in Table 25.

Table: 25 Effect of forward Speed of Implement on Soil Disturbance

Parameters of oil Disturbance, cm	T1			T5			T20		
	Speed (m/s)			Speed (m/s)			Speed (m/s)		
	0.56	1.0	2.5	0.56	1.0	2.5	0.56	1.0	2.5
RD	4	8	9.5	13.5	15	17	22	18	31
/C (WFS)	4.5	8.5	10.5	14.5	17	18.5	23	31	32.5
DW	6.5	11	12.5	23	2.9	32.5	34	40	42.5
	1.5	4.5	6	3.5	5	5.5	2.5	3	3.5
	0.9	1.5	2.8	3.0	4.5	5	1.8	2.5	2.8
	12.0	12.5	13.0	21.5	22	23	25.5	26	26.5
Draught, N	165	182	300	420	470	720	680	750	1068
Specific Draught, N/cm	36.66	21.41	28.57	28.96	27.6	38.91	29.56	24.19	32.86
= 90° d = 15 cm mc = 11.5% db									

The parameters of soil disturbance are seen to increase with increase in forward speed of implement according to the test conditions given in the Table 25. The width of crescent of tine T1, T5 and T20 increased by an amount 133, 27.7 and

41.3 % in the range of speed given. In the same manners the rupture distance increased correspondingly by an amount equal to 8.3%, 6.9% and 3.92%.

(a) On Draught

The effect of speed on draught of tines is shown in Figures 90 and 91. In the two treatments, depth of operation and moisture content were held constant at 15.0 cm and 11.5%(db) respectively. In Figure 90, the rake angle is 45° while it is 90° in Figure 91

Draught increased with speed at an increasing rate. Quadratic regression equation best described the relationship. This is similar to that reported by Collins et al. (1978), Koolen and Kuipers (1983). Draught increased at an increasing rate with speed of operation. It is also noted that draught increased from about 44% to 114% due to the difference in rake angles of 45° and 90° .

Spoor (1969) reported that increased forward speed increased draught with most implements, mainly because of the more rapid acceleration of the soil. Greater forces are required to provide this acceleration and since they also increase the reaction at the interface a higher sliding resistance contributes most of the increased draught force.

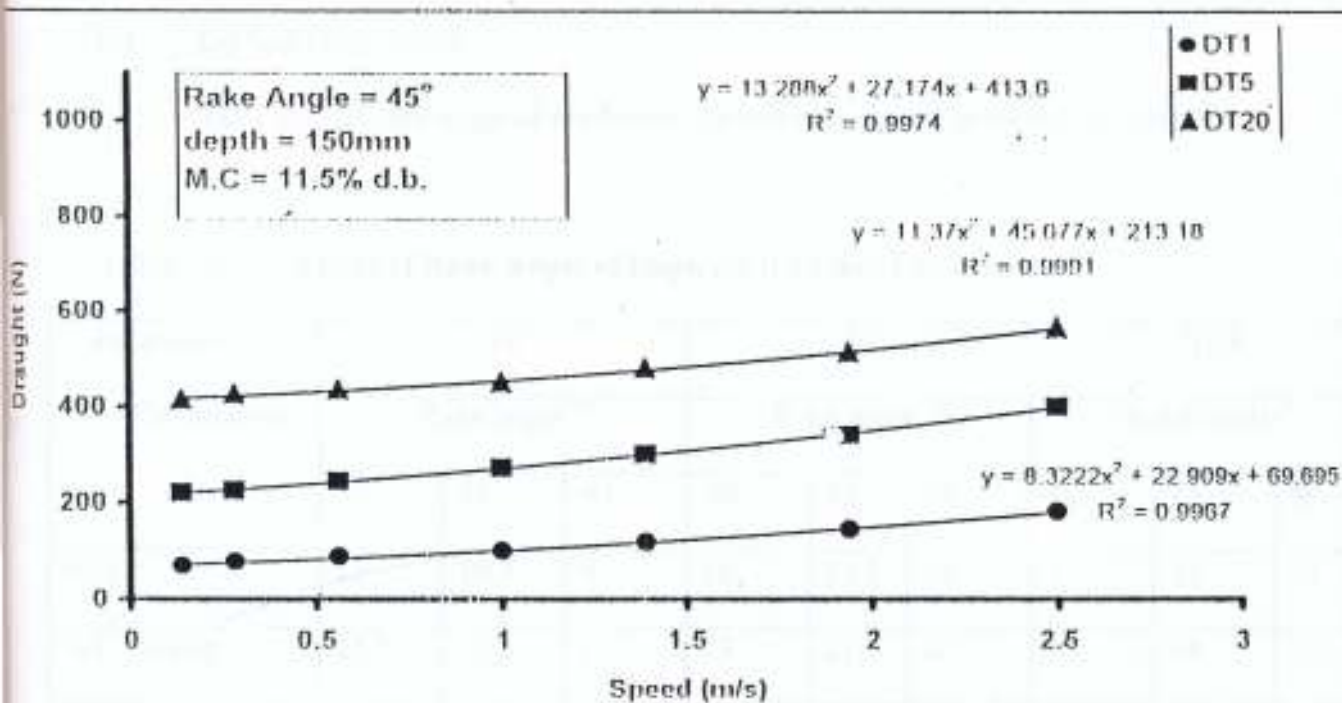


Fig.90: Effect of Speed on Draught of Tines

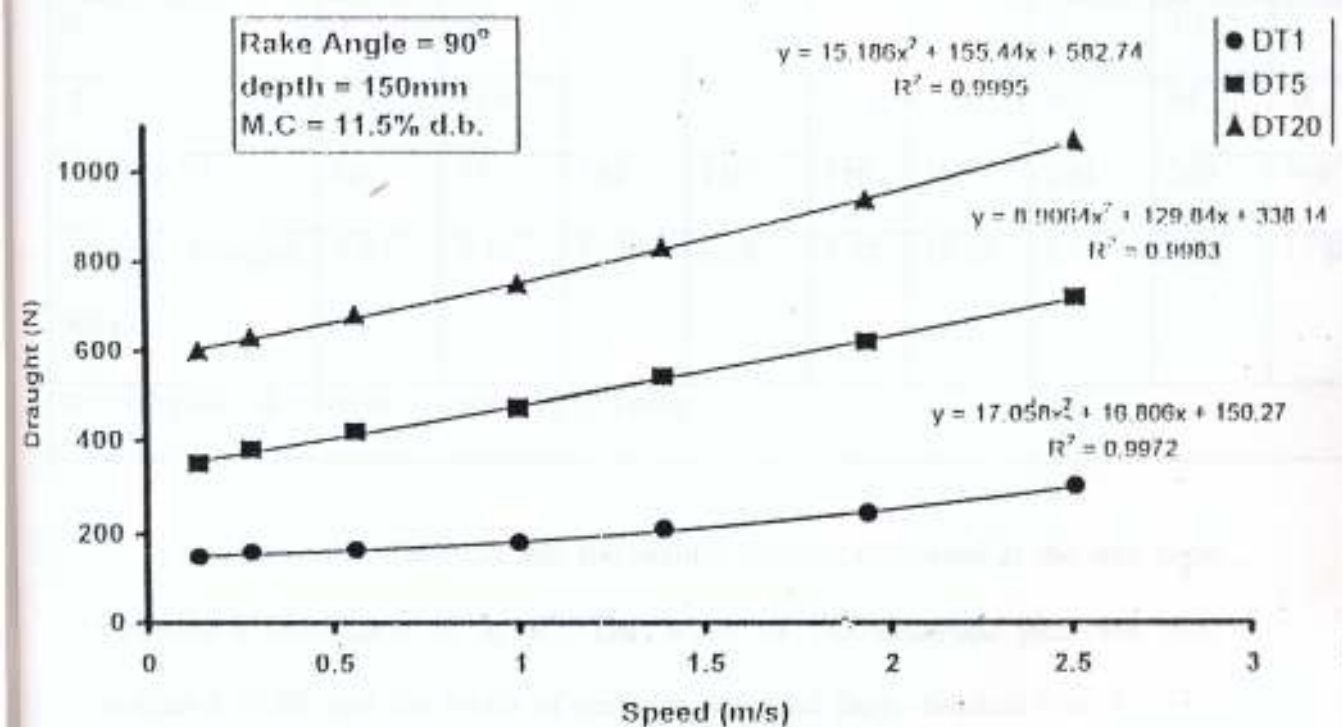


Fig.91: Effect of Speed on Draught of Tines

5.7.3 Effect of Rake Angle

(a) On Soil Disturbance

The effect of rake angle of implement on soil disturbance is shown in Table 27

Table: 26 Effect of Rake Angle of Implement on Soil Disturbance

Parameters of Soil Disturbance, cm	T1			T5			T20		
	Rake angle, °			Rake angle, °			Rake angle, °		
	30	45	90	30	45	90	30	45	90
RRD	12	10.5	9	16	14.5	13.5	37	33	30
WC (WFS)	13.5	12.5	11	23	21.5	20	36	34	32
TDW	21	19.5	17	33	31	27.5	47	45	43.5
d_r	4.5	5	6.5	4.5	5	5.5	2.5	3	3.5
h_r	3	2.5	1.5	6	5.5	4.5	4	3.5	3
f	13.8	12.5	11	23	21.5	20	36	34	32
Draught, N	60	55	142	140	120	250	290	280	500
Specific Draught, N/cm	4.44	4.40	12.90	6.08	5.58	12.50	8.05	8.23	15.62
V = 1.0 m/s d = 10 cm mc = 11.5 % (db)									

It is seen in this Table 26 that the rupture distance decreased as the rake angle increased in the range of 30° to 90° . The width of the disturbed area: the total disturbed width and the width of crescent remained fairly constant (that is small increases recorded) with change in rake angle. However, there is a slight increase. These trends were also reported by Spoor (1969).

The effect of rake angle on draught of tines is shown in Figures 92 through to 94. The three tines tested were T1, T5 and T20. In the three treatments, the forward speed (1.0 m/s). Moisture content (11.5% db) were held constant. The three levels of depth s are 5.0 cm, 10.0 cm and 20.0 cm.

Generally, it is seen that draught increased quadratically with increased rake angle and the draught requirements of the tines increased in ascending order of magnitude. DT1, DT5 and DT20. The R^2 values of the regression quadratic models ranged from 0.9691 to 0.9949. It is also noted that, draught increased as the depth of operation increased.

It was reported (Spoor, 1969; Gupta et al., 1989) that the tine rake angle has a very large effect on the draught force. The draught increase slowly from rake angles of 10° to 50° , above 50° however, the rate of increase is very rapid indeed. Therefore for minimum draught, rake angles of less than 50° should be used providing that tines set at this inclination will do the job satisfactorily.

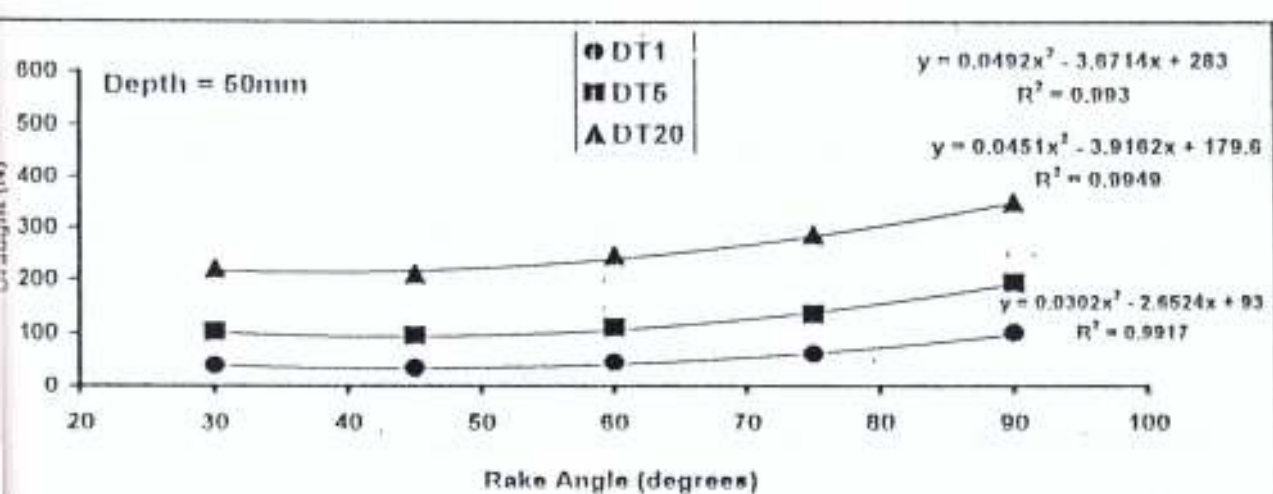


Fig.92: Effect of Rake angle on Draught of Tines

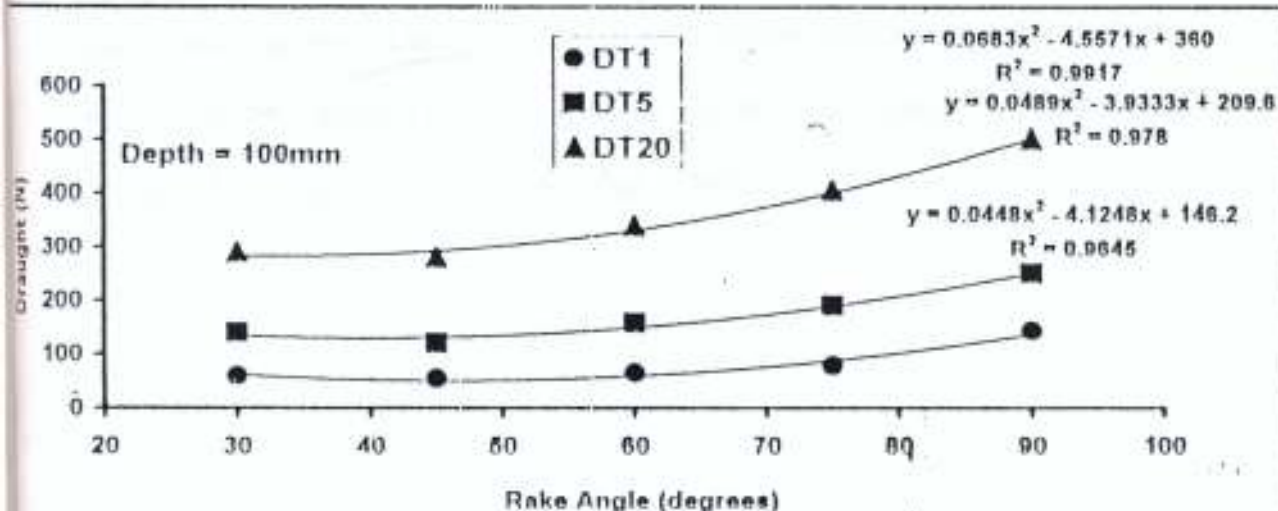


Fig.93: Effect of Rake angle on Draught of Tines

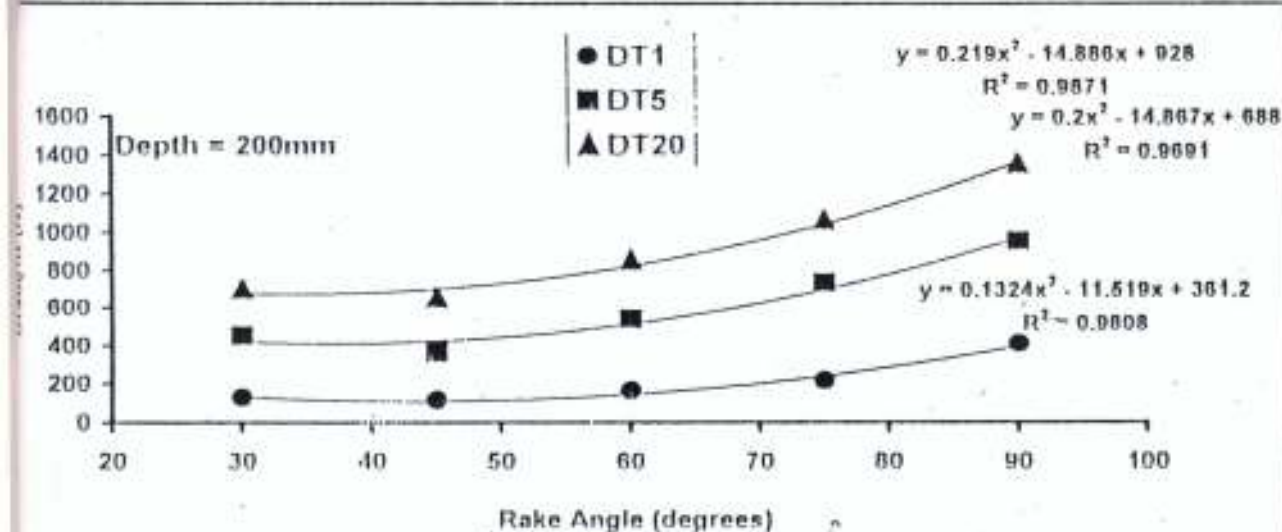


Fig.94: Effect of Rake angle on Draught of Tines

5.8 Tillage Power

Tillage power is the rate of doing work in tillage operations. It is estimated as the product of the horizontal force (Draught) and the forward speed of the tractor-implement system

5.8.1 Power Requirements of Model Tillage Tools

The power requirements of the tillage tools in this study can be estimated from the respective draughts and forward speeds. However, the draughts depend on a number of parameters such as implement parameters, soil parameters and operational parameters discussed in this study. The range of power requirement in this study was 0.161 to 92.28 Watts and this is comparable with the work reported by Al-Suhabani, S.A and Al-Janomi, A (1997); Grisso et al. (1996)

6. CONCLUSIONS AND RECOMMENDATIONS

There has been a dearth of knowledge in the specialized area of soil tillage dynamics in this country (Nigeria) and this has made the development of facilities and equipment for soil tillage dynamics to be long overdue. In order to proffer solutions to some of the problems of soil tillage dynamics in Nigeria and to hearken to the calls of some researchers in this regard, a comprehensive research project was embarked upon. The research aimed to develop equipment for soil tillage dynamics research and to evaluate the different tillage parameters. At the end of this study, the following conclusions were drawn.

6.1 Development of Soil Tillage Dynamics Equipment

A soil tillage dynamics equipment has been developed (designed, fabricated, assembled, tested and used to evaluate tillage parameters). The equipment consists of a soil bin, soil processing trolley, tool carriage, tool carriage subframes (including adjustable and fixed types). Other items of the equipment developed for this study is the soil-material friction measuring device. It was used to measure or evaluate angle of soil-interface friction.



6.2 Properties of Agricultural Soils

Physical, chemical and mechanical properties of some agricultural soil were determined for the purposes of;

- (a) Knowing the suitability of the soil for agricultural production
- (b) Developing soil engaging implements.

The soil tested were loamy sand, clay, sandy loam and sandy clay loam (bin soil). Mean values for bulk density, saturated hydraulic conductivity, clay ratio and loss on ignition were 1.56 Mg/m^3 , 5.3 mm/min , 13.6 and 1.12 respectively for the moist condition considered for loamy sand soil.

For the clay soils, the mean values in the moisture range of friable consistency ranged between 1.03 to 1.2 Mg/m^3 for bulk density, 0.012 to 0.02 mm/min for saturated hydraulic conductivity, 66.7 to 104.0 for clay ratio and 1.78 to 2.43 for loss on ignition.

For the sandy loam soils, the mean values in the moisture range of friable consistency were: 1.35 to 1.42 Mg/m^3 for bulk density; 0.38 to 0.92 mm/min for saturated hydraulic conductivity; 6.4 to 16.2 clay ratio and 2.91 to 4.31 loss on ignition for the sandy clay loam soil (bin soil), the mean values of the physical properties in the moisture range of friable consistency were: 1.39 to 1.55 Mg/m^3 for bulk density; 0.85 to 1.22 mm/min saturated hydraulic conductivity; 33.3 to 44.9 clay ratio and 3.12 to 3.92 for loss in ignition. The chemical properties also revealed the organic carbon, macro-element, nitrogen, available phosphorus, cation exchange capacity and others.

6.3 Soil Parameters

Mean values were obtained for cohesion of the soils. Cohesion was lowest in loamy sand soil, about 1.62 kPa . It was followed by sandy loam soil, about 10 to 15.6 kPa . Cohesion of sandy clay loam was next about 23.0 to 30.6 kPa . Cohesion was highest in clay soil about 35.2 to 44.2 kPa .

Similarly, the cone index of the soils averaged 130 kPa for loamy sand; about 752 to 870 kPa for sandy loam soil and 870 to 1340 kPa for clay soils.

The effect of compaction on the agricultural soil was also studied.

It was found out that loamy sand soil achieved higher bulk densities when the soil is approaching saturation, which was thought as a feature of the unique particle re-arrangement of sands with changing water content rather than the effect of an applied pressure at intermediate water contents.

Effect of moisture content and applied pressure on compaction of clay soils showed that clay soils are highly susceptible to compaction especially when their consistency changed from moist to wet. Therefore clay soils should be trafficked in dry periods and with a low ground pressure as possible.

Compaction characteristics of sandy loam soils showed that increase in compaction are less dependent on moisture content but rather almost entirely due to applied pressure, though these were not high neither. Therefore as sandy loam soils are water content insensitive, there is unlikely to be much danger as a result of traffic on agricultural soil of the type of sandy loam.

Effect of moisture content and applied pressure on the compaction of the soil of the three layers (or horizons) of the bin soil showed that sandy clay loam soils are extremely sensitive to water content at the time of compaction. The percentage increase in soil compaction for the sandy clay loam is related more to changes in water content than to applied pressure. Therefore scheduling tillage operations on these type of soil will have greatest benefit in lowering soil compaction, notwithstanding changes in ground pressure.

Effect of applied pressure on bulk density of sandy clay loam soil (bin soil) was also investigated. Models were proposed. These models or compaction behaviour equations would enable us to apply bulk density into the mechanics or soil-tool interaction for Nigerian soils. The compaction behaviour equations that were

adjudged best for the soil type are of the forms: linear; logarithmic; exponential and power fit equations.

Effect of moisture content and compaction on strength properties of the sandy clay loam soil (bin soil) showed that the shear strength and cone index of the soil first increased with moisture content up to a maximum and then decreased with higher moisture contents. At low moisture contents, the strength of the soil increased with increasing moisture content because the addition of moisture created greater pore water pressures when stresses were applied.

The Angle of internal friction of the soil were also determined. The mean values are 39.6 to 40.2 degrees for loamy sandy soil; 25.3 to 30.1 degrees for clay soils; 29.6 to 32.9 degrees for sandy loam soils and 30.7 to 33.0 degrees for sandy clay loam soil (bin soil).

The Angle of soil-interface friction was determined for the soil in the form of coefficient of soil-interface friction. The surfaces considered were rubber (RUB), smooth steel (SST), galvanized steel (GAS) and Teflon coated surface (TEF). Generally, the coefficient of soil-interface friction was highest with rubber, followed by smooth steel and lastly Teflon.

6.4 Performance of the Soil Bin and Equipment

The performance of the soil bin and equipment had been satisfactory in the last two years of its use. The equipment had continued to be functional without any problem whatsoever. The soil bin had been strong enough because there was no buckling of side walls not sagging or railings. The processing trolley had functioned satisfactorily since there was no hitch in its operations. It is more or less trouble-free.

All the other components performed or functioned normally and satisfactorily: that is, the tool carriage; the tool bar; the tool carriage subframes (adjustable and fixed) types.

6.4.1 Equipment and Soil tillage Dynamics Studies

The equipment developed had been used to study soil tillage dynamics. The following studies were carried out:

- (i) Effect of variation in soil parameters on soil disturbance and draught.

It was established that draught of implements increased at a decreasing rate as the soil moisture content increased from 11 to 22.5% (db) in the sandy clay loam soil (bin soil). Polynomial equations best described the relationships with very good R^2 values. Soil disturbance parameters were also evaluated and reported in this thesis.

It was also established that draught of implement increased at an increasing rate as the penetration resistance (cone index) increased by means of compaction. The curves were also fitted by polynomial (quadratic) equations with very good R^2 values.

- (ii) Effect of variation in implement parameters on soil disturbance and draught.

Results show that the parameters of soil disturbance increased with increase in tine width. It was also established that draught increased at a decreasing rate with tine width. The increase is also affected by the forward speed since higher draught values were obtained at higher forward speeds.

Draught is affected by shape of the implement. In increasing order of magnitude, the draught of the experimental blades increased in the order: BVE; BTR; BCV; BSC; BCC and TWT. That is, the BVE blade had the least

draught requirement while the TWT (wide tine) had the highest draught requirement. In all the blades, the draught increased gradually at an increasing rate.

The draught of an implement is also affected by the surface finish of the implement. In this study it was established that draught force requirement was highest for rusted steel surface (SRS) followed by steel clean surface (SCS) and least for Teflon coated surface (STS). For these surfaces, draught increased gradually at an increasing rate.

The cutting edge thickness also affected the draught of implement. Increasing the cutting edge thickness from 1 to 8 mm increased the draught force by typically 48 to 62%. Draught increased at an increasing rate for all the edge thicknesses.

(iii) Effect of variation in operational parameters on soil disturbance and draught

It has been shown that depth of operation affected draught of implement and soil disturbance. The relationship between draught force and depth of operation was curvilinear. Draught increased with depth of operation at an increasing rate. The relationship was best fitted by exponential equation.

Forward speed also affected draught of implements. It was found out that draught increased with forward speed at an increasing rate. Quadratic models best described the relationships.

Rake angle also affected the draught of implements and soil disturbance. It was shown that draught increased quadratically with increase in rake angle and at an increasing rate. Minimum draught was observed at about 45° rake angle. On soil disturbance, it was observed that, rupture distance decreased as the rake angle increased in the range of 30° to 90° . The width of the disturbed

area remained fairly constant (that is, small increase recorded) with change in rake angle. However, there is a slight increase in width as the rake angle decreased.

6.4.2 Specific Power of Model Tillage Tools

The specific power requirements of model tillage tools in this study ranged between 0.161 to 92.28 Watts. This was found comparable with the work reported by other researchers under similar conditions.

6.5 Recommendations

The following recommendations are given for further study.

- (1) Further work should consider tests in other textural soils, and possibly at higher forward speeds.
- (2) Research in soil tillage dynamics should be adequately funded by Government so that large full scale (outdoor) soil bins can be developed for full scale implement testing and evaluation.

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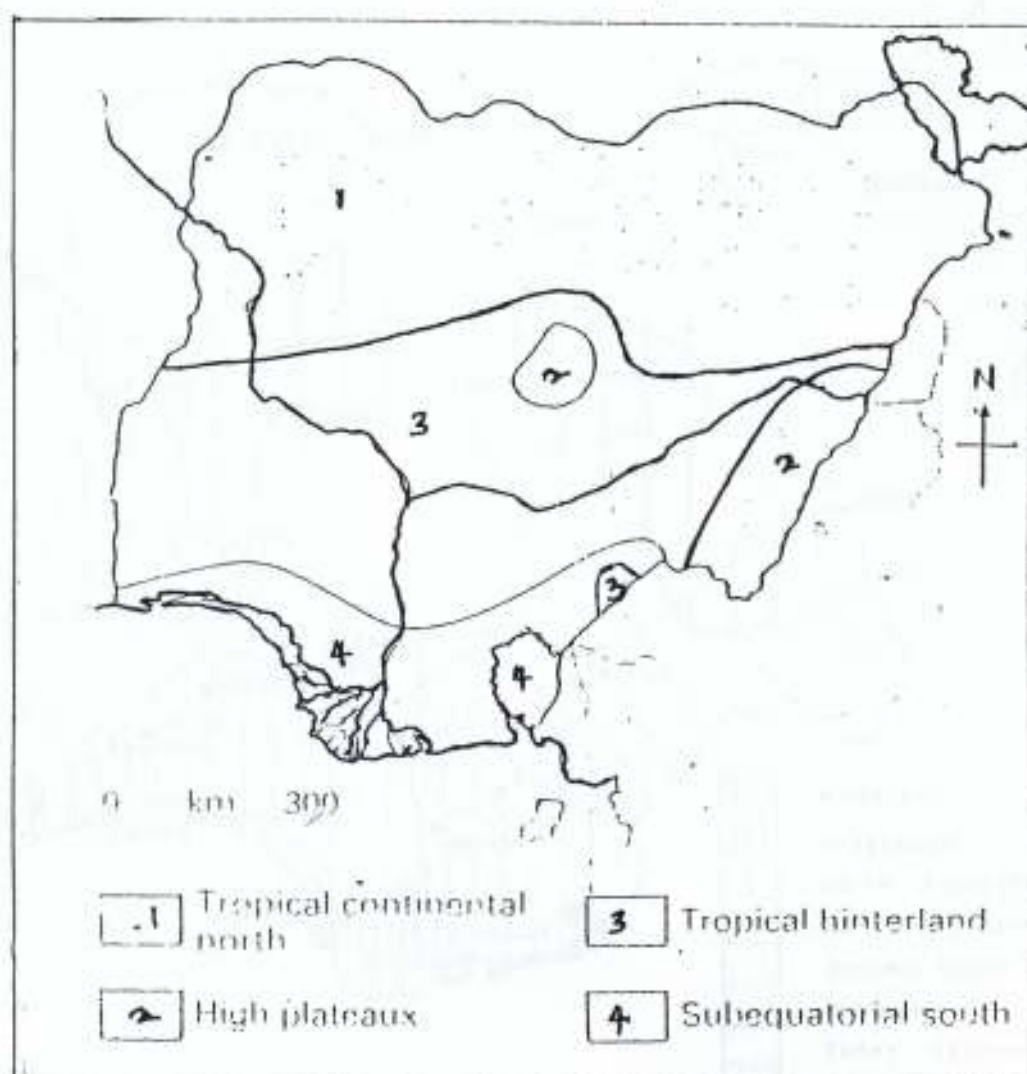
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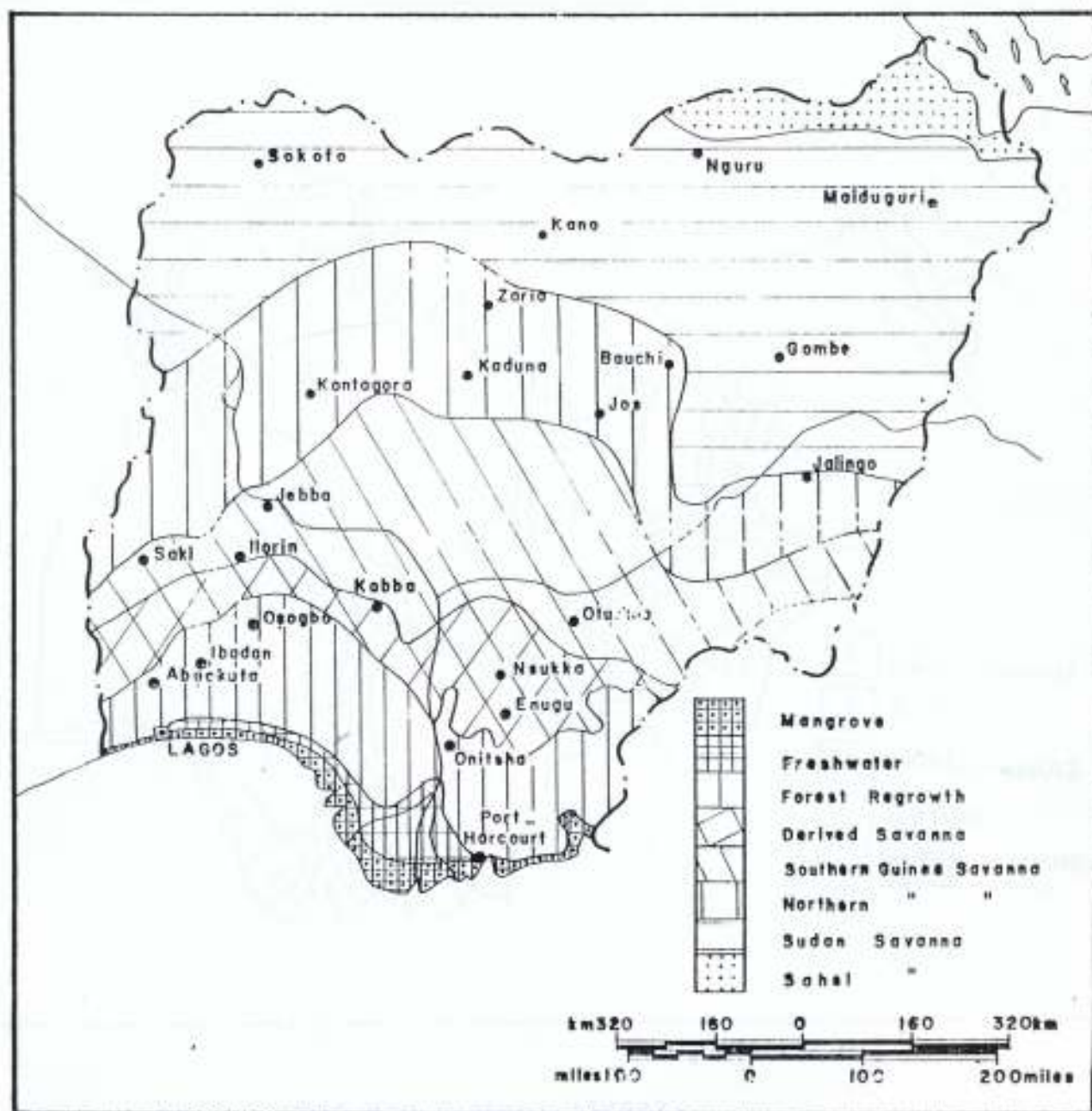
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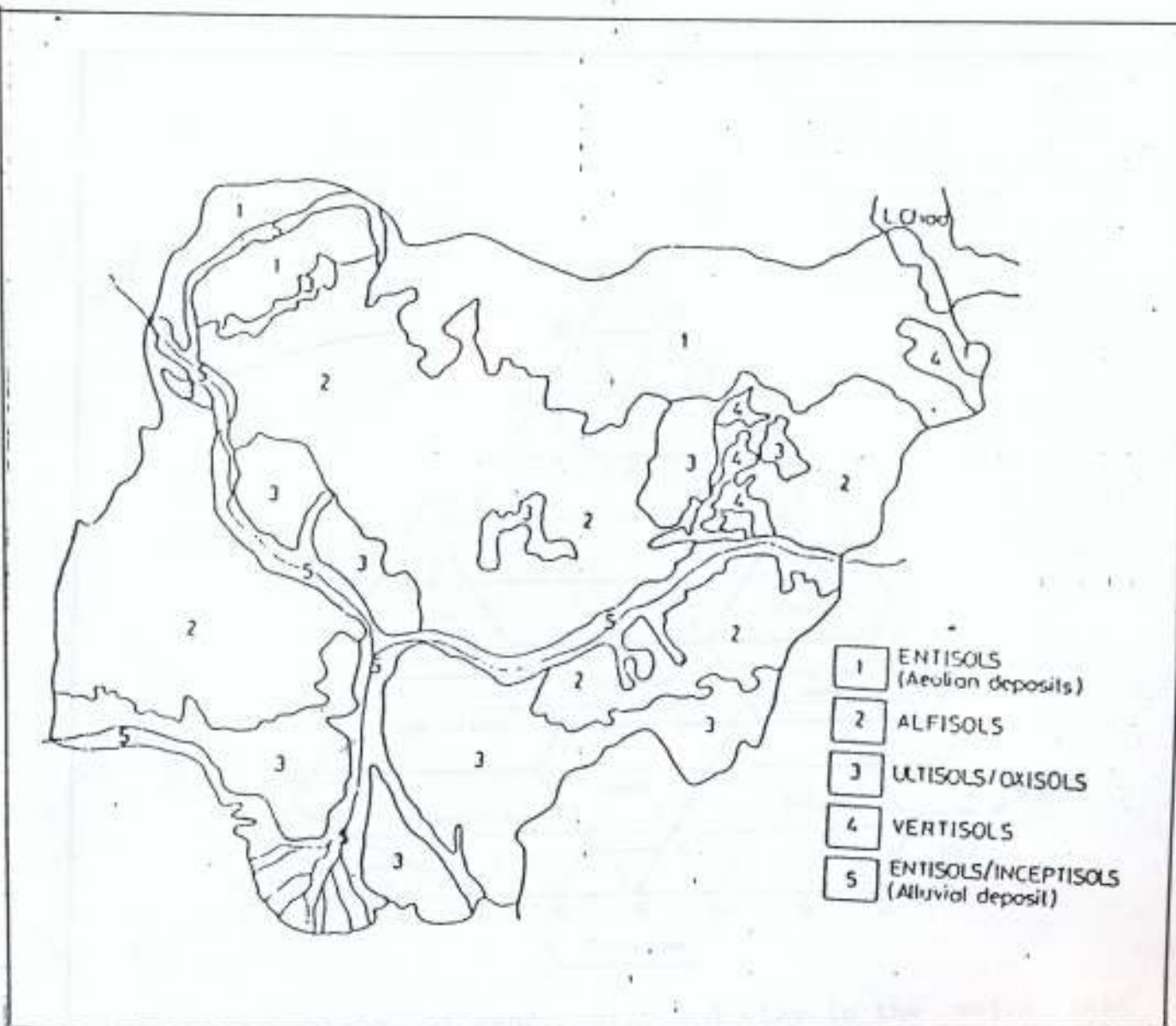
APPENDIX A1 - Climatic Regions of Nigeria



Source ; Illoeje (1981)

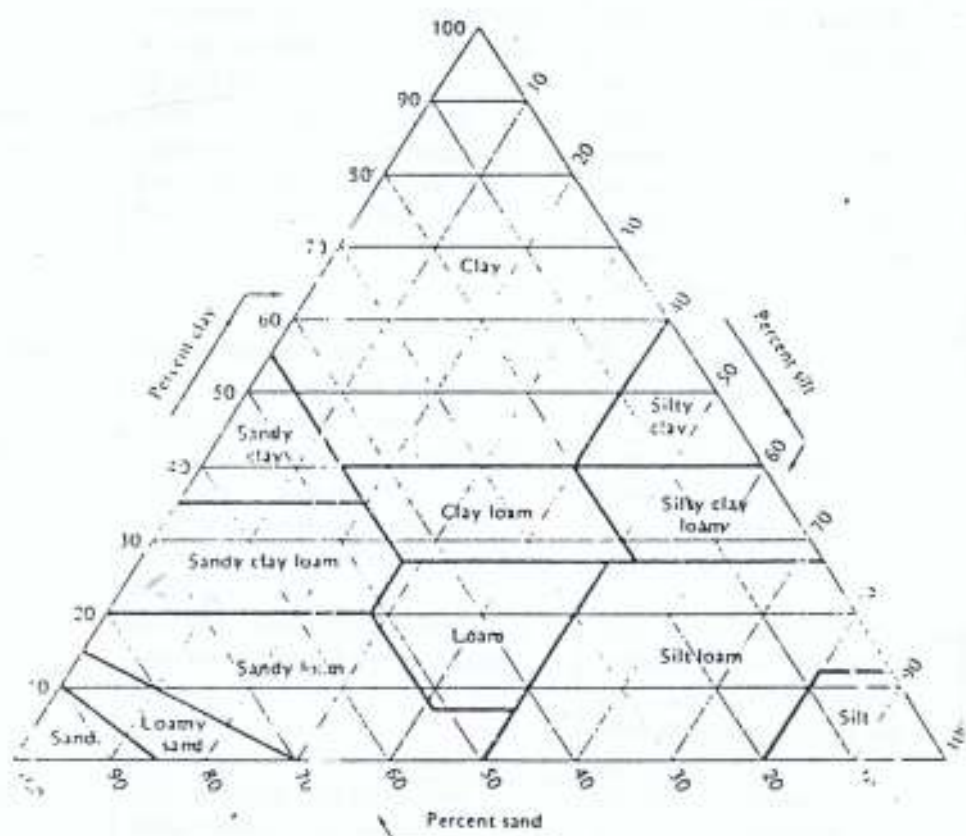


Source; Agboola (1979)



Source Combin and Fagbami (1994)

APPENDIX A4 Soil Textural Triangle



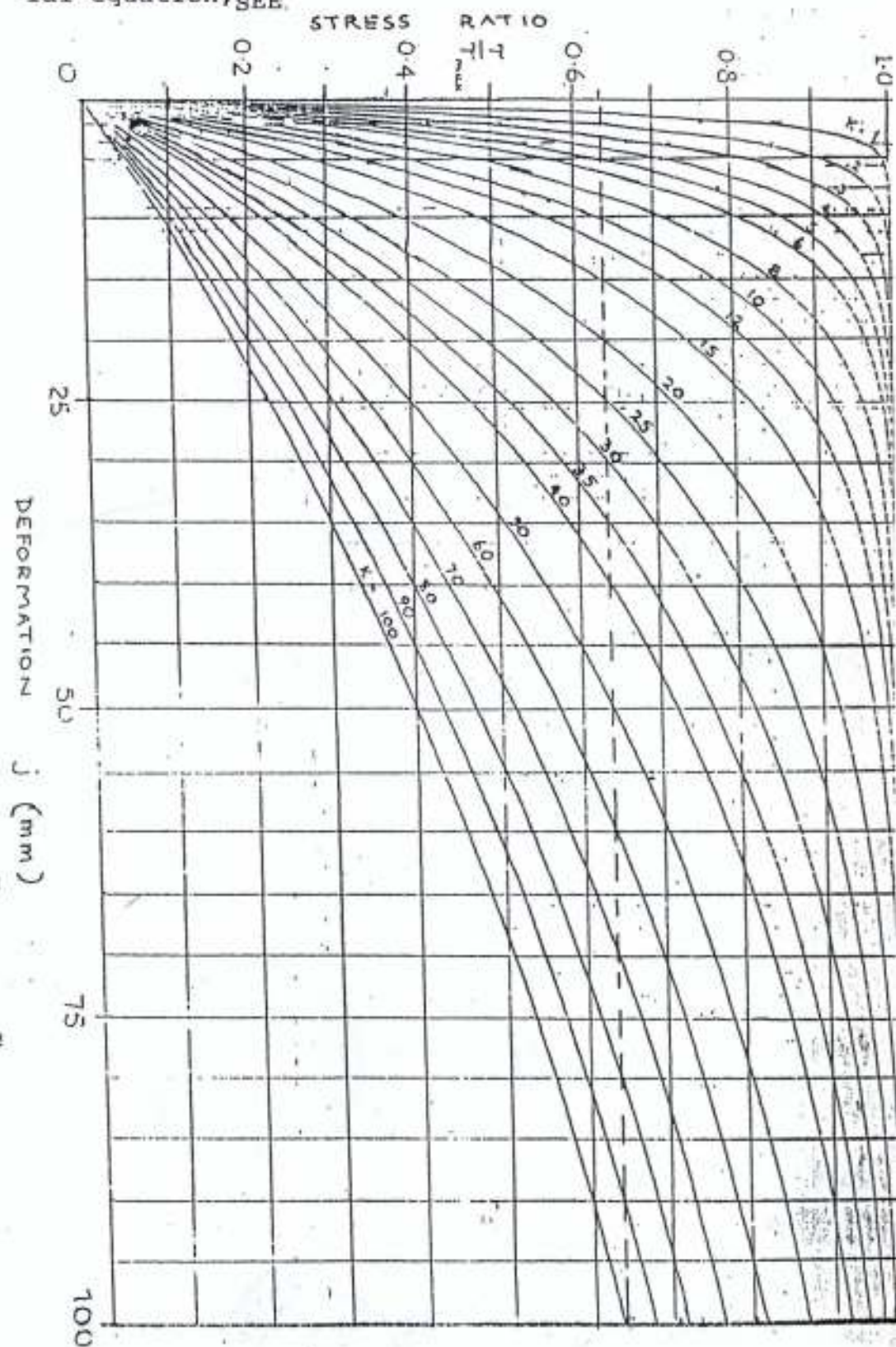
Percentage of sand, silt and clay in the major soil textural classes (Brady, 1984)

Appendix A5: Summary of the global soil orders*The New American Soil Classification System: Summary of the Global Soil Orders.*

Soil order	Diagnostic properties	Equivalent soils
Entisols	No diagnostic horizons or profile development	Azonal soils tundra litho - sols, regolith, alluvium, sands
Vertisols	Dark topsoils that crack badly when dry; slanted columnar structure	Grumusols, tropical black clays, regur, tirs
Inceptisols	Young soils, with profile nature tip beginning; no clear - cut diagnostic horizons, usually dark epipedons	Subarctic brown forest, brown forest, ando, lithosols, regosols, some humic gleys
Aridisols	Desert soils that have one or more diagnostic horizons but no spodic or oxic horizons; light - coloured epipedons	Desert, red desert, Grey desert (sierozem), reddish - brown. Lithosols, regosols, solod, solonchak
Mollisols	Dark brown to black, mellow epipedons; one or more diagnostic horizons except spodic or oxic horizons; often or calcareous horizon	Chernozems, prairie (brunizem), chestnut, red prairie, humic gleya, . planosols, black rendzinas, some brown forest, reddish - chestnut soils, solonchak solonetz
Spodosols	Spodic horizon; usually also an albic horizon; usually coniferous forests over sandy soils	Podzols, brown podzolic, groundwater podzols
Alfisols	Pronounced argillic horizon without a spodic or oxic horizon; may have a nitric horizon; no pronounced colour changes vertically; high base exchange	Grey - brown podzolic, grey forest non - calcic brown soils, planosols, half - bogs, solods, terra rossas
Ultisols	Red or yellow argillic horizon, no oxic horizon low base exchange throughout	Red - yellow podzolic, reddish - brown lateritic, rubruzem, humic gleys, low - humic gleys, ground water laterites
Oxisols	Oxic horizon with many free sesquioxides, little horizon differentiation; deep soils	Litosols, ferrallites, groundwater laterites, laterites
Histosols	A surface organic layer at least 30 - 45 cm thick	Peat, muck

Source: Faniran and Areola (1978)

APPENDIX A7 Family of curves given by the simplified exponential equation, SEE



The family of curves given by $\tau = \tau_m [1 - e^{(-j/K)}]$

Note: j and K in any identical units.