

# EVALUATION OF TILLAGE INDUCED SOIL PHYSICAL ENVIRONMENT AND WHEAT PERFORMANCE

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IN

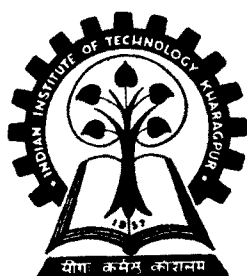
SOIL SCIENCE

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### C E R T I F I C A T E

The thesis entitled " Evaluation of Tillage Induced Soil Physical Environment and Wheat Performance " is submitted by Shri D. B. Rane to the Indian Institute of Technology, Kharagpur for the award of the degree of Doctor of Philosophy in Soil Science. The experiments described in the thesis are the record of bonafide research work carried out by him under my supervision and guidance. In my opinion, the thesis is worthy of consideration for the award of the degree of Doctor of Philosophy in accordance with the regulations of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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## Chapter I

### INTRODUCTION

Our conceptions of the functions of tillage practices have changed materially over the last 15 years and there is yet much that is not understood. Since tillage is the largest single item that shares the major amount of cost of production, it entails that the energy used should be a minimum consistent with optimum monetary returns. Improved tillage practices accompanied by development in new tillage tools came up through the use of trial and error method. Though various tillage practices and implements have been compared and evaluated in terms of crop yields, a little attention has been paid to the changes that are induced by them. Many a time, excess tillage is given, though it is not essential for the crop yields, for the want of an optima for a crop in question under the prevailing soil-climate complex. If optimum conditions are well defined, the tillage cost may be brought down considerably.

Realising the high cost involved in tillage as early as 1943, the Joint Committee on Soil Tilth, established by the American Societies of Agronomy and Agricultural Engineering rightly pointed out :

" No amount of empirical experimentation will tell us whether sub-surface tillage is superior to ploughing, whether ploughing is superior to disking or what changes are desirable in the design of tillage machinery. Before any progress in this direction can be made, we must know what soil physical state is desired for a given crop under specified climatic conditions. Hence,

there is a need to measure the changes produced in soil by our different management practices".

Tillage studies are now being undertaken to determine how tillage alters soil condition especially in relation to growth and yield of crops. Cook et. al. (1953) introduced the concept of minimum tillage and proved that for some crops the number of tillage operations could be reduced without sacrificing the yield. This work has formed the basis for the two zone concept of row crops (Larson, 1964). More recently, the practice of no-tillage has been introduced for growing some crops successfully under a specified climatic condition (Free et. al., 1963; French and Blake, 1965).

It is necessary to define the requirements of crop root system in detail before drawing any conclusion because of the inability of no-tillage or minimum tillage to achieve its objectives under varying agro-climatic condition. During the last 20 years, agricultural scientists and engineers are actively engaged to find out the requirements of crop plant at varying stages of growth in terms of quantitative measurements of soil physical environment. It is no secret that physical edaphic factors, namely : soil water, soil aeration, soil temperature and mechanical impedance govern to a large extent the emergence of seedlings, growth of roots and shoots and the final yield of crop. Once the range of each factor for a crop is known, it is not too difficult to provide the desired soil environment to the growing plant. However, it is still a complex problem to obtain this conducive soil condition due to wide variations in soil, climate and crop adaptation.

Wheat was not being grown widely in West Bengal, India. With the advent of irrigation resources, considerable land is being brought under wheat cultivation. However, there is no report on the desirable soil physical environment that should be provided for wheat growth in this region a part of which falls under acid lateritic soils, though earlier Tripathi and Pande (1971) reported the feasibility of wheat cultivation in this agro-climatic region. The present investigation was, therefore, carried out to assess and evaluate the influence of physical edaphic factors as induced by tillage on wheat growth. Since there is a distinct lack of information regarding the optimum soil physical conditions for wheat growth, the present investigation was carried out to meet the following objectives:

- 1) to study the changes brought about in the soil physical environment as induced by various tillage practices and to find out the response of seeds to changed environment,
- 2) to evaluate the influence of edaphic factors on wheat crop performance at various growth phases,
- 3) to find out how economically the most conducive soil physical environment can be created for successful wheat growth under the agro-climatic condition prevailing over Kharagpur, and
- 4) to evaluate the properties of clods or aggregates and to find out the feasibility of the information thus obtained to predict the bulk density of cloddy surface immediately after tillage.

Although considerable research has been carried out on the design parameters of tillage tools, the resultant soil physical conditions are yet to be known fully (Bhushan et. al., 1971). It is a common observation that in spite of tool geometry, soil physical conditions and operating speed also have a profound influence on the cloddiness of the seedbed and draft requirement. Furthermore, the soil fracture during tillage was found to be proportional to the new soil (clods) surface produced. It was, therefore, felt necessary to evaluate the influence of bulk density, soil moisture and speed of operation on tillage tool draft and cloddiness potential of the seedbed which governs the soil physical properties at various growth phases of crop.

## Chapter II

### REVIEW OF LITERATURE

Every crop has range of physical environment that provides optimum conditions which may be achieved by various tillage practices. It is a well recognised fact that tillage operations which consume more energy than any other field operation bring about changes in soil structural relationship and thereby modify soil physical factors. The pertinent literature reviewed in this chapter is presented under the following heads :

1. Relation between tillage induced soil conditions and edaphic factors
2. Seedling emergence as influenced by tillage induced seedbed
3. Tillage induced soil environment and root growth
4. Tillage in relation to crop performance
5. Factors influencing tillage tool draft.

#### 2.1 Relation Between Tillage Induced Soil Conditions and Edaphic Factors

##### 2.1.1 Clod size, bulk density and porosity

Tillage machine features such as size, shape, sharpness and speed of operations do affect the clod size. The evaluation of soil structure was made in terms of size distribution of aggregates, aggregate stability and such soil properties as synonymous

with soil structure. Recently, Jain and Biswas (1969) reviewed the methods for evaluation of soil structure which were based on mean weight diameter, geometric mean weight diameter and arithmetic mean diameter of soil aggregates. The use of mean weight diameter was suggested as a suitable parameter by which the resulting aggregate distribution could be handled (Van Bavel, 1949; Gardner, 1956; Stirk, 1958; Puri and Puri, 1939; Basu and Kibe, 1946).

It is a well recognised fact that tillage essentially involves the fracture of the soil, leaving the surface soil cloddy. Allmaras et.al. (1965) used four pre-plant tillage treatments to obtain different soil conditions in the row-zone. They observed that within 6 weeks after planting, the bulk density;  $D_B$  increased but the logarithm of geometric mean weight diameter of aggregates ( $\log GMD$ ) and the dispersion of aggregate diameter ( $\sigma \log d$ ) changed differently depending on tillage treatments and year of study. Larger differences occurred in these measurements among tillage treatments. It was evident that  $D_B$  of the 0 to 3-inch layer increased as  $\sigma \log d$  increased, but comparatively smaller decrease occurred as the  $\log GMD$  increased. A similar relation was shown in laboratory using mixtures of aggregate-diameter separates. These changes in  $D_B$  were mainly due to the modifications of the aggregate void space. In the laboratory, an increase in weight fraction of water was observed for increasing  $\sigma \log d$ . Therefore, they suggested that both  $\log GMD$  and  $\sigma \log d$  were measurable parameters of soil conditions in the beds of aggregates, and might help explain soil water

retention and movement, evaporation losses, seed-soil contact, and root-soil contact. The significance of aggregate size distribution for describing packing arrangement was evaluated from changes in  $D_B$  as predicted by changes in  $\log GMD$  and  $\sigma \log d$ . Soil aggregate stability indices -  $M^*D$ ,  $\log GMD$  and change in  $M^*D$  were comparable with soil structure index expressed as percentage of water stable aggregates greater than 0.25 mm (Pharande et. al., 1969; Puri and Puri, 1939; Van Bavel, 1949). Geometric mean diameter, bulk density and total air space and water retention at 1/3 - bar suction also provided good indication of structural status of the soil.

The size and arrangement of aggregates in soils greatly influence the amount of configuration of the pore space which in turn governs air and water relations. Hill and Sumner (1967) reported that soil bulk density changes had marked effects on the moisture characteristics of different soils. Grable and Siemer (1968) reported the influence of bulk density and aggregate size on soil water absorption, oxygen diffusion at lower depths and growth of corn crops. The moisture content was a predominant influencing factor in producing the quantity and quality of soil clods (Lyles and Woodruff, 1963). The volume of water retained per unit volume of air-dry aggregates was negatively related to the diameter of aggregate separates (Tamboli, 1961; Wittmuss and Mazurak, 1958).

Jaggi et. al. (1972) concluded that in black cotton soil a fine seedbed of aggregate size of 1-2 mm with bulk density of 1.2 - 1.3  $g\ cm^{-3}$  favoured the wheat yield. A curvilinear

relationship existed between aggregate density and the diameter of aggregates. The aggregate density increased as the diameter of aggregate decreased (Wittmuss and Mazurak, 1958).

Stability of aggregates ranging from 3-5 mm diameter increased initially but decreased with the lapse of time (Arya and Black, 1972). Their findings suggested that an intense rain soon after ploughing would puddle the soil to a great extent than if it was delayed a few hours. It was assumed that drying was the significant interceding factor in soil stabilization following the tillage.

The soil type and the condition at the time of tillage determined the resulting clod size to a far greater extent. Ploughing the soil when it was too wet (near field capacity) or too dry (below wilting percentage) usually produced larger clods (Baver, 1956). He further stated that when the soil moisture was midway between these two extremes, it produced a finely pulverised soil with smaller clods. The type of tillage implement had decided influence on the size and stability of the clods formed and the differences persisted longer than those due to moisture content (Lyles and Woodruff, 1962). They reported the occurrence of larger clods in the plots worked with mouldboard as compared to surface sweep. Different tillage implements produced varying clod sizes (Woodruff *et. al.*, 1965; Siddoway, 1963; Gill, 1967; Chepil *et. al.*, 1962; Wenhardt, 1962; Lyles and Dickson, 1968).

Furthermore, the occurrence of clod sizes was also influenced by shape and size of tillage tools (Gill and McCreery, 1960).

They indicated that clod mean weight diameter increased with increasing sizes of cut. The radius of curvature of mouldboard plough was observed to have linear relationship with clod size indicating thereby that as the radius of curvature increased the size of resulting clods increased (Bhushan and Ghildyal, 1970b). They established beyond doubt that clod size distribution is a single parameter to influence various soil physical conditions. Bhushan and Ghildyal, (1970a) working with implements of varying shapes from blade type (Guntaka) to complex (mouldboard plough) one, reported higher clod mean weight diameter in the plot ploughed with the mouldboard plough under the agro-climatic conditions of Kharagpur.

Very recently, Bhushan et. al. (1973) conducted the investigation on this line to study the changes brought about in soil physical properties by various implements and attempted to assess the resultant clod size distribution in relation to bulk density, total porosity and water retention immediately after treatments and during the growth period of wheat. It was reported that the use of disk plough or mouldboard plough followed by disking helped in keeping the bulk density low, higher porosity and greater moisture retention in the soil throughout the growth period of wheat crop.

Initial compaction at optimum moisture prior to tillage proved helpful in increasing soil cloddiness (Lyles and Woodruff, 1961). However, the quantity and quality of clods were dependent on various factors that influence cohesion (Lyles and Woodruff, 1963). Bulk density was found lower in plots ploughed with a

plough than rotary cultivator or tined cultivator (Wilton, 1964). Bhushan and Ghildyal (1970a and 1970b) related this occurrence of lower bulk density to larger clod sizes. Bulk density under plough was lower than that under disk harrow or guntaka.

Even though the porosity is an important parameter in a tilled soil, it was not measured throughout the growing season of a crop. In recent years, the total porosity of the tilled layer was determined from changes in elevation of the soil surface (Kuipers and Van Onwerker, 1963; Burwell *et. al.*, 1963; Larson, 1964; Wilton, 1964; Bhushan and Ghildyal, 1970a).

In general, scientists observed noticeable increase in total porosity by ploughing which diminished quickly after the operation, at the rate that was greatly influenced by rainfall and that the higher porosity was maintained for longer time by the use of mouldboard plough (Burwell *et. al.*, 1963; Wilton, 1964; Allmaras, 1967), wheel track and conventional tillage (Allmaras *et. al.*, 1966; Burwell and Larson, 1969).

### 2.1.2 Edaphic factors

#### 2.1.2.1 Soil moisture

Conservation of soil water under arid condition was achieved through tillage which helped control evaporation. Willis and Bond (1971) observed that tillage effectively terminated first stage drying and evaporative losses were reduced considerably. The reduction in water loss was reflected in higher soil water content throughout the column length below the tilled layer.

Evaporation was slightly reduced with 7.5 cm tillage as compared to 2.5 cm. The moisture loss from soil was faster under disk and mouldboard than other treatments (Bhushan *et. al.*, 1973; Holmes *et. al.*, 1960). Evaporation and drying rate were greatly influenced by degree of aggregation and compaction which in turn were affected by tillage operations. Johnson and Buchele (1961) using stable clay loam aggregates found that drying rate in the top 7.5 cm of the seed zone increased more than two fold with the increase in clod size from 1.25 to 6.25 cm diameter. However, compaction of these clods at 5 psi decreased the drying rate by 20 per cent for smaller clods and 50 per cent for larger clods. Large clods and loose soil promote greater rates of drying.

Van Duin (1958) predicted that the capillary pore volume fraction could be increased by a factor of 1.4 or so by changing the aggregate arrangement from close to open packing if the aggregates were 0.2 mm diameter. This should increase the available water holding capacity on volume basis. On the other hand, when aggregates larger than 0.6 mm diameter were changed from close to open packing, the capillary pore volume fraction was reduced and consequently decreased the available water holding capacity. Amemiya (1965) indicated that decrease in aggregate diameter increased the capillary conductivity when dealing with aggregates about 1 mm diameter. Manipulation of aggregate or pore size arrangement by tillage which decreases soil moisture suction at a given volume moisture content, can increase capillary conductivity of the soil. Subramanyam (1959) noted that deep ploughed land had the highest infiltration capacity, even higher

than that of sod land immediately following the tillage operation. But after about a month, it lagged behind the sod land in its infiltration capacity. Similar results were obtained by Rauhe (1956).

#### 2.1.2.2 Soil aeration

The seed environment is usually close enough to the soil surface where gaseous exchange poses no problem to germination and emergence. Dobby and Kohnke (1956) showed that unless the surface was completely impervious or very wet, gas diffusion through the soil did not depend on properties of the surface layer. Dasberg and Bakker (1970) attempted to evaluate different soil aeration indices in relation to plant growth (Sojka *et. al.*, 1972; Varade *et. al.*, 1970) during fluctuations in soil moisture content. They found that oxygen concentration of the soil air decreased to less than 10 and 5 per cent respectively, for oxygen concentrations at the soil surface of 21 and 11 per cent. The oxygen diffusion rate (ODR) measurements as influenced by tillage practices were quite variable (Burwell *et. al.*, 1963; Wilton, 1964; Allmaras *et. al.*, 1966; Burwell and Larson, 1969). Furthermore, they pointed out that total root production was hardly influenced but the depth of root penetration was affected strongly by these aeration treatments.

#### 2.1.2.3 Soil temperature

Burrows (1963) stated that tillage could influence the thermal properties of soil. He found that the soil temperature at the

4 inches depth on 40-inch recurring ridge (ridge planting) averaged 3.8°F greater than that in the furrows (lister planting) and 2.1°F greater than that in the soil with smooth microrelief (conventional planting). The results of Shaw and Buchele (1957) also lend a support to this view. Peak daily temperature difference of 1 to 5°C at the 5 cm depth occurred between furrow bottom and ridge top depending on soil moisture and clod cover. The mechanism of achieving higher temperature in the ridge top was partly associated with lower soil moisture content and partly with the geometry for heat flow. Olson and Schoeberl (1970) created a wide range of soil conditions with four tillage systems, namely: conventional, wheeltrack planting, till planting, and listing. They found that soil temperature at seed depth was lowest in the listed plots wherein corn was planted in the bottom of furrow. The maximum temperature was observed in tillage treatments where amplitude of temperature fluctuation was greater and thermal conductivity low (Allmaras, 1967).

Surface roughness and soil moisture content affected reflectance of radiation from the soil surface (Gates and Hanks, 1967) and hence the soil temperature. Smooth soil surface reflected upwards 50 per cent more radiation than rough, cloddy surface. The rough and cloddy surface dried faster. Dry surfaces reflected upwards 50 per cent more radiation than wet surfaces. Holmes *et. al.* (1960) noted that temperature in the beds of aggregates depended on aggregate size and wind speed.

#### 2.1.2.4 Mechanical impedance

The basic objective of tillage is to keep the soil loose enough so that plant root can penetrate easily and grow profusely.

Mulches, rainfall and tillage have as great influence on impedance as on any other seed environment characteristics (Carnes, 1934; Duley, 1939). Phillips and Kirkham (1962) showed that the relationship between needle penetration and bulk density was linear (Tabatabai and Hanway, 1968; Lyles and Woodruff, 1963; Terry and Wilson, 1953). The soil strength was also influenced by soil moisture (Martin and Buchele, 1960; Lyles and Woodruff, 1963).

Every increase in bulk density is accompanied by increase in mechanical strength of soil and decrease in porosity, void ratio, hydraulic conductivity, water permeability, and gaseous diffusion but increased capillary conductivity and diffusivity of the soil (Vomocil and Flocker, 1961; Gill, 1959; 1961; Lutz, 1952; Gill and Miller, 1956; Swanson and Jacobson, 1956; Phillips and Kirkham, 1962; Parker and Taylor, 1965; Drew *et. al.*, 1965; Varade and Ghildyal, 1967).

## 2.2 Seedling Emergence as Influenced by Tillage Induced Seedbed

Grover (1955) indicated that the seed environment was composed of three distinct parts, namely : chemical, biological and soil physical environment. Although strict control of the physical environment is obviously impossible under field conditions, modification of the same may be achieved to a great extent from (a) change in soil profile, and (b) application of additives (Arndt, 1945; Camp and Walker, 1927; Christiansen, 1963; Evans and Kirkham, 1949; Evenari, 1956; Hendricks, 1956; Hanks and Thorp, 1956).

Larson (1964) suggested that the parameters selected to describe the required conditions in the seedling environment zone were soil temperature, secondary aggregate size, bulk density, and the width and depth of the zone. According to Johnson and Taylor (1960) the occurrence of aggregates smaller than 2.5 mm provided a proper soil condition for optimum emergence of corn. However, while working with sugarcane Jain and Agarwal (1970), found higher germination percentage in 3.2 to 6.4 mm aggregate size. Maize seedling emergence decreased as the aggregate size increased from 1.2 to 6.7 mm diameter (Johnson and Buchele, 1961). Though a little compaction at surface gave beneficial results (Stout and Snyder, 1957; Stout *et. al.*, 1960), the moderate compaction at seed level proved still better than surface compaction. This better emergence was ascribed to higher water availability (Stout *et. al.*, 1960).

Fransworth (1941) indicated that soils with an air porosity of less than 12 per cent suppressed the germination of sugarbeet. For initial germination and root elongation of corn, the critical air porosity was near 30 per cent in larger aggregates which decreased as aggregate size decreased or bulk density increased (Grable, 1967). The critical porosity seems to approach a lower limit of about 12 per cent in dense soil and smaller aggregates. Hanks and Thorps (1957) observed that oxygen was a limiting factor in the emergence of wheat seedlings, whenever the oxygen diffusion rate was below 75 to 100 x 10<sup>-8</sup> g cm<sup>-2</sup> min<sup>-1</sup>. Erickson and Vandoren (1960) observed that oxygen deficiency for a day could have a great influence on emergence.

Similar views were also expressed by Cline and Erickson (1959). Bowen (1966) did not consider aeration becoming limiting to emerging seeds if the air permeability,  $k = 0.05 \times 10^{-8} \text{ cm}^2$  or more was maintained.

If the average net hydraulic pressure required to rupture the soil over the first eight days after planting was less than 11.5 psi, mechanical impedance was considered not limiting (Bowen, 1966; Hanks and Thorps, 1957; Stout *et. al.*, 1957; Hanks, 1960) to seedling emergence.

The beneficial effects of diurnal temperature on germination and emergence are reported for several crops (Toole *et. al.*, 1956; William, 1963; Parker and Taylor, 1965). From the review by Chaudhary (1968), it appears that minimum and maximum soil temperature for germination and emergence of seedlings lies in the range of 12 to 35°C. Bowen, (1966) was of the view that seeds required about 2600 or more deg hr (based on 55°F as a lower cardinal temperature) for emergence. If the soil temperature was low, the emergence of seedlings might be delayed because longer time would be required to attain 2600 deg hr (Wanjura *et. al.*, 1969; Ronald and Carlton, 1969; Langride and McWilliam, 1967).

### 2.3 Tillage Induced Soil Environment and Root Growth

After the emergence of the seedling, the growing roots of the plant continuously encounter the resistance of the soil. Root growth of many crop plants was adversely affected when the

plant roots encountered high mechanical strength of soil (Pfeffer, 1893; Gill, 1961; Phillips and Kirkham, 1962; Tackett and Pearson, 1964; Varade, 1965; Satyanarayana and Ghildyal, 1969). Taylor et. al. (1962) reported that when soil strength was lower (250 psi or lower), the root growth was not affected but if the strength increased (400 psi or above), the root growth was restricted severely. The results are in agreement with Fox and Lipps, 1960; Taylor and Gardner, 1963; Gardner and Danielson, 1964; Barley et. al., 1965; Taylor and Burnett, 1964; and Taylor et. al., 1967.

Root growth was significantly influenced by clod size in the seedbed (Jain and Agarwal, 1970; Grable and Siemer, 1968; Bayer, 1949; Bayer and Fransworth, 1940). Voorhees et. al. (1971) observed that root growth within a given aggregate was also affected by the soil strength and pore size distribution within adjacent aggregates. It was observed that the growth of primary and secondary corn seedling roots decreased as the bulk density increased or as needle penetration decreased. Varade (1965) working with rice plant reported  $1.7 \text{ g cm}^{-3}$  bulk density, the limiting value for root proliferation and attributed the failure of root development to the size of pores. Adverse effects of high bulk densities on crop root growth were also observed by many other scientists (Gill and Miller, 1956; Taylor et. al., 1962; Tackett and Pearson, 1964; Gardner and Danielson, 1964; Parker and Taylor, 1965; Meredith and Patric, 1961; Wiersum, 1957). Air-filled porosities less than 10 per cent limited the crop growth (Vomocil and Flocker, 1961). Edwards et. al. (1964)

determined that 33 per cent total porosity was the minimum limit for penetration of corn roots in weir silt loam soil.

Low availability of oxygen at the root surface was found to affect the corn seedling root growth (Gill and Miller, 1956). Letey and Stolzy (1964) concluded that roots of many crops would not grow when the ODR was less than  $20 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$  and that root growth would be retarded when ODR values were less than  $30 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ . Gradwell (1965) reported that adapted plants could extend their roots where ODR value was  $2 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ . Williamson (1964) found depressed root growth at ODR  $5 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ .

The importance of high moisture for root growth was emphasized by many workers (Gardner and Danielson, 1964; Gardner, 1966; Kozlowski, 1964; and Phillip, 1966). Gingrich and Russell (1956) showed that the weight and elongation rate of corn roots decreased with increasing moisture stress. Barley *et al.* (1965) suggested that increased physical resistance, as the medium decreased in water content, might offer an alternative explanation.

It is evident from the literature that in spite of variation in ability to withstand temperature, in different plant roots, roots grow better with increasing temperature upto certain limit (in most cases  $30^{\circ}\text{C}$ ) and the temperature beyond that injures the growing cells of roots. In general, plant roots grow better when the soil temperature ranges between  $20\text{-}30^{\circ}\text{C}$  (Nielson and Humphries, 1966).

Barbar (1971) observed that roots of corn developed extensively, penetrated to a greater depth and were finer in tilled soil than in untilled soil. Experiments with tillage upto a depth of 70 cm conducted on deep, impervious, montmorillonitic, black clay soils, where root development of annual crops was restricted to the upper part of the soil profile, indicated the benefits of modifying the structure of heavy clay soils by mechanical means in increasing root development and crop yields (Buornett and Tackett, 1968). Very recently, Mallick and Rao (1972) observed that the quantity of wheat roots was related to the depth of ploughing, and the roots were longest under chiseling followed by mouldboard ploughing, deshi ploughing and disk-ing. Thus deep ploughing facilitated the penetration of roots to lower depths. Similar results were reported by Reddy and Dakshinamurti (1971), Dakshinamurti and Pradhan (1966), and Rode (1955).

#### 2.4 Tillage in Relation to Crop Performance

Since tillage operation shares huge expenditure in farming, attempts are being made to study more precisely and closely the requirements of crop and then provide that environment at the lowest cost. Keeping this in view, Cook *et. al.* (1953) introduced the concept of minimum tillage and proved that for some crops, the number of tillage operations could be reduced without sacrificing the yield. This work formed the basis for two zone concept of row crops (Larson, 1964). More recently, the practice of no-tillage was introduced and in some cases successful results were achieved (Free *et. al.*, 1963; French and Blake, 1965).

Olson and Schoeberl (1970) reported higher dry matter and grain yield of corn in till-planting and listing than those in the wheel track planting and conventional tillage. Since moisture depletion was fast in the conventional tillage, it was thought that moisture became limiting to the growth and grain yield. It appears quite reasonable to adapt reduced tillage system, with its low cost and greater moisture conservation, without sacrificing the yield under the prevalent climatic condition (Jones *et. al.*, 1968; 1969; Olson and Schoeberl, 1970; Shear and Moschlar, 1969). However, there are contradictory reports. According to Jain and Agarwal (1970), tillage producing clods falling in the range of 3.2 to 6.4 mm diameter proved beneficial for the growth and yield of sugarcane. Similarly, for wheat crop seedbed preparation proved to be better (Horning and Overson, 1962; Bhushan *et. al.*, 1973). Corn yields were not adversely affected when minimum tillage methods of wheel track planting or plough planting were used instead of conventional method of planting corn (Page *et. al.*, 1946; Musgrave *et. al.*, 1955; Peterson, 1960). However, Balton and Aylesworth (1957) working in Ontario obtained mixed results from plough planting during 3 years of trials.

The high bulk density, and low porosity affected aeration and strength of soil. Under such condition, the root development and proliferation was restricted, thereby resulting in limited feeding zone (Flocker and Robert, 1960) which is ultimately reflected in lower yield of corn (Van Diest, 1962; Blake 1948;

and Aldrich, 1955), millet and spring wheat (Smith and Cook, 1948; Bhushan *et. al.*, 1973), barley (Kubota and William, 1967), rice (Varade and Ghildyal, 1967; Satyanarayana and Ghildyal, 1969), tomato (Flocker and Nielson, 1960), potato (Blake and Aldrich, 1955), sugarbeet (Smith and Cook, 1948) and sugarcane (Primavesi and Primavesi, 1964). However, Vomocil (1955) indicated, quite reasonably, that the relation between soil bulk density and plant yield may be described by a parabola. Thus, it would appear that very low bulk density or high bulk density would not be optimum for good plant growth.

High mechanical impedance of the soil was found to reduce yield of many crops either through reduction in root growth or seedling emergence (Veihmeyer and Hendrickson, 1948; Lutz, 1952; Bertrand and Kohnke, 1957; Phillips and Kirkham, 1962; Varade and Ghildyal, 1967).

Soil moisture stress decreased root penetration and prevented normal growth and development of wheat according to Kramer (1963) and Salim *et. al.* (1965). It is well established by now that at flowering stage the wheat plant can not tolerate water stress because maximum leaf development occurs at this stage and maximum stem development takes place during filling stage of growth (Florell and Faulkner, 1934; Robins and Domingo, 1962; Johnson, 1953; Azzi, 1922; Kezer and Sackee, 1931, Malibage, 1928; Robertson, 1934). However, Day and Intalap (1970) recently observed that a critical period in the growth span of wheat was the jointing stage for moisture. Stressing wheat for

water at jointing stage resulted in early flowering, short plants, low grain yield, few heads per unit area and fewer grains per ear head. Water stress at flowering and dough stage of wheat growth also reduced yield and enhanced maturity.

## 2.5 Factors Influencing Tillage Tool Draft

Most of the development of tillage tools came through trial and error and, therefore, the designer was mostly guided by experience and judgement. To supply the basic information on the forces involved, the study of soil resistance encountered by tillage tools and the relation of this force with another forces on the tool is very essential. It is a common observation that in spite of tool geometry, soil physical conditions at the time of tillage play a significant role in affecting the cloddiness of the seedbed and power requirement (Bhushan et. al., 1971).

Statistics indicated that field operations constituted about 48 per cent of the farm draft work and that tillage work such as ploughing, listing, fitting ground and cultivating crops made up approximately 58 per cent of the total H.P. - hrs. utilized in field operations (Walker, 1930).

Various workers tried to give an equation, from time to time, to predict draft of a simple tillage implement considering the various properties of soil, tool parameters and working speed (Pyne, 1956; Soehne, 1956; Kawamura, 1952a; 1952b). Very recently, Bhushan et. al. (1971) carried out an extensive work on draft in relation to tool variables like tool angle, nose angle, rake

angle, height and width of tool, depth of operation on a sandy loam soil. Similar studies were also carried out in the past by Pyne (1956); Sahay (1969); Gill and McCreery (1960); Osman (1964); Pyne and Tanner (1959). An attempt was made to develop a mathematical expression, not limited by soil type, to relate the variation assumed to influence draft force on mouldboard plough (Larson *et. al.*, 1968).

The soil is a highly variable material and this variability is largely apparent in the resistance offered by it to tillage tools. The resistance of the soil to the action of a tillage tool was found to vary constantly as a result of the effect of heat, water, bacterial and chemical action and plant life, all modified in turn by time (Randolf and Reed, 1938).

Soil type (Bainer *et. al.*, 1955) and soil condition determined the soil behaviour during tillage to a great extent. Under field conditions, the presence of roots, crop residues and stones etc. substantially affected the magnitude of soil behaviour. Randolf and Reed (1938) pointed out that the effects of plough design and operation factor should be compared only for similar soil conditions, unless comprehensive correlation curves to compensate for variation in moisture, bulk density and other factors in the physical condition of the soil were available.

Sahay (1969) opined that energy or draft required by a tillage tool would be minimum when the soil was at friable condition. Lyles and Woodruff (1961) reported that soil moisture, soil texture, type of tillage implement and soil density largely

determined clod size distribution and power requirement. The results of Gill and McCreery (1960) and Gill (1968) also lend a support to this view. Furthermore, they expressed the relationship between the energy from dropping and the soil break-up and illustrated the possibility to determine the efficiency of various tillage tools. They further stated that equivalent energy as determined by drop-shatter method could be used to determine the most effective manner by which the clod size of a hard soil might be reduced. Farrell *et. al.* (1967) used shatter test to establish a relationship between the energy imparted to the soil and the degree of fragmentation. They established substantially constant relationship between cumulative drop height (CDH) and the break-up of soil. They found that the ratio of CDH and tensile strain energy was approximately constant over the wide range in water content of the soil. Similar results were reported by Fox *et. al.* (1967) and Bateman *et. al.* (1965). They showed that increasing bulk density of the soil by compaction, increased the energy required to achieve a given degree of fragmentation.

The effect of soil moisture content was studied by Ashby and his associates (1932), and found that a rainfall of 1.3 inches on a fairly dry clay loam reduced the unit draft by about 40 per cent. Randolph and Reed (1938) noted that increase in moisture content from 9.1 to 11.7 per cent reduced the unit draft of mouldboard plough in a fine sandy loam by 15 to 35 per cent.

The speed of operation also has a pronounced effect on draft requirement of a tillage tool irrespective of soil and tool variables. Randolph and Reed (1938) noted that the draft per

square inch of furrow slice turned, increased with speed, but due to the limited speed range it was not possible to predict whether or not it was a straight line ratio. They further found that within certain ranges of speed and soil conditions, the rate of increase in longitudinal, side and vertical components of draft were a parabolic function of speed in a 14-in. general purpose bottom plough. McKibben and Reed (1952) concluded that draft of implement was made up of a number of elements ranging from forces which were probably independent of speed and acceleration forces, proportional to the square of the speed. They developed the empirical equation :

$$\frac{P_s}{P_3} = 0.83 + 0.189 V^2$$

where,

$P_s$  = draft at any speed  $s$  miles per hour

$P_3$  = draft at 3 miles per hour

$V$  = speed in miles per hour.

Lehoczky (1962) recorded specific resistance and draft for a tractor drawn plough in sandy and medium loam soil. Draft was measured for tillage tools (Telischi *et. al.*, 1956; Collins, 1921) and it was observed that it increased considerably with the increase in operating speed, moisture content, clay content and bulk density (packing force) of the soil. They opined that because of the non-uniformity of soil, and the fact that the control of soil properties in the field is almost impossible, had made field draft tests for tillage implements difficult.

From the survey of literature available, it appears that in tillage research, more attention need to be paid to specific crop requirements under varying soil climatic complex. Crops are generally grouped into cereals, pulses and root crops etc. and it is expected that species within groups respond alike to tillage treatments or soil manipulation. However, individual crop in a given group responds differently to various edaphic factors.

Although considerable research has been carried out on the design parameters of the tillage tools, the resultant soil physical conditions are yet to be known fully. It is a common observation that in spite of tool geometry, soil physical conditions and speed of operation affect the cloddiness of the seedbed and power requirements. There is a lack of information on the influence of these factors on the resultant soil conditions in lateritic soil of Kharagpur.

## Chapter III

### MATERIALS AND EXPERIMENTAL TECHNIQUES

This chapter deals with the materials and experimental procedure during the course of present investigation. For the convenience of explanation, it is divided into three parts. Part I deals with field experiments and Part II deals with physical properties of soil aggregates while Part III is concerned with soil bin experiments.

#### Part I

#### Field Experiments

##### 3.1 Experimental Site

The experiments were conducted on the Experimental Farm of the Agricultural Engineering Department, Indian Institute of Technology, Kharagpur situated within the Kasai drainage basin in the district of Midnapur, West Bengal on the east coast of India at a distance of about 115 km from the sea coast and has the mean elevation of about 48 m from the mean sea level. The longitude and latitude of this Institute are  $87^{\circ} 19'$  and  $22^{\circ} 19'$  respectively.

##### 3.2 Climate

The average annual rainfall of this region is 1500 mm, mostly concentrated during monsoon from June to October. The mean minimum temperature ranges from 12 to  $25^{\circ}\text{C}$  and maximum temperature from 20 to  $40^{\circ}\text{C}$  in January and May respectively. The mean minimum relative humidity varies between 18 to 64 per cent and

maximum relative humidity from 85 to 98 per cent. The details of temperature and rainfall during the period of experiments are given in Fig. 3.1 and 3.2.

### 3.3 Soil Characteristics

The soil of the farm is lateritic sandy loam. The pertinent physical and chemical soil properties are presented in Tables 3.1 and 3.2 respectively.

### 3.4 Test Crop

Wheat (*Triticum aestivum*), multi-variety Kalyansona(S 227) was used as a test crop for the present experiments. It is a short duration (110-120 days), high yield and fertilizer responsive two gene dwarf variety. The relevant seeds were obtained from National Seed Corporation, Government of India undertaking.

### 3.5 Experimental Layout

The experiments were established in a simple randomized block design with five tillage practices replicated five times giving 25 plots (Fig. 3.3). The details of the treatments are presented in Table 3.3 with their symbols. The experiments were conducted during rabi season, November, 1971 to March, 1972 and November, 1972 to March, 1973. Each plot was provided with irrigation channel. Water gates to each plot were used for regulating flow and a Parshall flume was used for the measurement of water.

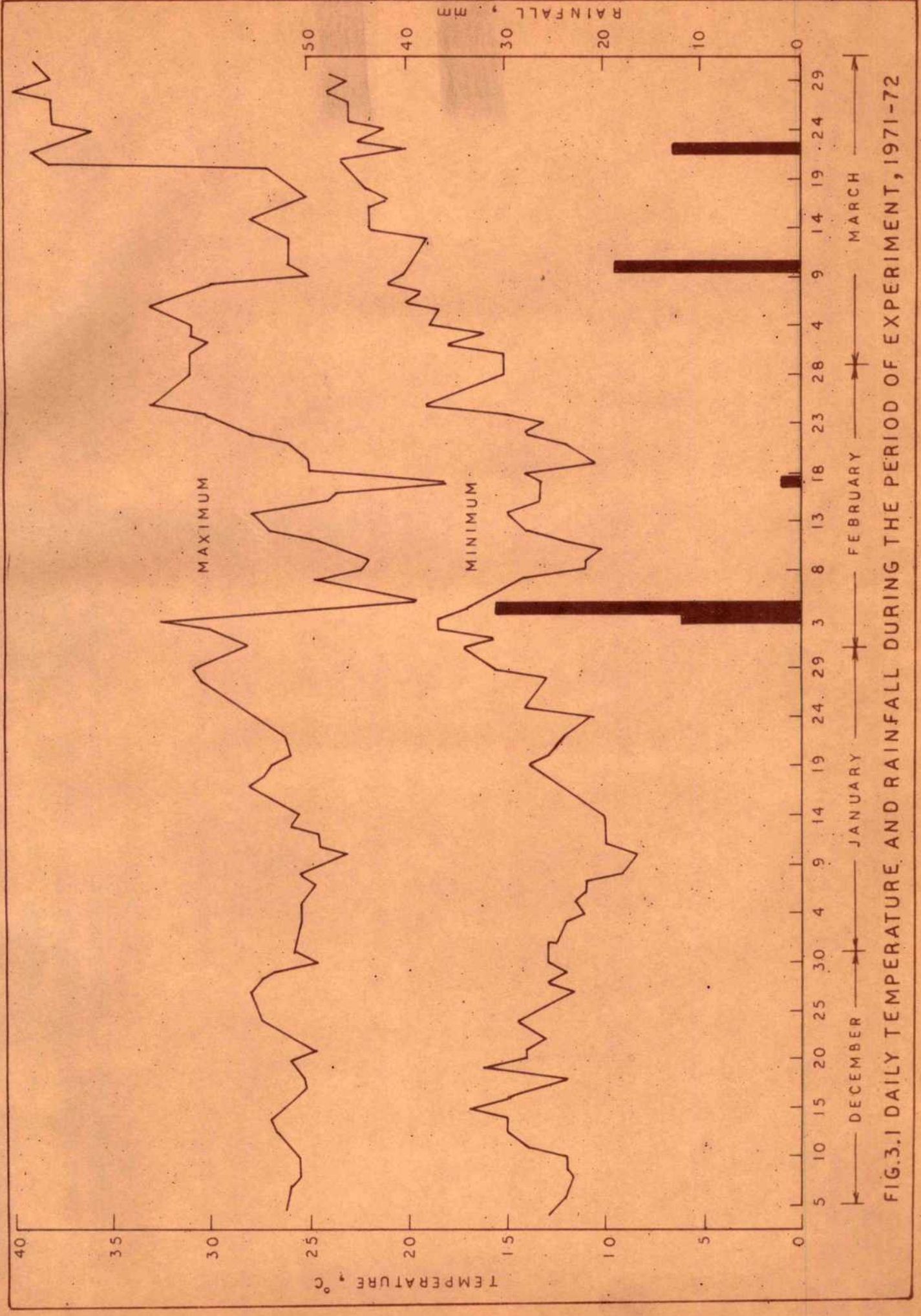


FIG.3.1 DAILY TEMPERATURE AND RAINFALL DURING THE PERIOD OF EXPERIMENT, 1971-72

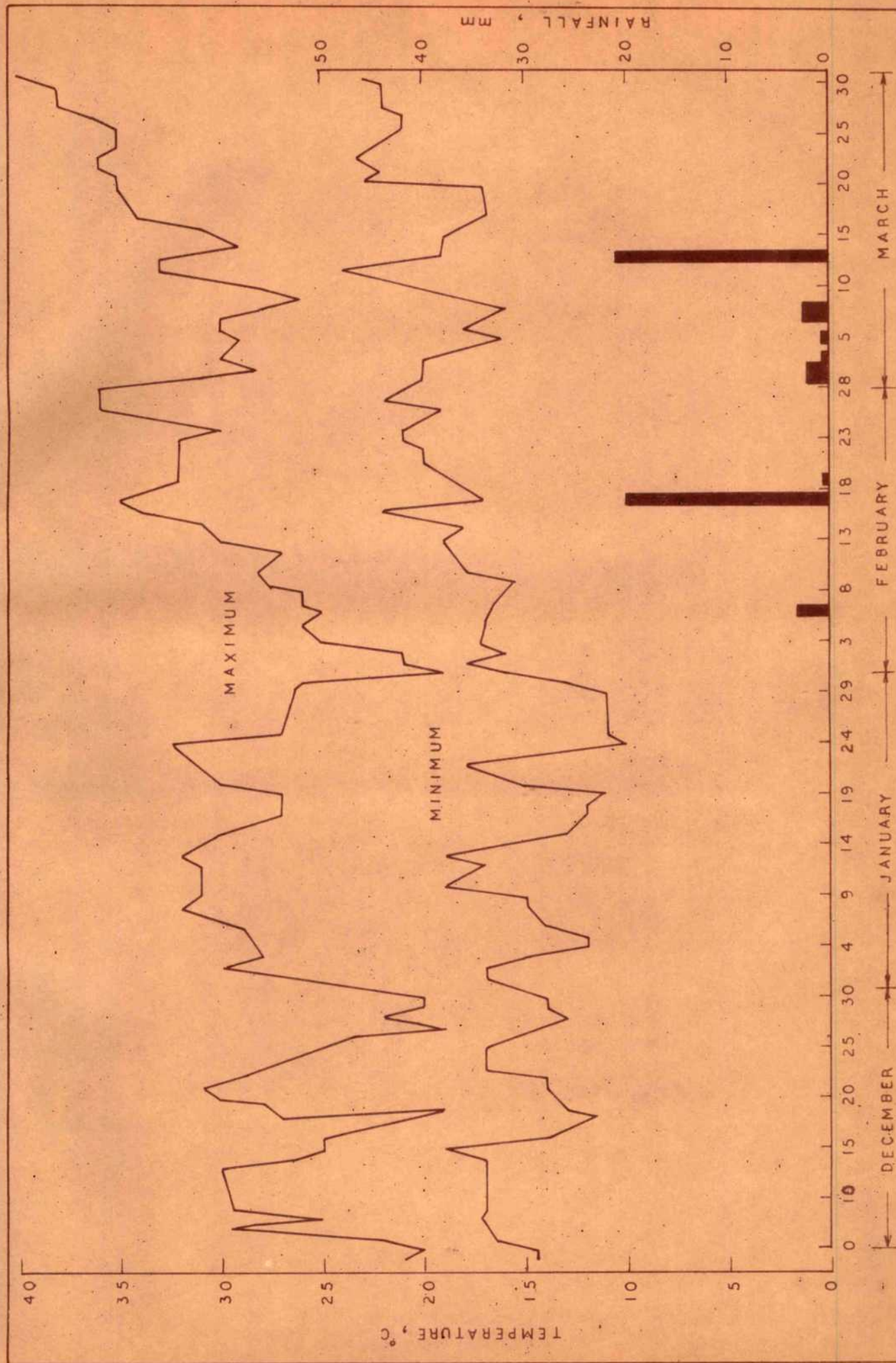


FIG.32 DAILY TEMPERATURE AND RAINFALL DURING THE PERIOD OF EXPERIMENT, 1972-73

Table 3.1 Physical properties of soil

Mechanical composition		Textural class	Field capacity %	Wilting percent-age %	Water holding capacity %	Lower plastic limit %	Liquid limit %	Proctor moisture content %		
Coarse sand %	Fine sand %									
24.54	38.60	17.60	19.26	Sandy loam	14.9	4.5	32.6	9.35	15.75	8.8

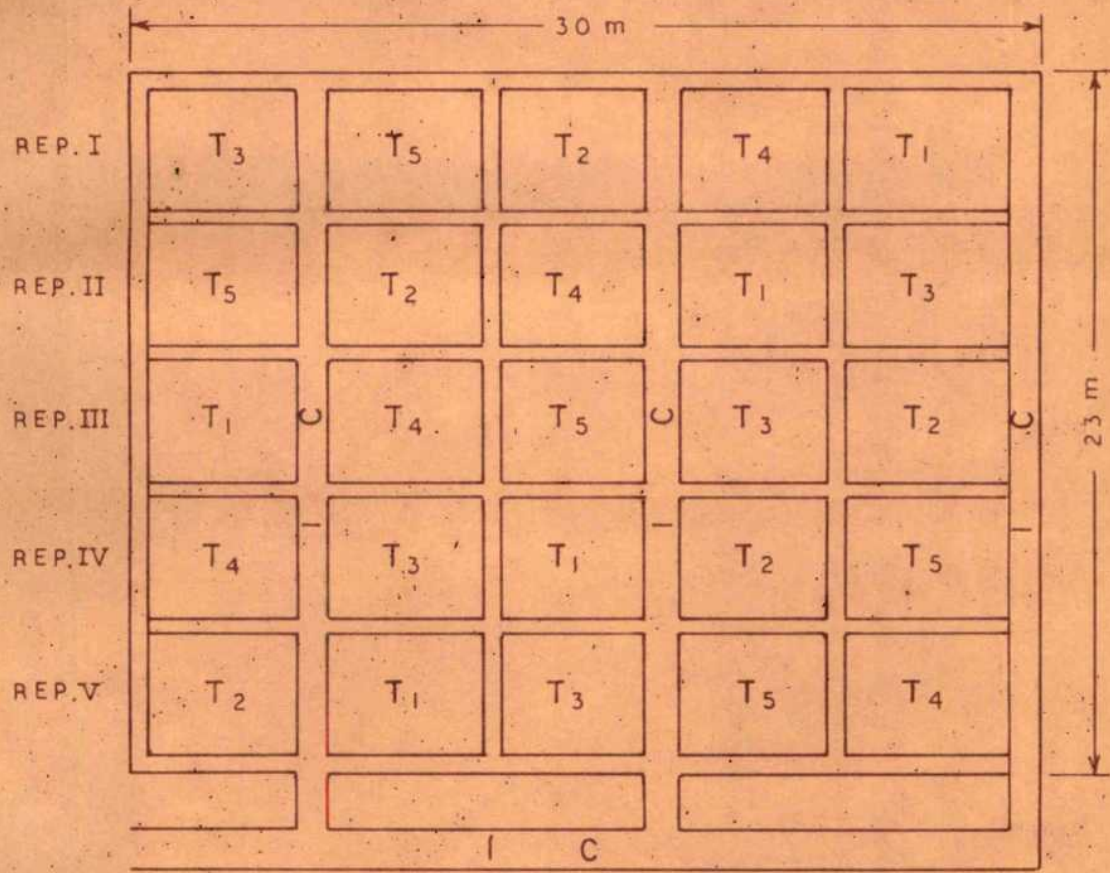
Table 3.2 Chemical properties of soil

pH	5.8	Electrical conductivity mhos/cm at 25°C	84.88 x 10 <sup>-5</sup>	Cation exchange	6.40	Organic carbon %	0.380	Total nitrogen %	0.044	Available P %	0.0005	Available K %	0.0101	Free oxide of iron %	6.43	Manganese dioxide %	0.290	Silica %	0.61
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T 3686



LAYOUT : RANDOMISED BLOCK DESIGN  
 NO. OF REPLICATIONS : 5  
 NO. OF TREATMENTS : 5  
 NO. OF PLOTS : 25  
 NET PLOT SIZE : 5 m X 4 m  
 I, C : IRRIGATION CHANNEL  
 T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, T<sub>4</sub>, T<sub>5</sub> : AS GIVEN IN TABLE 3.3



SCALE : 0.4 cm = 1 m

FIG.3.3 PLAN OF LAYOUT FOR FIELD EXPERIMENTS

**Table 3.3** Experimental treatments showing five tillage treatments (T) followed in field experiments during 1971-72 and 1972-73

Treatment symbol	Treatment abbreviation	Description of treatments
T <sub>1</sub>	Disk	Ploughing with a tractor drawn disk plough followed by harrowing with a tractor drawn disk harrow.
T <sub>2</sub>	Mouldboard	Ploughing with a tractor drawn mould-board plough followed by harrowing with a tractor drawn disk harrow.
T <sub>3</sub>	Rotary tiller	Tilling the soil with a rotary tiller.
T <sub>4</sub>	Wedge	Ploughing with a bullock drawn wedge plough followed by harrowing with a bullock drawn disk harrow.
T <sub>5</sub>	Untilled	The plots not ploughed with any implement.

### 3.6 Application of Treatments

It was considered essential to bring the whole experimental area to as uniform a condition as possible in order to compare the resultant changes brought about and the effects produced on the soil by various tillage practices. In order to achieve this desired uniform condition of soil and thus avoiding differences in compaction from plot to plot, the field was ploughed upto 15 to 16 cm with the help of a tractor drawn mould-board plough. After ploughing, double harrowing with disk harrow followed by planking was done. The soil was then uniformly compacted by a 75 kg roller moving over it when the moisture content was 9.00 per cent. All these operations were carried out in the last week of October and the field was left as such with frequent use of weedicide to keep land completely free of weeds.

Just prior to seeding wheat, various tillage operations were carried out according to experimental plan. A single pass was made with respective implement in all the treatments. All the tillage operations were completed during the same day when the soil moisture content was 8.7 per cent.

### 3.7 Sowing of Wheat

Wheat seeds previously tested for its viability were sown at 8 cm depth providing a distance of 20 cm from row to row and 5 cm from hill to hill.

### 3.8 Fertilizer Application

Nitrogen (N), Phosphorus (P) and Potassium (K) were applied at the rate of 100, 80 and 50 kg/ha respectively in two

split doses. At the time of sowing N, P and K were applied at the rate of 50 : 50 : 50 kg/ha respectively in the form of ammonium sulphate, single superphosphate and muriate of potash. Second dose of fertilizer application was done 30 days after sowing at the rate of 50 and 30 kg/ha of N and P respectively.

### 3.9 Plant Protection

In the seedling stage, BHC (benzene hexachloride, 5% EC) was dusted at the rate of 20 kg/ha as a measure against insects and pests attacking the new seedlings. Rogour was spread twice during the growth period of wheat. First spraying was done when the crop was in vegetative growth phase and the second spray was applied at flowering stage.

### 3.10 Observations

#### 3.10.1 Vegetative growth of wheat

Sampling technique : The plants of 30 cm drill were selected from each plot with the help of a random table and tagged. Tiller count and observations on growth and yield attributes were made on this sample. Plants with roots were taken out completely with the help of spade and shovel. Care was taken to ensure maximum extraction of roots from 0-40 cm depth. The roots were washed off the soil immediately after the sampling. The whole soil lump, with plant sample was placed in a specially fabricated 0-5 cm galvanized screen basket lined internally with cloth. The screen basket containing soil and plant samples was shaken manually in a trough of water. The roots were gently

washed free of soil that gradually sloughed off, accumulating in the bottom of the trough, while plant sample with roots was retained on the screen basket. It was then removed from the basket and finally washed with a fine spray of water so as to remove the closely held soil particles. After recording the length of root and height of plant, roots were separated from the plant.

Plant sampling was started on 20th day after sowing, thereafter sampling was done weekly. However, the sampling for root studies was done at different stages of growth.

3.10.1.1 Plant height : Plant height was measured in cm from the base of the shoot to the tip of the upper most unfolded leaf.

3.10.1.2 Tiller number : Changes in number of viable tillers <sup>were</sup> recorded throughout the growth period of crop and was reported as number of viable tillers per 30 cm drill.

3.10.1.3 Leaf area : The leaves of plants were graded into different groups according to their sizes. Three leaves from each group were traced and area was measured with a planimeter to get an average leaf area. Average leaf area from different groups of leaves multiplied by number of leaves in each group and added together gave the total leaf area. The leaf area index (LAI) was calculated according to the formula given by Watson (1947) as follows :

$$\text{LAI} = \frac{\text{Leaf area, cm}^2}{\text{Land area, cm}^2}$$

3.10.1.4 Total dry matter : Plants excluding roots were chopped into small pieces and were kept in paper bags. They were labelled properly and dried in an oven at 70°C and weighed and reported as g/30 cm drill.

### 3.10.2 Yield and yield attributes

The plants of 30 cm drill, already selected in each plot, were harvested first and were analysed for number of fertile tillers and other yield attributes.

3.10.2.1 Number of fertile tillers/30 cm drill : All the ear bearing tillers of the sample were counted and recorded.

3.10.2.2 Number of grains per spike : Five well grown ears were selected from each sample and grains per spike were counted. Average of five spikes was recorded.

3.10.2.3 Test weight : A random sample from total grains, obtained earlier from each sample, was taken. From this random sample, 1000 grains were counted and weighed. The weight thus obtained was recorded and reported as test weight.

3.10.2.4 Grain yield : After threshing the net plot produce, the grains were cleaned and weighed. The moisture content in the grain from each plot was determined and yield was calculated and reported as kg/ha, adjusted to 10.0 per cent moisture content.

3.10.2.5 Straw yield : Before threshing the grains, total weight of the produce was recorded. The weight of grains was subtracted from the total weight to obtain the straw yield. The straw yield was also reported as kg/ha.

### 3.10.3 Root length and weight

After measuring the root length in cm, they were firstly air dried and finally oven dried at constant weight at 70°C and reported as g/30 cm drill.

### 3.10.4 Clod size distribution

Just prior to seeding wheat, various tillage implements were operated and the clods were allowed to dry for 6-7 days. From randomly selected 30 x 30 cm area, the entire soil was removed for clod size distribution. The whole soil was transferred on the top of a nest of sieves. A set of sieves of opening 52.8, 38.0, 25.4, 19.1, 12.7, 9.5, 5.0 and 2.0 mm was used for the purpose. The soil was shaken gently for a minute taking due care to avoid breaking of clods. The clods retained on each sieve were weighted and reported as percentage.

The clod mean weight diameter was calculated by statistical method as suggested by Youker and McGuinness (1957) which states:

$$Y = 0.876X - 0.079$$

where, Y is the mean weight diameter (MWD) and X is the sum of the product of aggregate size times weight of aggregates within that size. The mean weight diameter is a single value statistical mean of the clod size distribution and serves as a good index of cloddiness.

### 3.10.5 Bulk density

Bulk density before tillage operation was determined from the undisturbed cores taken from the experimental plots. Five

core samples were randomly taken from each replication of a treatment and bulk density determined. Average of such values was noted.

Microrelief meter was used to determine the bulk density of the tilled layer. As described in the case of porosity determination (3.10.6), one set of heights of measuring pins was recorded on the top of the ploughed surface. Ploughed soil was then removed, weighed and corresponding elevations of plough sole layer were recorded. The difference of the corresponding heights of the top profile and the plough sole layer gave the depth of the tilled soil. The average of all such readings was considered as the average depth of the soil. The computation was as follows:

$$D_p = h_t - h_s$$

where,  $D_p$  is the average depth of ploughed layer in cm;  $h_t$  and  $h_s$  are the average heights of the profile and sole layer, respectively.

The bulk density was then calculated. During the latter part of the experiments, core samples were once again taken for the determination of bulk density. The 10 cm long cores were used for this purpose.

### 3.10.6 Measurement of total porosity

A technique described by Burwell *et. al.* (1963) was employed to determine the total porosity. Prior to tillage operation, 5 undisturbed cores were randomly taken from depth of 10 cm within

a single replication of a treatment. For the experiment, the initial total porosity was estimated from composite of cores from all treatments. From the undisturbed cores obtained before tillage, the initial porosity  $P_i$ , for the layer to be tilled was calculated as follows :

$$P_i = \frac{2.65 - D_b}{2.65} \times W$$

where,  $D_b$  is the average bulk density in  $g\ cm^{-3}$  obtained from undisturbed cores, and  $W$  is the depth of the sampled layer in cm. Since ploughing depth was 10 cm, in the experiment  $W$  was taken as 10 cm for computation of  $P_i$  having unit of cm and may be defined as 'initial porosity in cm per initial 10 cm layer'.

Total porosity after tillage operation throughout the growth period of crop was measured with a microrelief meter (Plate 1). It measures the elevation of soil surface profile. It is designed to measure surface elevation on 5 x 5 cm grid over 100 x 100 cm area (Fig. 3.4). The microrelief meter consists of (a) the scale board and measuring pin unit, (b) scale board support frame and (c) the support pins. During measurements the scale support frame was kept fixed on four support pins. The scale board and measuring pins move horizontally over the support frame. Twenty measuring pins spaced 5 cm apart are supported by pin guides attached to the scale board. When measuring pins are resting on the soil surface, heights at the top of the pins are read on the scale board. The measuring pins are then raised, the scale board is moved 5 cm horizontally towards

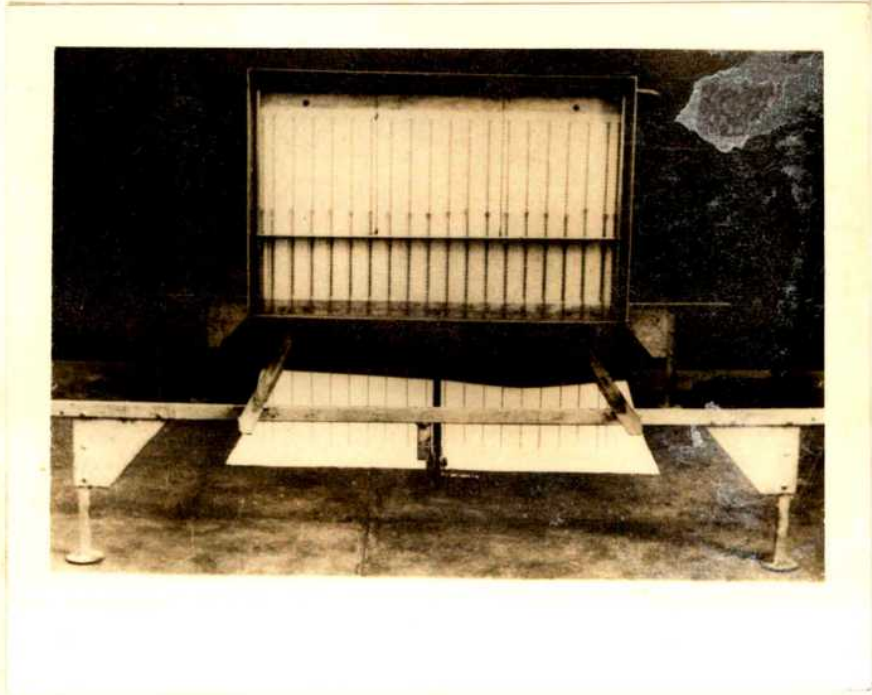


PLATE I. MICRORELIEF METER



the observer, with the help of a chain provided on the frame. The measuring pins are lowered and heights are read again. This procedure was continued until 20 such readings were taken at each of the 20 such positions of the scale board unit on the frame. Thus, 400 readings were recorded on a 5 x 5 cm grid over an area of 100 x 100 cm in each plot.

Four support pins per plot are required to rest the legs of the microrelief meter frame. These pins are driven firmly into the soil. The top of the pins are levelled with respect to each other with the help of a dumpy level in order to keep the top of the pins in the same horizontal plane. The support pins remained in this position throughout the growing period. Before all subsequent observations were taken, the elevation of the support pins was checked and height adjusted in case of variation in elevation of top of the support pins.

From the microrelief meter readings recorded for the initial setting and at any time,  $t$ , total porosity was computed as follows :

$$\bar{h}_1 = \frac{1}{n} \sum_{i=1}^n h_i$$

where,  $\bar{h}_1$  was the average height of the pins, at the time the undisturbed cores were taken, prior to tillage;  $h_i$  was the individual height readings in cm; and  $n$  was the number of readings.

The average height of measuring pins at time  $t$ , was calculated as :

$$\bar{h}_t = \frac{1}{n} \sum_{t=1}^n h_t$$

where  $\bar{h}_t$  was the individual height readings in cm at time, t.

The total porosity at time t was then given by

$$P_t = P_1 + ( \bar{h}_t - \bar{h}_1 )$$

The total porosity, thus obtained, may be defined as 'cm of porosity per initial 0-10 cm soil layer'. In latter part of the thesis, porosity will be given in cm which should be taken as porosity per initial 0-10 cm soil layer.

### 3.10.7 Soil moisture

#### 3.10.7.1 Matric suction

Soil moisture was determined by gravimetric method. The core samples taken for bulk density and porosity measurements were utilized for the determination of soil moisture prior to tillage operations. During the seedling emergence stage of wheat growth, moisture content was determined upto a depth of 10 cm because seeds were placed at 8 cm depth. Soil samples were taken from 0 to 10 and 10 to 20 cm depths with the help of spiral screw auger during the latter part of wheat growth and average moisture content recorded. Three soil samples per treatment were taken on every alternate day. The per cent of soil moisture content was converted to matric suction in bars from water release curve of the soil obtained (Fig. 3.5) with the help of a pressure plate apparatus.

Three tensionometers in each treatment were also installed at 15 cm depth to note the fluctuations in moisture content during

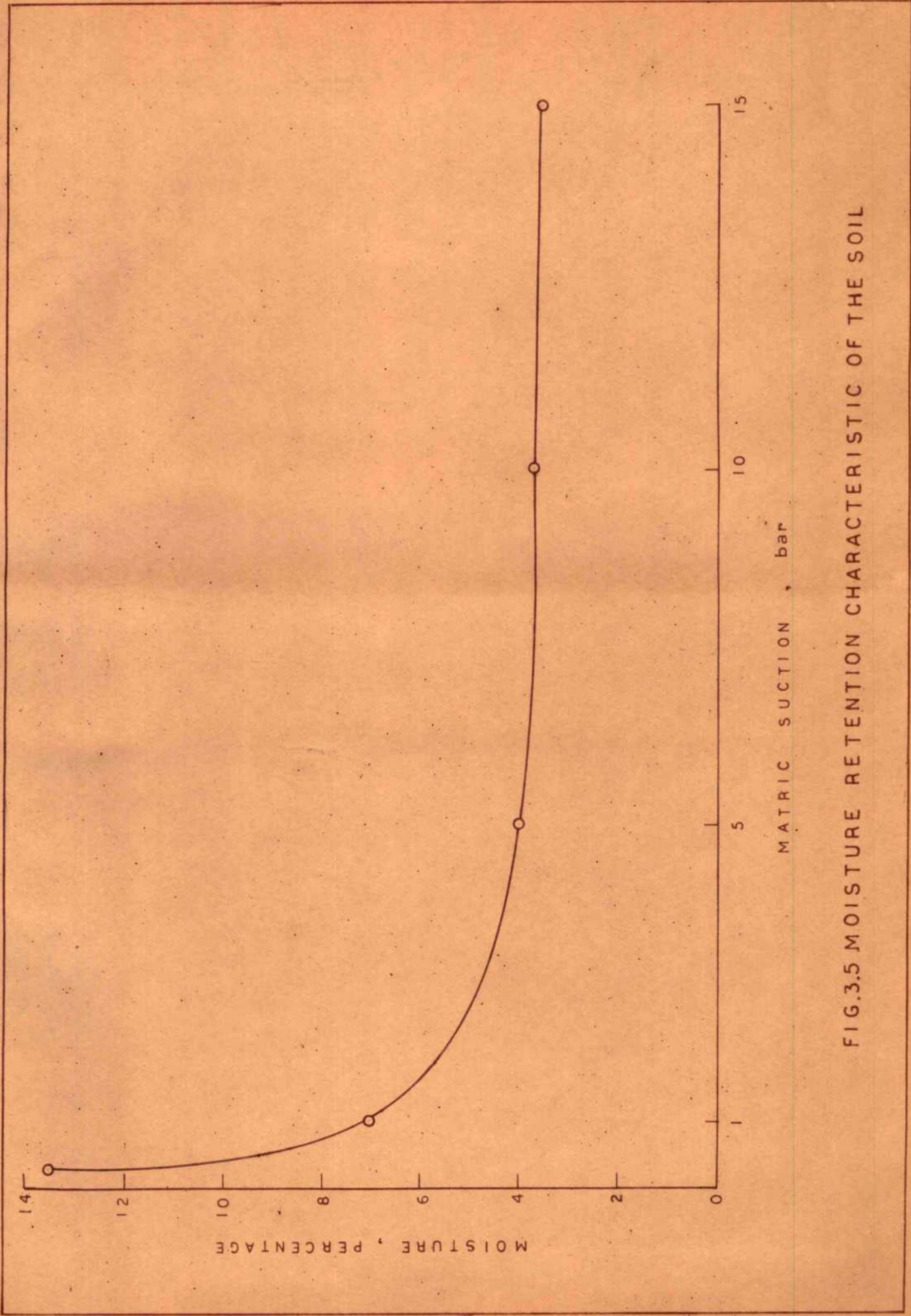


FIG.3.5 MOISTURE RETENTION CHARACTERISTIC OF THE SOIL

the various growth phases of wheat crop which also served to be used as a supplement for moisture determinations. Irrigation interval was approximately 15 days depending on the moisture availability in the soil. It was decided to irrigate the crop when the mercury column in the tensiometer set-up raised upto 45 cm in a plot which retained maximum water. Equal quantity of water was applied to each treatment in order to know the influence of different tillage practices on water retention.

#### 3.10.7.2 Infiltration

Infiltration fluctuates widely under different conditions of soil moisture and management. The infiltration rates of treated plots were, therefore, determined at a constant moisture content between 8 to 9 per cent in order to assess the influence of different tillage practices on soil physical conditions immediately after tillage and during the various growth phases of wheat crop. However, infiltration studies were carried out only during 1972-73.

Infiltration rate was determined with a single cylinder infiltrometer of 15 cm diameter and 30 cm length placed at 20 cm depth in each treatment as described by Subramanyam (1959). The initial infiltration rate denoted the intake rate during the first 15 minutes immediately following the application of water to the infiltrometer and the final infiltration rate was the rate of entry of water during the 7th and final hour of the infiltration run at which the rate of entry practically becomes constant.

### 3.10.7.3 Hydraulic conductivity

Hydraulic conductivity, prior to seeding wheat and during different growth phases of the crop was determined with 5 undisturbed core samples from each treatment as suggested by Dakshinamurti and Pradhan (1966). The average value for each treatment was recorded. The sensitivity and significance of hydraulic conductivity at the minimum bulk density value was taken as an index of soil structural change as influenced by various tillage treatments.

### 3.10.8 Soil aeration

Aeration status of soil under different soil physical conditions was characterised by the measurement of oxygen diffusion rate (ODR) of soil. ODR in soil (3 replicates for each treatment) at 8 cm depth was measured by the platinum micro-electrode method as proposed by Stolzy and Letey (1964), at regular intervals throughout the growth period of wheat.

Non-capillary porosity was determined with tension table as described by Leamer and Shaw (1941). Similarly the porosity determined with the help of microrelief meter also gave an idea about the aeration status of soil as influenced by various tillage practices.

### 3.10.9 Penetration resistance

The strength of the soil was measured by a ball point impact type penetrometer in terms of energy required for penetration to

different depths (5, 10 and 15 cm) at the increments of 5 cm (Kumar et. al., 1971). The measurements were taken in each treatment when the soil moisture content was 7.0 to 8.0 per cent. Penetration tests were started after the first irrigation and the last readings were taken a day after the crop was harvested.

## Part II

### Physical Properties of Soil Aggregates

Application of these laboratory studies for interpretation of field results involving beds of aggregates is hazardous unless more is learnt about the aggregate - diameter distribution attained in the field. It is also a common observation that determination of bulk density of cloddy surface by core samples immediately after the application of tillage treatments becomes difficult. Moreover, it does not represent the real bulk density of the field at tillage. The equation based on the estimation of  $\log GMD$  and  $\sigma \log d$  as suggested by Allmaras et. al. (1965) was, therefore, tried to predict the bulk density of soil under tillage treatments.

This part describes a procedure used to measure aggregate-diameter distributions along with their other related physical properties as influenced by various tillage practices.

#### 3.11 Collection of Soil Sample

Various tillage treatments (Table 3.3) were operated according to experimental plan as described in Part I. In all the cases a single pass was made with respective implement. The operations

of all treatments were completed in a day at 8.7 per cent soil moisture content.

After the soil was tilled, the clods were allowed to dry for 6-7 days. The entire soil was removed for clod size distribution from randomly selected 30 x 30 cm area in each treatment. Thus collected soil samples were subjected to different tests in the laboratory.

### 3.12 Aggregate-diameter Distributions

Five hundred grams of air-dry soil sample containing the aggregates having diameters  $< 19.05$  mm was placed in the top sieve of a nest of sieves with different openings as stated in Table 3.4. The array of sieves was so arranged that the largest diameter sieve was on the top of the nest of sieves. The nest of sieves was then placed in a electrically operated mechanical vibrator in which the degree of vibrations was suitably adjusted and was run for two minutes. After sieving, all the sieves were separated from the nest and the soil aggregates retained on each sieve were weighed and recorded. The quantity of air-dry aggregates in each of 7 sieve size classes was determined as described in Part I.

#### 3.12.1 Weight fraction of aggregates

The weight fraction of soil aggregate-diameter separates was calculated using the equation :

$$\text{Weight fraction} = \frac{\text{Weight of soil aggregates retained in each sieve}}{\text{Total weight of sample taken}}$$

Table 3.4 Openings of different sieves used in the experiment

Sieve class	Diameter of openings	Average diameter	Logarithm of average diameter (log d), mm
	mm	mm	x
I	19.05 - 12.70	15.87	2.762
II	12.70 - 9.50	11.10	2.403
III	9.50 - 4.76	7.13	1.968
IV	4.76 - 2.38	3.57	1.273
V	2.38 - 1.19	1.78	0.577
VI	1.19 - 0.50	0.84	-0.174
VII	< 0.50	0.25	-1.383
			Average; $\bar{x} = 1.068$

### 3.12.1.1 Cumulative weight fraction

Cumulative weight fraction was computed from the values of weight fraction of aggregate-diameter separates. The relationship between the cumulative weight fraction and the logarithm of the respective diameter separates was established which particularly referred to a tillage treatment performed with a mould-board plough ( $T_2$ ). The similar relationship can be drawn for other treatments also. The least square method was used to find out the regression equation  $y = mx + c$ .

### 3.12.2 Mean weight diameter (MWD)

The mean weight diameter was calculated by the following equation as suggested by Van Bavel (1949) :

$$MWD = \sum_{i=1}^n X_i W_i$$

where,  $n$  is the number of observations i.e. 7 sieve classes, and  $W_i$  represents the weight of aggregates in a size class with an average diameter  $X_i$ .

The observations were recorded separately for each tillage treatment .

### 3.12.3 Geometric mean diameter (GMD)

The geometric mean diameter was computed using the equation suggested by Mazurak (1950) :

$$GMD = \frac{\sum_{i=1}^n W_i \log X_i}{\sum_{i=1}^n W_i}$$

where,  $W_i$  is the weight of aggregates in a size class with an average diameter  $X_i$ ,

$\sum_{i=1}^n W_i$  is the total weight of the sample.

The values of GMD which is a composite of different sieve classes in tillage treatments obtained and then from these values of GMD for a respective tillage treatment, the logarithm<sub>e</sub> of the geometric mean diameter (log GMD) was estimated.

#### 3.12.4 Dispersion of aggregate-diameter separates ( $\sigma \log d$ )

The meaning of the word dispersion is analogous to the variance in statistical concepts. Their meaning is not same, because variance deals with precision as a component of error and dispersion as used in this study deals with diameter heterogeneity in a mixture of aggregate-diameter separates. Furthermore, dispersion as used here should not be associated with the sample preparation for mechanical analysis or vertical segregation of aggregate diameters in the seedbed. It indicates here the range of variation or heterogeneity in aggregate-diameter separates from that of geometric mean diameter of aggregates.

From the logarithm of average aggregate-diameter separates as stated in Table 3.4 and the value of log GMD of a tillage treatment in question, the standard deviation of the average limit of sieve size classes was then calculated which is stated as an index of dispersion of aggregate-diameter separates ( $\sigma \log d$ ) for the corresponding tillage treatments. The values of  $\sigma \log d$ , thus obtained, were recorded for the tillage treatments.

### 3.13 Weight Fraction of Water

The known quantity of soil mixture containing the aggregates within the upper and lower limit of sieve sizes was taken in a core from each tillage treatment separately. The muscline cloth was tied at one end of such core and was placed in water to allow it to saturate by capillarity. The weight of saturated soil was recorded. The cores were subjected to 0.06 bar tension on a tension table as described by Leamer and Shaw(1941). The cores were weighed when the equilibrium was attained. The water content at equilibrium was treated as the moisture retained at 0.06 bar tension. The weight fraction of water by volume was also computed by multiplying the value of weight fraction of water on weight basis with the respective bulk density of the aggregate-mixture depending upon the tillage treatment.

### 3.14 Volume Loss upon Mixing

The volume loss per 100 cm<sup>3</sup> of initial volume of aggregates, which results from mixing, was computed using the following equation as suggested by Allmaras *et. al.*(1965):

$$V_l = \left[ 1 - \left( V_f / \sum_{i=1}^n V_i \right) \right] 100$$

where,

$V_l$  is the volume loss upon mixing, cm<sup>3</sup>/100 cm<sup>3</sup>,

$V_f$  is the volume loss after mixing the aggregate-diameter separates,

$V_i$  is the bed volume of the  $i$ th aggregate-diameter separate before mixing and is computed as the ratio of oven-dry weight and the dry bulk density, and  $n$  is the number of sieve classes i.e.7.

The observations were recorded separately for each tillage treatment.

### 3.15 Density Determinations

The bulk density of aggregates was determined with a core sampler. Pycnometer method was adopted to determine the particle density of each diameter separate. Aggregate density was determined by paraffin wax method. The dry density of aggregate mixture was simply determined by noting the weight of mixture sample in a core and the volume occupied by a corresponding mixture in a core sampler.

### 3.16 Computation of Constants $\beta_1$ and $\beta_2$

The equation for determination of bulk density ( $D_B$ ) by incorporating the values of  $\log GMD$  and  $\sigma \log d$  as suggested by Allmaras *et. al.* (1965) was tried. The equation of the interest was :

$$\Delta(D_B) = \beta_1 [\Delta(\log GMD)] + \beta_2 [\Delta(\sigma \log d)]$$

The constants  $\beta_1$  and  $\beta_2$  were computed by solving the two equations simultaneously for two tillage treatments.  $\Delta$  symbolizes the variations that occurred during measurements. The average values of  $\beta_1$  and  $\beta_2$  were noted for the corresponding average values of  $\log GMD$  and  $\sigma \log d$ . These mean values could be taken as the constants for Kharagpur soil.

### Part III

#### Soil Bin Experiments

##### 3.17 Experimental Set-up

The experimental set-up was designed and fabricated to study the effect of some factors like soil density, soil moisture content and speed of operation on clod size distribution and draft. The set-up consisted of soil bin, motor with speed reduction unit coupled with winding drum, processing trolley, tool mounting trolley and draft recording device.

##### 3.17.1 Soil bin

Soil bin with a motor and speed reduction unit coupled with winding drum and specially designed tool mounting trolley is shown in Fig.3.6. On two sides of a soil bin, there are two parallel I shaped beams, supported by vertical angle iron posts at fixed interval of two metres. These rails guide the motion of the trolley on which tillage tool is mounted. A 5 H.P. electric motor drives the rope winding drum through speed reduction unit, equipped with reversible switch. This makes it possible to obtain forward as well as reversible motion. One end of the flexible rope is fixed over the surface of the drum and the other end is attached to one end of dynamometer. The other end of dynamometer is attached to a hook fixed at one end of the trolley.

##### 3.17.2 Processing trolley

Processing trolley consists of a rotary tiller, a leveller blade, a roller and water sprinkling arrangement (Plate 2). Rotary

tiller is capable of working to 10-15 cm depth. The working depth of tiller, leveller and roller can be varied with the help of depth adjusting screw provided separately for each. A tank is provided on the top of the trolley to store water. A valve is provided to control flow of water through the perforated sprinkler to moisten the soil.

### 3.17.2 Tool mounting trolley

The tillage tool was attached to a tool mounting trolley through a specially designed tool bar (Plate 3 ). The tool which consisted of a simple rectangular flat plate (14.5 cm x 5.5 cm) fitted at 90 degree angle with the horizontal plane and was adjusted to a working depth of 8 cm throughout the experiments.

Extensive studies have been carried out by Bhushan et. al. (1971) on tool parameters and depth of working of a tillage tool. They opined that even with the best design of the tool, the degree of resultant soil cloddiness and energy requirement was governed to a large extent by soil factors and operating conditions. It was, therefore, decided to study soil factors and operating conditions with reference to a simple tillage tool.

### 3.17.4 Draft recording device

Draft recording device consists of a strain gauge type dynamometer coupled with a dynograph during the test. As shown in Plate 4, a strain gauge dynamometer was designed and fabricated to measure the draft. The dynamometer is made of mild steel flat plate. The cross section of dynamometer where strain

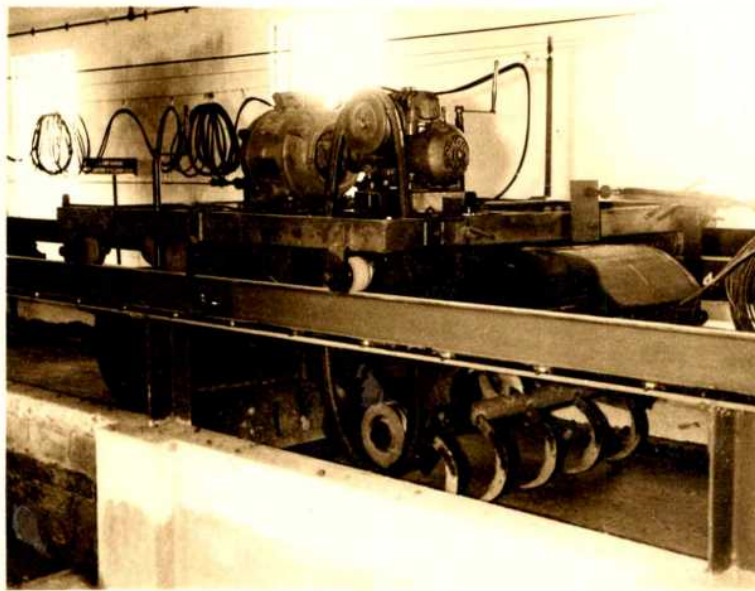


PLATE 2. SOIL PROCESSING TROLLEY

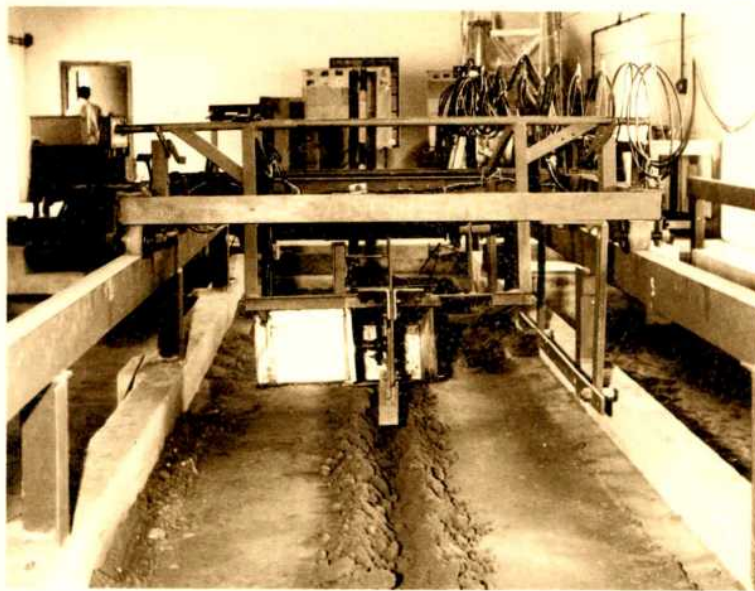


PLATE 3. TOOL MOUNTING TROLLEY WITH  
A TILLAGE TOOL

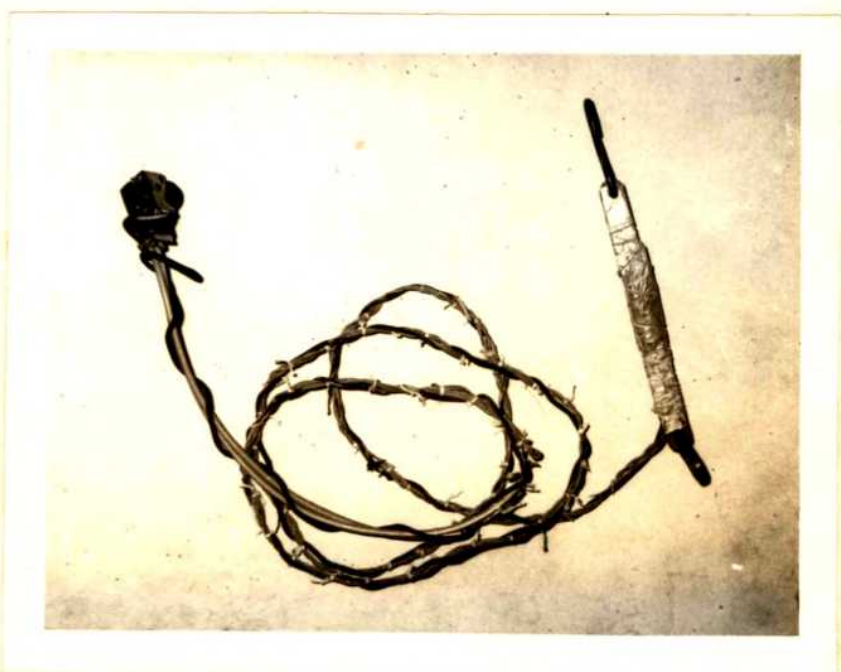


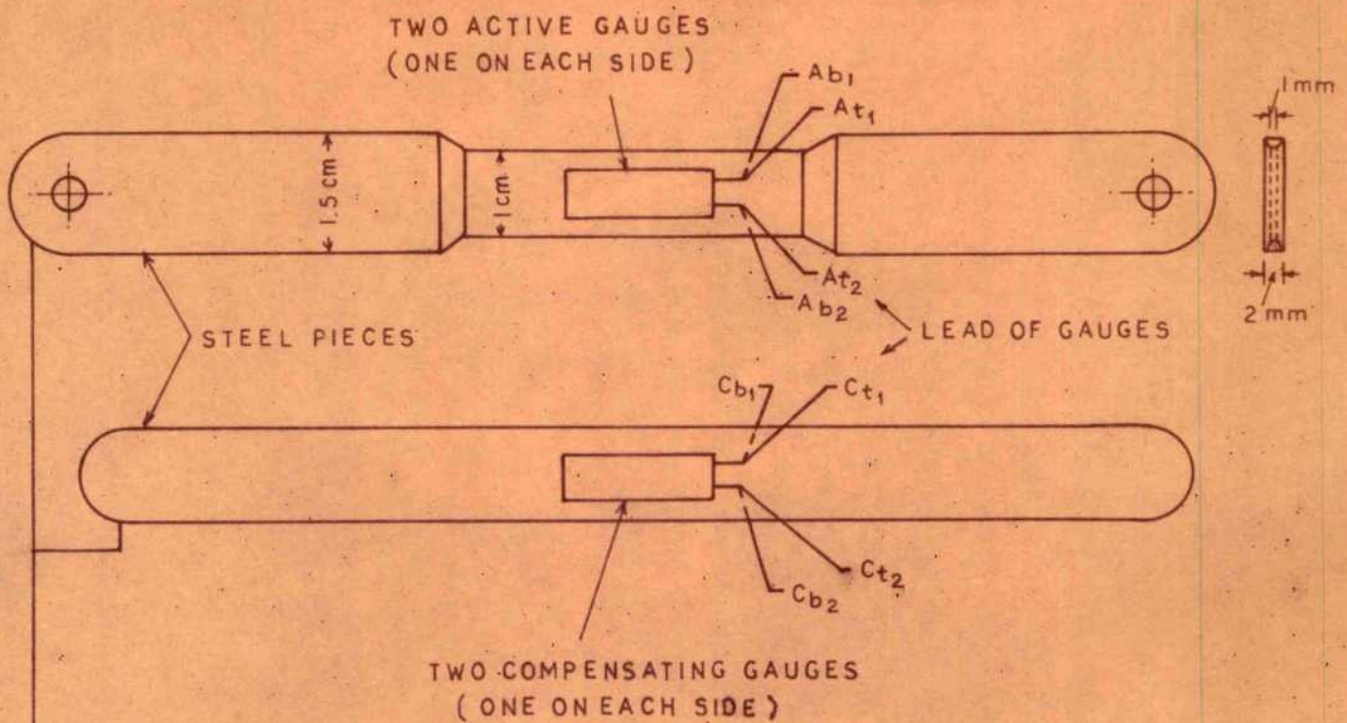
PLATE 4. STRAIN GAUGE DYNAMOMETER



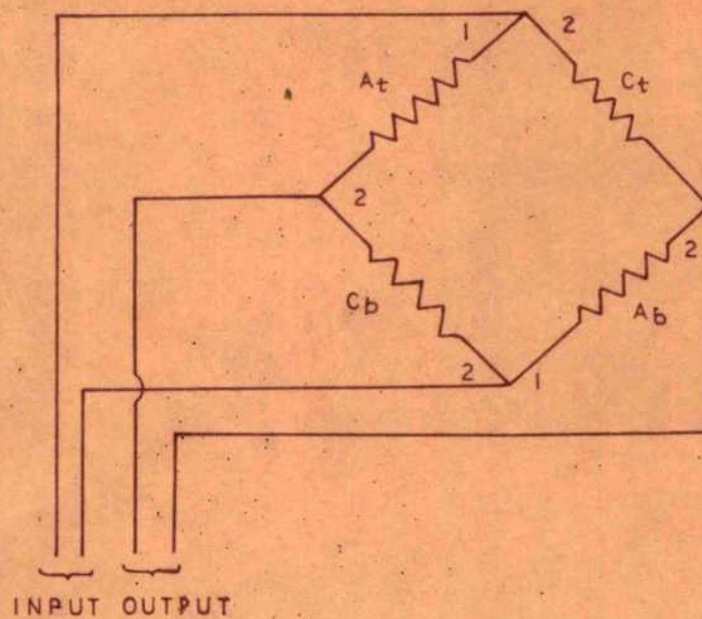
PLATE 5. SOIL BED READY FOR TOOL OPERATION



PLATE 6. SOIL BED AFTER TOOL OPERATION



(A) MOUNTING ARRANGEMENT



(B) STRAIN GAUGES IN WHEAT STONE'S BRIDGE

FIG.3.7 STRAIN GAUGE DYNAMOMETER

gauges are fixed is 1 mm x 10 mm. It consists of four strain gauges connected in Wheatstone's bridge circuit as shown in Fig. 3.7.

### 3.18 Experimental Variables

The variables that affect the draft are : resistance to compaction, shear, friction, compression, cohesion, and speed (Telischi *et. al.*, 1956). These variables are the functions of the following factors : composition and percentage of colloidal content, moisture percentage, bulk density and speed of the implement. Therefore, only the bulk density, per cent moisture and speed of operation were considered on sandy loam soil. Details of the experimental variables included in the present investigation were as follows :

#### a) Bulk density

$$D_1 \quad 1.65 \pm 0.02 \text{ g cm}^{-3}$$

$$D_2 \quad 1.79 \pm 0.02 \text{ g cm}^{-3}$$

$$D_3 \quad 1.85 \pm 0.03 \text{ g cm}^{-3}$$

#### b) Soil moisture content

$$M_1 \quad 8.66 \pm 0.04 \text{ per cent}$$

$$M_2 \quad 9.84 \pm 0.04 \text{ per cent}$$

#### c) Speed of operation

$$S_1 \quad 0.25 \text{ m/sec}$$

$$S_2 \quad 1.25 \text{ m/sec}$$

For determination of bulk density and moisture content, core samples were taken from random points located in the path of a

tillage tool. The desired bulk density was obtained by several passes of the roller which were predetermined for the density in question at the moisture that was monitored. The moisture content was adjusted by the sprinkler unit provided on the processing trolley. However, there was no appreciable variation in both factors i.e. bulk density and soil moisture between experimental runs. The operating speed was achieved or adjusted by the gear mechanism. Draft was measured and recorded by a previously calibrated recording strain gauge dynamometer coupled with a dynograph during the test.

### 3.19 Preparation of Soil Bed and Recording Observations

#### 3.19.1 Preparation of soil bed

The surface soil (0-15 cm depth) collected from the field was crushed, air-dried and screened through a sieve of 5 mm openings. Physical characteristics of the soil are given in Table 3.1. The soil bin was filled up with this processed soil and levelled. It was watered and allowed to settle for 30 days. The soil was then initially opened to a depth of 15 cm with a spade and was then tilled 3-4 times by a rotary tiller. It was levelled using a blade mounted on the processing trolley. The desired density and moisture content were achieved as described earlier. The uniformity of compaction was ascertained by a cone type penetrometer. The height of the roller and the direction of its movement over the soil during each pass was same in all sets of experiments. The soil bin, thus prepared (Plate 5), was allowed to settle for twenty four hours before tool was operated. This procedure was repeated prior to each run.

### 3.19.2 Draft measurement

When a force is applied at one end of the dynamometer, it causes change in resistance of strain gauges, consequently the voltage signal fed to the recording unit of dynograph (Plate 7) is proportional to the force applied. The dynamometer was calibrated prior to each test by noting the deflection of pen on recording chart paper after applying known forces by standard weights with 5 kg increment upto 35 kg. The calibration curve for the strain gauge dynamometer fabricated and used is shown in Fig. 3.8.

First of all, the trolley was pulled without any tillage tool attached to it and deflection noted. Then tillage tool was attached to a tool bar. After making adjustments for depth and angle etc. the tool mounting trolley was pulled by a motor through a rope. The deflection of the pen on the chart was noted. Since the deflection was not uniform (Plate 8) throughout the length of run, an average was taken. From the calibration curve, the average draft was computed. From the draft, thus obtained, resistance offered by the trolley alone was subtracted in order to get the draft for a particular set of experiment. Unit draft was calculated by dividing the total draft, calculated from the record of strain gauge dynamometer as described earlier, by the area of cross section of a tillage tool (8 cm depth x 5.5 cm width).

### 3.19.3 Soil sampling for determination of bulk density and moisture content

The core sample to 10 cm depth was taken prior to operating tillage tool with core sampler. By measuring the length and

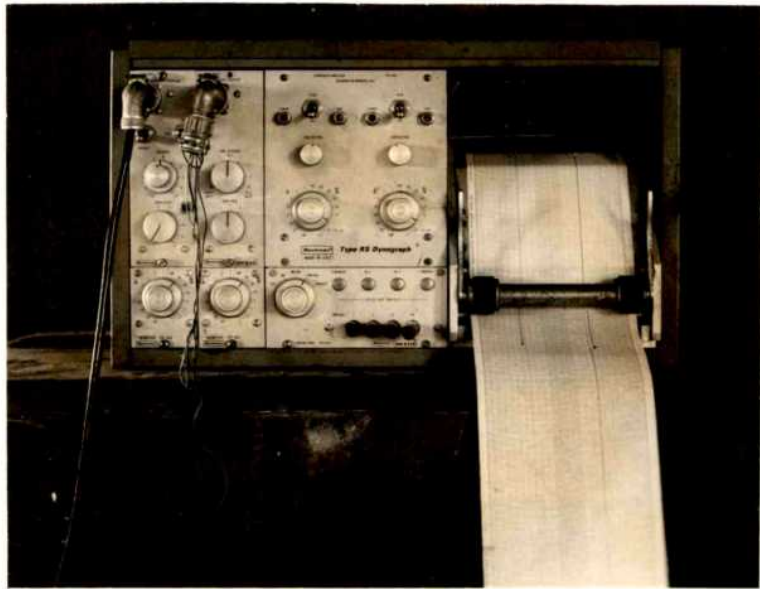


PLATE 7. DYNOGRAPH

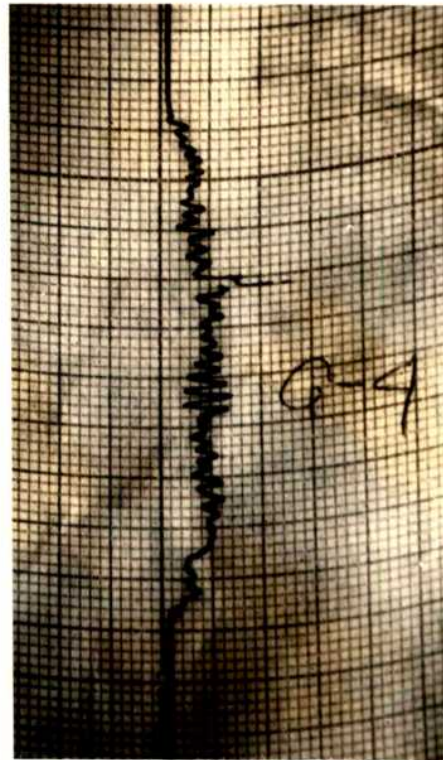


PLATE 8. A SAMPLE RECORD OF DRAFT

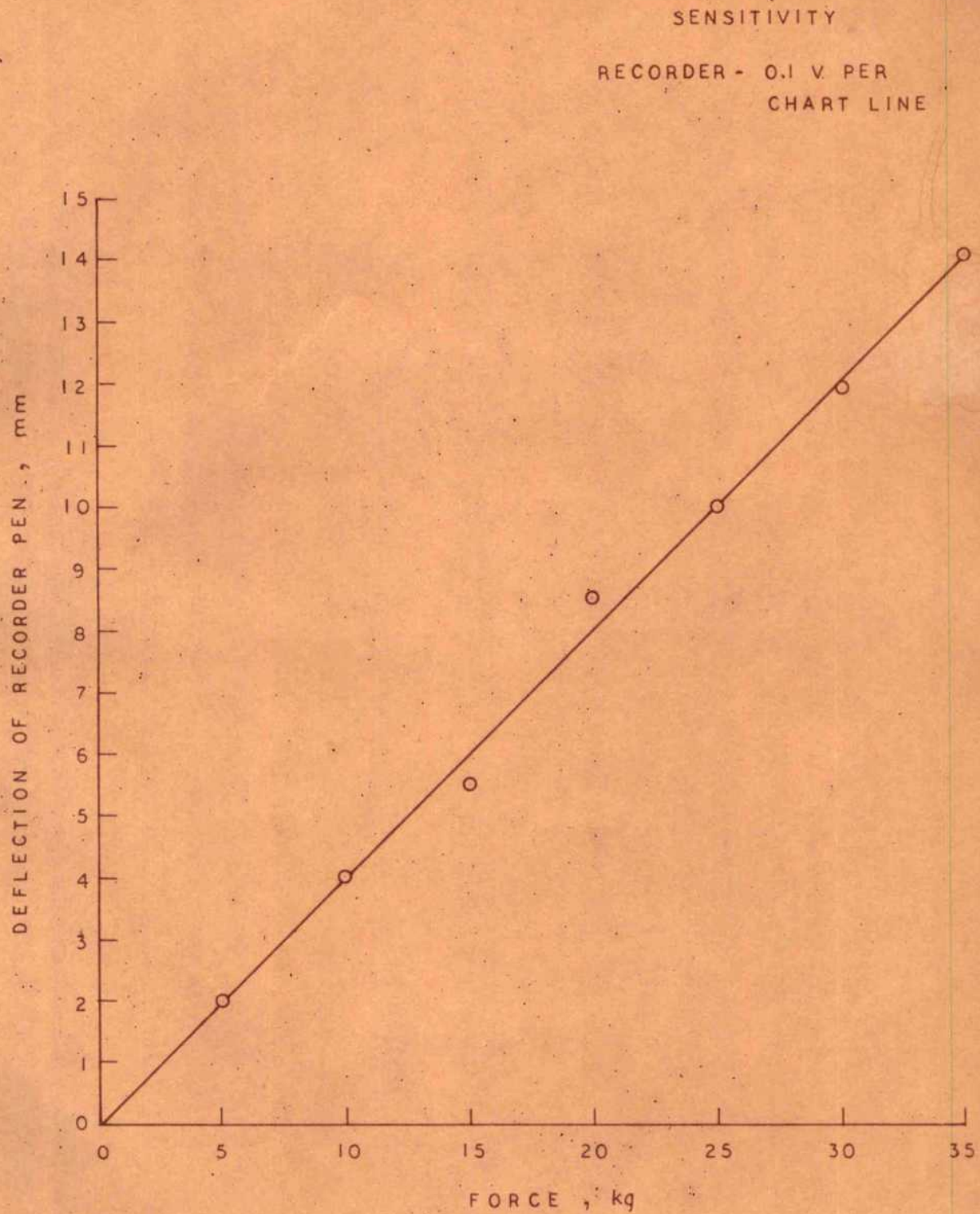


FIG.3.8 CALIBRATION CURVE FOR STRAIN GAUGE DYNAMOMETER

diameter of the core, the volume of core was determined. Knowing dry weight and volume of soil core, bulk density was calculated. The moisture content of the soil was determined from the same soil core by gravimetric method.

#### 3.19.4 Sampling for clod size distribution

Soil samples were collected for clod size distribution studies immediately after the tillage operation. Prior to ploughing each furrow, five plastic sheets were placed on both sides along the tool path so that furrow slice could be collected. The sections of the furrow slice collected on the plastic sheets were carefully removed and air-dried. When dry, the distribution of aggregates was determined as described in Part I. The mean weight diameter was calculated as described by Van Bavel (1949). The entire soil along the length of 30 cm furrow was also collected to measure the volume of soil fracture during each run.

#### 3.19.5 Drop-shatter method

The equivalent energy was determined by a drop-shatter method which was utilized to determine the strength of the soil (Gill and McCreery, 1960). The energy-clod size relation could be used as a basis for determining the amount of effective work done to a particular soil by a tillage tool (Gill, 1968).

Larger blocks of undisturbed air-dry soil weighing roughly 5 kg were taken from the test plot and dropped from a height ranging from 100 to 1000 cm into a large flat pan on a concrete

floor so that they could be shattered by the fall. The fragments were carefully collected and the mean weight diameter determined. The equivalent energy applied to the soil to break the sample down to each size was calculated from the mass of the sample, the acceleration of gravity and the distance of fall, and was expressed in dyne-cm as described by Gill and McCreery (1960). The clod sizes were separated as described earlier.

## Chapter IV

### RESULTS AND DISCUSSION

The observations and results obtained during the course of investigation are presented and discussed in this chapter. The chapter is divided into three parts. Part I deals with the field experiments and Part II covers the physical properties of soil aggregates while Part III is concerned with the experiments conducted in a soil bin.

#### Part I

#### Field Experiments

##### 4.1 Influence of Tillage Practices on Clod Size Distribution

The data on clod size distribution as influenced by different tillage practices are presented in Table 4.1. It is evident that different tillage practices produced varying clod sizes. The soil fraction under disk and mouldboard contained maximum percentage of larger clods and minimum of smaller ones. On the other hand, soil fraction under rotary tiller and wedge plough was dominated by the occurrence of smaller clods. Higher percentage of clods larger than 52.8 mm was recorded under disk and mouldboard as compared to other treatments. However, it is interesting to note that rotary tiller and wedge produced significantly higher percentage of clods smaller than 2 mm than that under disk and mouldboard treatments.

The clod mean weight diameter (MWD) values given in Table 4.2 revealed that significant differences occurred in MWD as

Table 4.1 Clod size distribution as influenced by various tillage treatments(T)

Treatments	Clod size expressed as percentage									
	>52.8 mm	52.8-38.0 mm	38.0-25.4 mm	25.4-19.1 mm	19.1-12.7 mm	12.7-9.5 mm	9.5 - 5.0 mm	5.0-2.0 mm	< 2.0 mm	
<b>1971-72</b>										
T <sub>1</sub>	5.28	7.52	6.83	6.56	6.14	9.46	15.44	14.44	28.95	
T <sub>2</sub>	4.51	8.05	7.13	6.37	6.68	8.52	10.65	15.14	35.48	
T <sub>3</sub>	Nil	0.57	3.83	5.23	3.41	4.47	6.63	12.63	64.39	
T <sub>4</sub>	2.81	5.04	7.30	4.89	3.67	5.75	8.94	15.45	45.30	
<b>1972-73</b>										
T <sub>1</sub>	5.45	7.67	6.80	6.53	6.43	9.43	12.69	15.49	30.22	
T <sub>2</sub>	5.48	7.30	6.37	6.26	6.65	8.27	10.73	16.24	32.62	
T <sub>3</sub>	Nil	0.38	2.28	4.31	4.94	5.64	9.13	11.13	61.67	
T <sub>4</sub>	2.41	5.56	6.41	7.02	5.80	5.78	8.34	12.44	46.74	

Table 4.2 Effect of various tillage practices (T) on clod mean weight diameter (MWD), bulk density and total porosity

Treatments	Clod MWD mm	Bulk density g cm <sup>-3</sup>	Total porosity cm/10 cm
<u>1971-72</u>			
T <sub>1</sub>	12.29	1.08	8.93
T <sub>2</sub>	11.83	1.17	8.49
T <sub>3</sub>	3.85	1.34	5.23
T <sub>4</sub>	7.41	1.21	6.93
T <sub>5</sub>	N11	1.69	3.71
	**	**	**
S. Em ±	0.229	0.061	0.983
LSD <sub>0.05</sub>	0.68	0.18	2.38
LSD <sub>0.01</sub>	0.95	0.25	3.28
<u>1972-73</u>			
T <sub>1</sub>	12.44	1.04	9.08
T <sub>2</sub>	12.07	1.13	8.55
T <sub>3</sub>	4.53	1.35	5.37
T <sub>4</sub>	8.81	1.22	7.17
T <sub>5</sub>	N11	1.67	3.75
	**	**	**
S. Em ±	1.423	0.028	0.327
LSD <sub>0.05</sub>	4.26	0.08	1.05
LSD <sub>0.01</sub>	5.87	0.12	1.35

\*\* significant at 1% level

induced by different tillage treatments. The MWD of clod was found to be maximum under disk followed by mouldboard, wedge plough and minimum under rotary tiller. This is attributed to the occurrence of higher percentage of clods larger than 52.8 mm diameter under disk and mouldboard treatments. Since rotary tiller produced higher percentage of clods smaller than 2 mm diameter, the MWD of clod was minimum. The clod MWD was statistically lower under rotary tiller as compared to other tillage treatments.

#### 4.2 Effect of Clod Size on Soil Physical Properties

The initial clod size distribution as induced by various tillage treatments continues to influence the soil physical environment around the seed even during the later stages of plant growth. The influence of clod size on soil physical properties was remarkable (Fig.4.1). The bulk density was found to have significant but negative correlation ( $r = -0.97$  and  $-0.94$  during 1971-72 and 1972-73 respectively) whereas, the porosity had positive significant correlation ( $r = 0.96$  and  $0.98$  during 1971-72 and 1972-73 respectively) with clod MWD. The bulk density decreased from  $1.35$  to  $1.04 \text{ g cm}^{-3}$  as the clod MWD increased from  $4.53$  to  $12.44$  mm under rotary tiller and disk respectively during 1972-73.

The tillage treatments reduced the bulk density considerably. As can be seen from Table 4.2, the bulk density was minimum ( $1.04 \text{ g cm}^{-3}$ ) in the plots tilled with disk plough and maximum ( $1.35 \text{ g cm}^{-3}$ ) under rotary tiller. Unlike bulk density, maximum

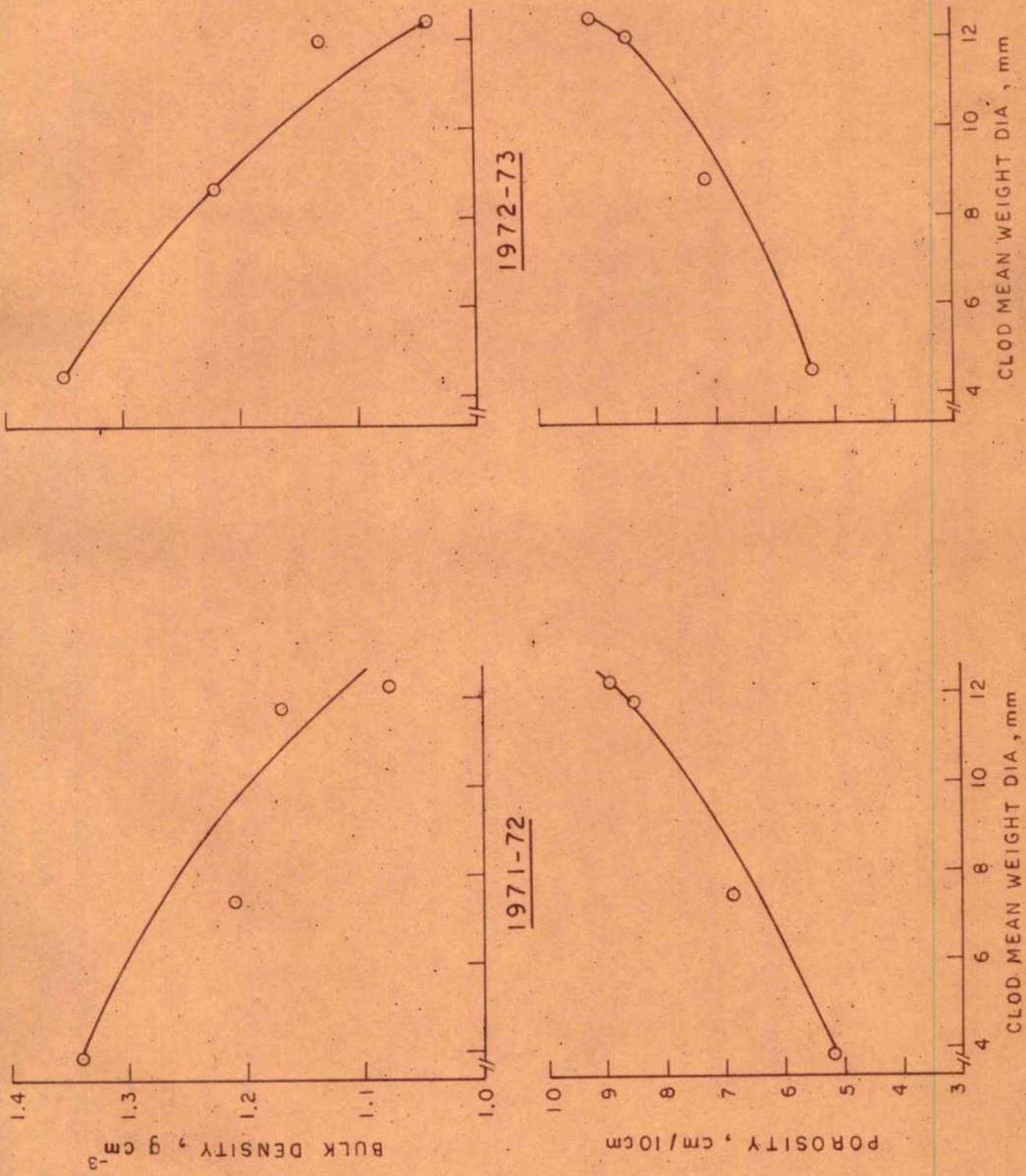


FIG.4.1 EFFECT OF CLOD MEAN WEIGHT DIAMETER ON PHYSICAL PROPERTIES OF SOIL

porosity occurred under disk followed by mouldboard, wedge and minimum under the rotary tiller. Statistically there was no marked difference in porosity produced by disk, mouldboard and wedge treatments, though it was significantly higher under disk and mouldboard as compared to the rotary tiller (Table 4.2). However, as expected, the soil under zero tillage had the maximum bulk density and hence the minimum porosity.

#### 4.3 Evaluation of Soil Edaphic Factors as Influenced by Tillage Practices During Growth Period of Wheat

The life span of wheat (culti-variety Kalyansona) and the duration of various growth phases under the agro-climatic conditions of this region was ascertained during the first year of experimentation. The experiment revealed that the crop took about 100 to 110 days to mature. The wheat crop passes through various growth phases i.e. seedling emergence, vegetative growth, jointing, bottling, dough and ripening stages. However, unlike rice, the above growth phases are not distinct. The vegetative growth may continue even at jointing or bottling phases. In the present investigation, the growth of wheat was divided into the following growth phases :

- 1 Seedling emergence : This phase continued from the day of seeding to seedling emergence. During this period seeds germinated and seedlings emerged. The duration was approximately 8 days.
- 2 Vegetative phase : This phase covered the growth period from seedling emergence to maximum tillering stage.

During this period, plant registered an appreciable increase in height, tiller number, total dry matter production and root proliferation. This phase lasted 50 days after sowing.

- 3 Reproductive phase : This phase ranged from panicle initiation stage to flowering stage. The phase lasted from 50 to 65 days after sowing.
- 4 Grain formation : This phase corresponded to the milking or dough stage. During this stage milk in panicles was converted to grain and vegetative parts started decreasing. The duration of this phase was 15 days and lasted till the crop attained 80th day of age.
- 5 Ripening or maturing : This phase continued from milking stage to harvesting. This phase was marked by sharp decrease in vegetative parts. The ripening of grain was accompanied by change in colour of the grain from green to yellow. The duration of this phase was 21 days and the crop was harvested on 104th day after sowing.

The above growth phases of wheat were defined in order to have a clear idea of changes in edaphic factors affecting growth of wheat. The influence of edaphic factors will be given according to the phases described above.

#### 4.3.1 Bulk density

The variation in bulk density with elapse of time after wheat sowing under various tillage practices is shown in Fig.4.2.

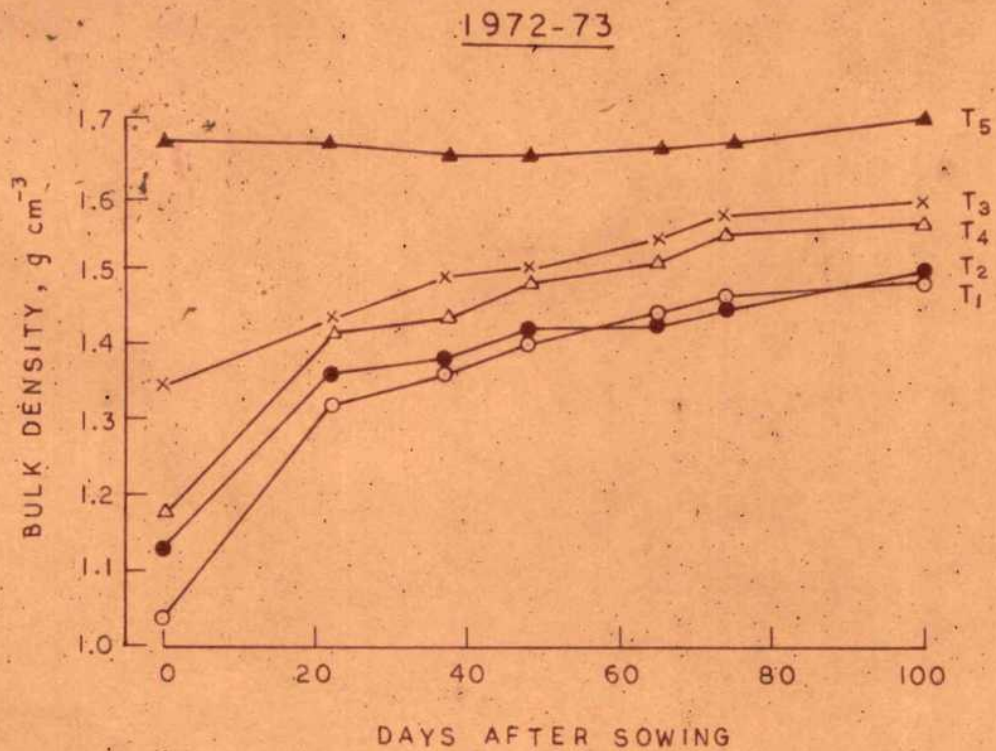
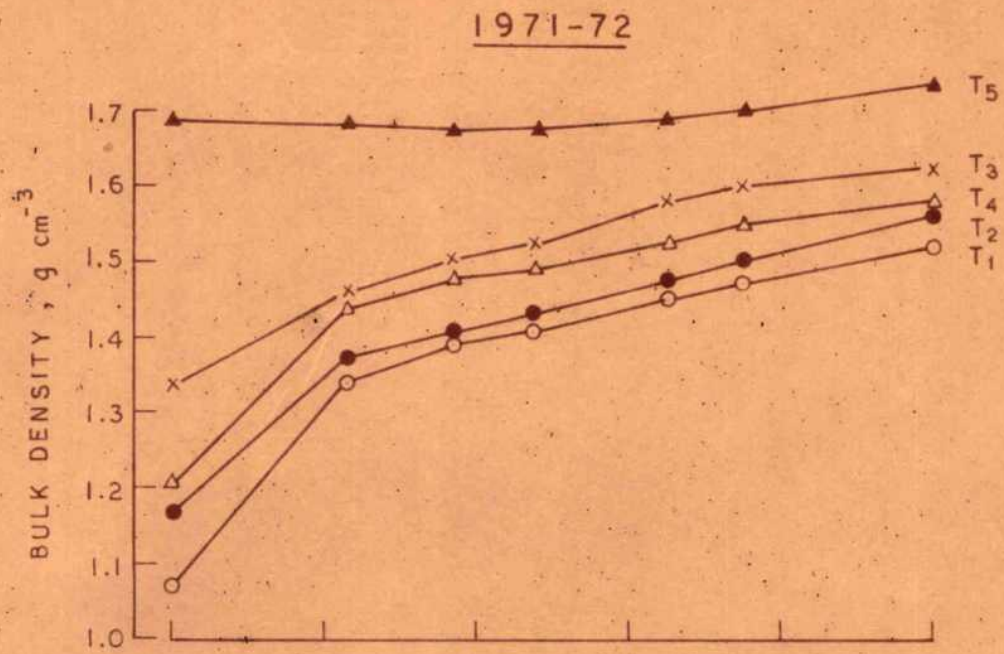


FIG.4.2 EFFECT OF TILLAGE OPERATIONS ON SOIL BULK DENSITY

The initial bulk density of soil prior to tillage was  $1.69 \text{ g cm}^{-3}$ . After tillage operations, the bulk density values recorded in different tillage treatments were 1.08, 1.17, 1.34, and  $1.21 \text{ g cm}^{-3}$  during 1971-72 and 1.04, 1.13, 1.35 and  $1.22 \text{ g cm}^{-3}$  during 1972-73 under disk, mouldboard, rotary tiller and wedge plough treatments respectively. It is evident that minimum density occurred under disk and mouldboard. Similar observations were made by Wilton (1964) while working with ploughs and disk harrow. The results of Bhushan (1971) also lend a support to these findings. The occurrence of lower bulk density is ascribed to the bigger clods initially produced by ploughs ( $r = -0.95$ ). However, Kharagpur soil was observed to stabilize very quickly. Just after first irrigation i.e. after 15 days of wheat sowing, corresponding bulk densities increased to 1.25, 1.30, 1.42 and  $1.35 \text{ g cm}^{-3}$  during 1971-72 and 1.23, 1.29, 1.40 and  $1.33 \text{ g cm}^{-3}$  during 1972-73. However, in untilled plots bulk density did not change. But it is worthwhile to note that the plots tilled with disk and mouldboard ploughs always maintained lower bulk density during the successive phases of wheat growth as compared to other tillage treatments. Thereafter, as time elapsed, the soil settled and bulk densities increased gradually under all treatments.

It is observed from Fig.4.2 that ploughing with either a disk or mouldboard plough followed by harrowing with a disk harrow resulted into minimum bulk density of soil throughout the growing period of wheat. As expected, the maximum bulk density occurred in untilled plots. At the time of sowing, the maximum values of

bulk density were obtained under rotary tiller. There was no appreciable difference in bulk density under disk, mouldboard and wedge plough though the value was considerably lower under disk as compared to wedge. The bulk density under rotary tiller was also significantly higher than that under disk and mouldboard. A critical observation of Table 4.3 reveals similar trend of bulk density values at various stages of wheat growth under all tillage practices.

As the initial clod mean weight diameter (MWD) was bigger under plough treatments, it might, therefore, be likely that it would require longer time and greater energy to disintegrate the clods. Irrigation water was the source of disintegrating force which was constant for all treatments. Moreover, greater root proliferation under ploughs also attributed towards keeping the bulk densities low under these treatments. The results of Reddy and Dakshinamurti (1971) and Mallick and Rao (1972) also lend a support to this view. At harvesting, the bulk density tended to attain its original value and reached 1.52 to 1.62 g cm<sup>-3</sup> because of the textural composition of soil. Varade (1965), while working with the same soil also observed that when loose soil was left open to rain impact during monsoon, it attained bulk density as high as 1.55 to 1.65 g cm<sup>-3</sup>.

It may be concluded that ploughing with a disk or mouldboard plough resulted into lower bulk density than with wedge and rotary tiller and was maintained minimum throughout the growth period of wheat.

Table 4.3 Bulk density of soil as influenced by various tillage practices (T) at different growth phases of wheat

Treatments	Bulk density, g cm <sup>-3</sup>				
	Seedling emergence stage	Vegetative growth phase	Reproductive phase	Grain formation phase	Post harvest
<b>1971-72</b>					
T <sub>1</sub>	1.08	1.39	1.45	1.47	1.52
T <sub>2</sub>	1.17	1.39	1.47	1.50	1.53
T <sub>3</sub>	1.34	1.50	1.58	1.60	1.62
T <sub>4</sub>	1.21	1.48	1.52	1.55	1.58
T <sub>5</sub>	1.69	1.68	1.70	1.71	1.73
	**	**	**	**	**
S.Em ±	0.061	0.006	0.011	0.005	0.007
LSD <sub>0.05</sub>	0.18	0.02	0.03	0.02	0.02
LSD <sub>0.01</sub>	0.25	0.03	0.05	0.03	0.03
<b>1972-73</b>					
T <sub>1</sub>	1.04	1.36	1.44	1.46	1.49
T <sub>2</sub>	1.13	1.38	1.45	1.47	1.52
T <sub>3</sub>	1.35	1.48	1.56	1.58	1.60
T <sub>4</sub>	1.22	1.45	1.52	1.53	1.57
T <sub>5</sub>	1.67	1.64	1.65	1.67	1.70
	**	**	**	**	**
S.Em ±	0.028	0.021	0.024	0.015	0.034
LSD <sub>0.05</sub>	0.08	0.06	0.07	0.05	0.10
LSD <sub>0.01</sub>	0.12	0.08	0.10	0.06	0.14

\*\* significant at 1% level

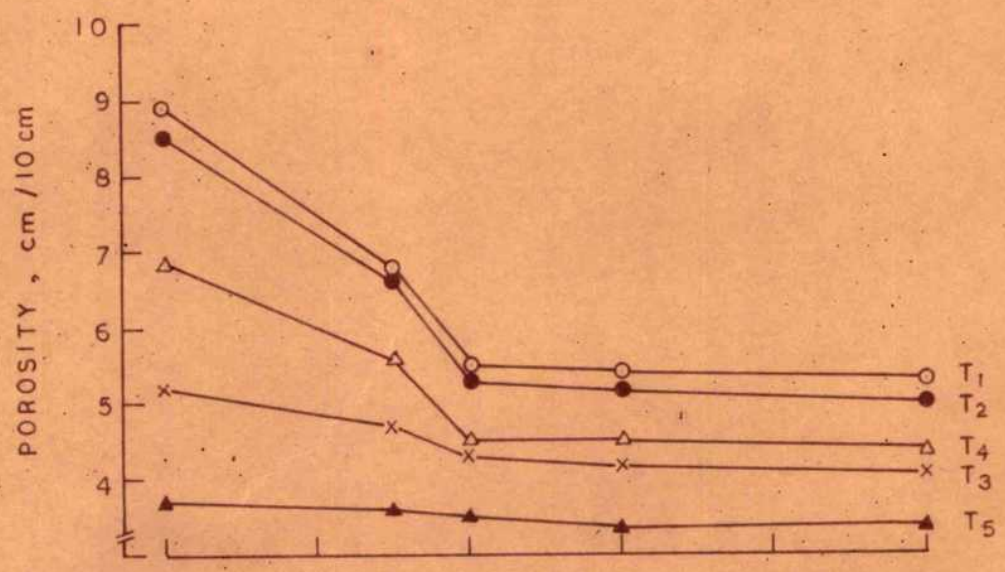
#### 4.3.2 Total porosity

The variation in total porosity with elapse of time after wheat sowing under different tillage treatments is depicted in Fig. 4.3 . The initial porosity of the soil prior to tillage was 3.71 cm/10 cm which greatly increased with different tillage practices. The porosity values recorded were 8.93, 8.49 6.93 and 5.23 cm/10 cm during 1971-72 and 9.08, 8.55, 7.17 and 5.37 cm/10 cm during 1972-73 under disk, mouldboard, wedge and rotary tiller respectively. Since the porosity is directly related to bulk density, any change in latter should produce corresponding variation in the former. Just after first irrigation, the porosity decreased to 7.90, 7.51, 6.20 and 4.95 cm/10 cm during 1971-72 and 8.40, 8.00, 6.31 and 5.15 cm/10 cm during 1972-73 with the increase in respective bulk densities. The decrease was gradual thereafter and reached very close to each other and to the value in untilled plot by the end of the experiments which was more or less constant throughout the growth period of wheat.

The data presented in Table 4.4 indicate significantly higher porosity under tillage treatments as compared to untilled. The differences in porosity under disk, mouldboard and wedge were non-significant. Similarly rotary tiller produced a little higher porosity than that under untilled treatment. However, porosity under disk and mouldboard was significantly higher than rotary tiller.

The porosity decreased considerably during the successive phases of wheat growth under all treatments. There was no

1971-72



1972-73

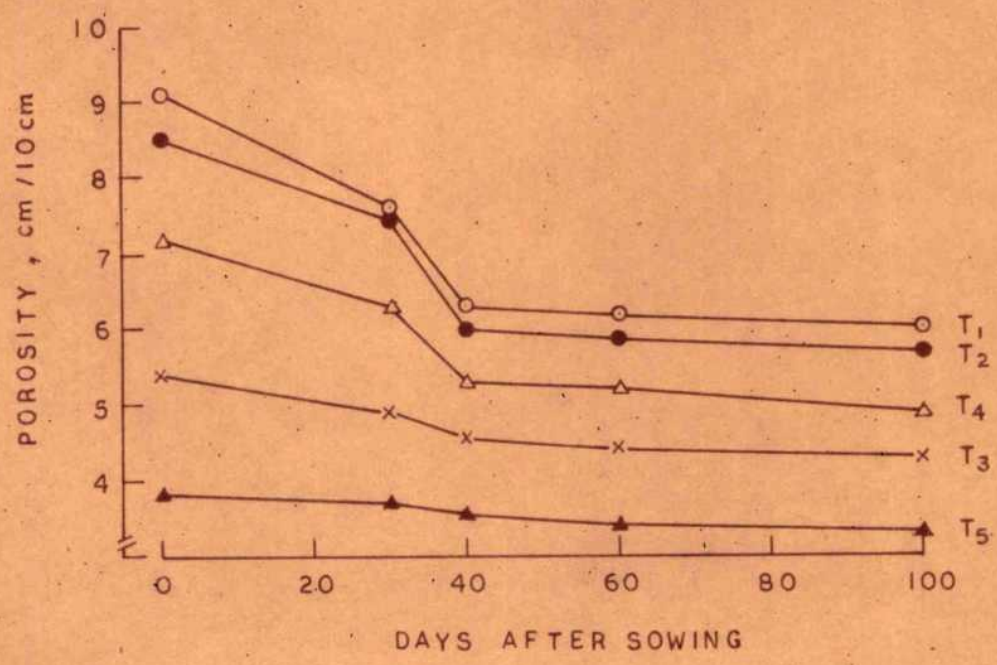


FIG.4.3 EFFECT OF TILLAGE PRACTICES ON SOIL POROSITY

Table 4.4 Total porosity as influenced by tillage treatments(T) at different stages of wheat growth

Treatments	Total porosity, cm/10 cm				
	Seedling emergence stage	Vegetative growth phase	Reproductive phase	Grain formation phase	Post harvest
<b>1971-72</b>					
T <sub>1</sub>	8.93	6.83	5.54	5.47	5.30
T <sub>2</sub>	8.49	6.76	5.32	5.19	4.99
T <sub>3</sub>	5.23	4.68	4.30	4.18	4.15
T <sub>4</sub>	6.93	5.63	4.52	4.50	4.38
T <sub>5</sub>	3.71	3.59	3.43	3.32	3.23
	**	**	**	**	**
S. Em ±	0.983	0.134	0.051	0.087	0.130
LSD <sub>0.05</sub>	2.38	0.40	0.15	0.26	0.39
LSD <sub>0.01</sub>	3.28	0.55	0.21	0.36	0.55
<b>1972-73</b>					
T <sub>1</sub>	9.08	7.61	6.28	6.15	6.04
T <sub>2</sub>	8.55	7.49	6.07	5.88	5.69
T <sub>3</sub>	5.37	4.92	4.56	4.38	4.34
T <sub>4</sub>	7.17	6.34	5.27	5.26	4.94
T <sub>5</sub>	3.75	3.68	3.52	3.41	3.30
	**	**	**	**	**
S. Em ±	0.327	0.174	0.281	0.179	0.126
LSD <sub>0.05</sub>	1.05	0.52	0.81	0.54	0.38
LSD <sub>0.01</sub>	1.35	0.72	1.16	0.75	0.51

\*\* significant at 1% level

appreciable difference between disk and mouldboard. Similarly the difference due to wedge and rotary tiller was also non-significant. However, porosity differed significantly in tilled plots during all growth phases as compared to the porosity under untilled plots. Similar observations were made by Burwell *et. al.* (1963) and Allmaras *et. al.* (1966). They also noted higher porosity in tilled plots than untilled throughout the experiment. The increased total porosity was always associated with lower bulk density which reflected a decrease in the fraction of bulk volume not occupied with solids. This is in conformity with results obtained by Veihmeyer and Hendrickson (1948), Gill (1959), Vomocil and Flocker (1961), Meredith and patric (1961), and Varade (1965).

Among the tillage treatments, higher total porosity was recorded under disk and mouldboard as compared to other treatments which remained higher throughout. Similar results were reported by Wilton (1964) while working at Nottingham and he observed greater increase in elevation of soil surface due to cultivation with a plough than with a cultivator or disk.

It may be concluded that ploughing with disk or mouldboard produced higher porosity than tilling the soil with wedge and rotary tiller and was maintained throughout the growth period of wheat.

#### 4.3.3 Soil moisture

##### 4.3.3.1 Matric suction

The initial matric suction at the time of tillage operation was 0.85 bar which rapidly increased as moisture was lost

due to evaporation. Two days after sowing, the matric suction increased to 2.20, 2.00, 1.00, 1.00 and 0.98 bar during 1971-72 under disk, mouldboard, wedge, rotary tiller and untilled plot respectively. The variation in matric suction under different tillage practices is presented in Fig. 4.4 and 4.5. The matric suction increased to 6.00, 6.00, 4.00, 3.00 and 2.90 bar in disk, mouldboard, wedge, rotary tiller and no-tillage treatment respectively, 12 days after sowing. The moisture retention order was reversed after first irrigation which was applied 15 days after sowing. Plots tilled with disk and mouldboard retained more moisture, thereby resulting in lower matric suction than the plots having no-tillage and tilled by rotary tiller.

The matric suction was significantly higher under disk and mouldboard than other treatments during seedling emergence stage. The difference between disk and mouldboard, rotary tiller, wedge and untilled plot was non-significant. However, it was significantly higher under disk and mouldboard as compared to untilled plot (Table 4.5). The seedbed prepared with disk or mouldboard contained bigger clods than the other tillage practices. Due to presence of bigger clods, the bulk density was lower and bigger pores were formed in the soil surface through which air could reach lower surface of clods more freely and conveniently. This helped in removing soil water faster through vaporization. The faster rate of moisture depletion under disk and mouldboard is attributed to the occurrence of bigger clods as evaporation and drying rate are greatly influenced by degree of aggregation.

T<sub>1</sub>  
 T<sub>2</sub>  
 T<sub>3</sub>  
 T<sub>4</sub>  
 T<sub>5</sub>

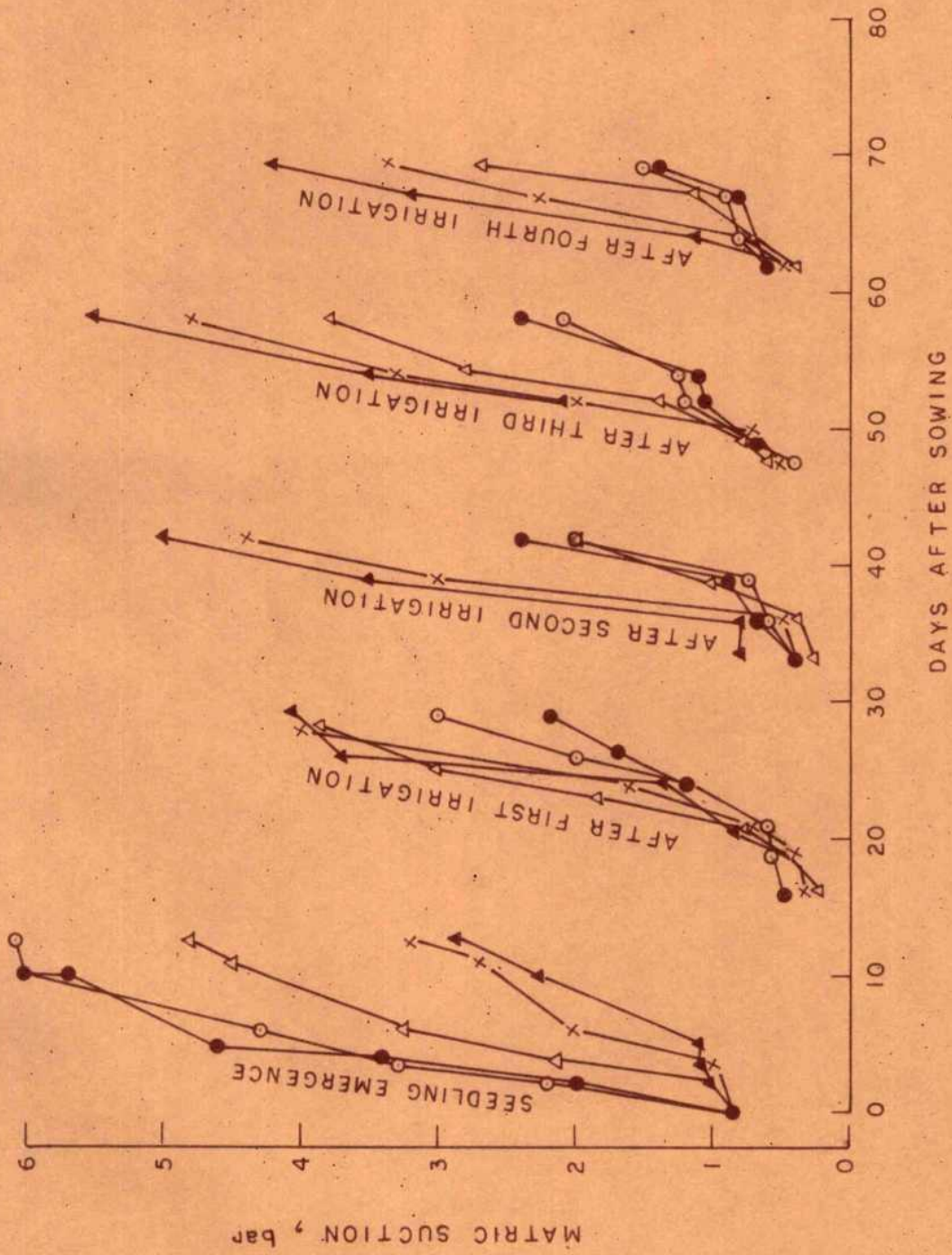
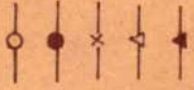


FIG.4.4 EFFECT OF TILLAGE PRACTICES ON MATRIC SUCTION DURING 1971-72

T<sub>1</sub>  
T<sub>2</sub>  
T<sub>3</sub>  
T<sub>4</sub>  
T<sub>5</sub>

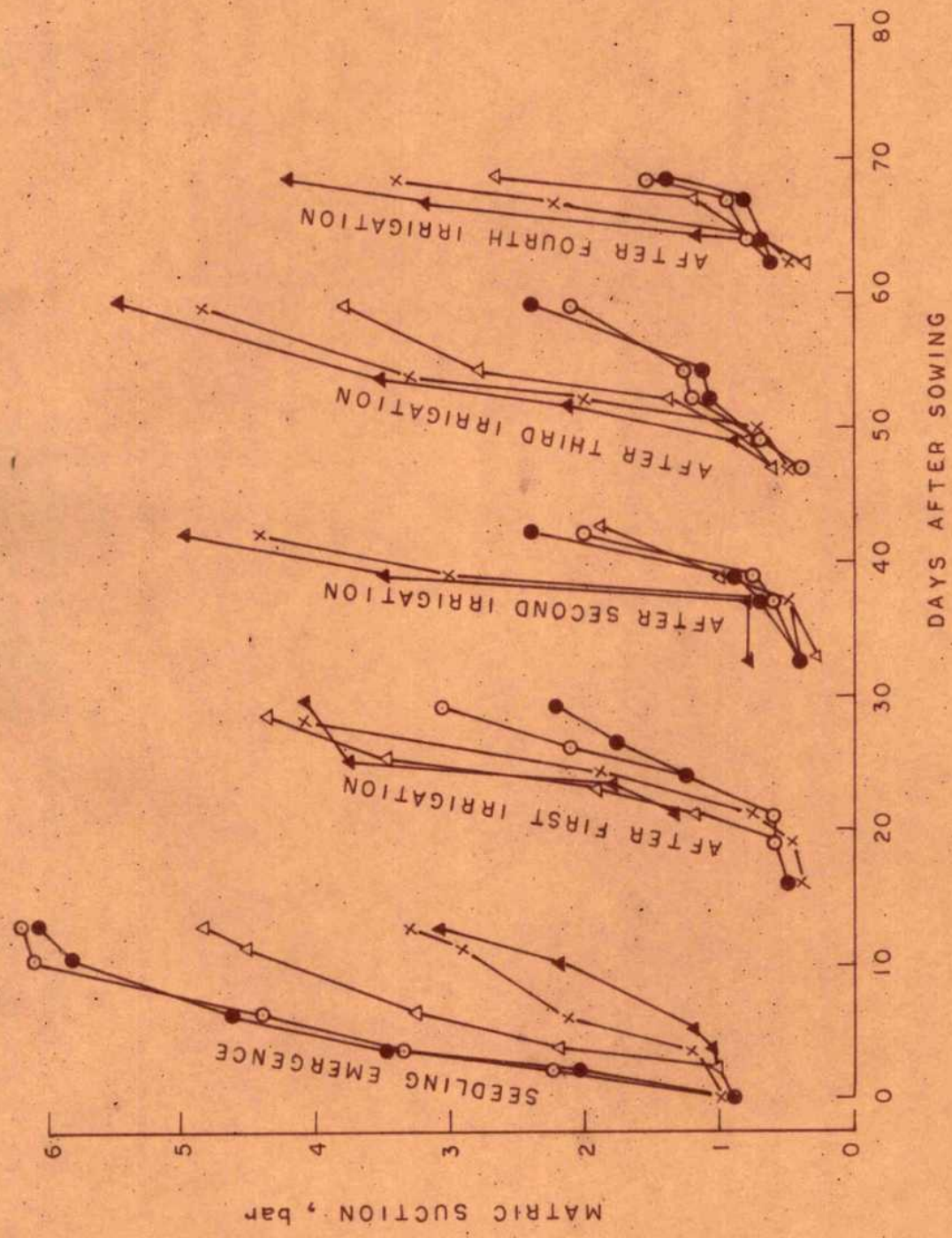
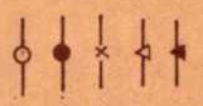


FIG. 4.5 EFFECT OF TILLAGE PRACTICES ON MATRIC SUCTION DURING 1972-73

Bigger clods in the surface soil favoured rapid drying rate due to increased radiation and wind speed. The results are in agreement with the observations of Holmes et. al.(1960) and Bhushan et. al.(1973). However, due to greater porosity water retention was higher during the later phases of growth when the bigger clods were disintegrated by irrigation. The correlation coefficient between clod MWD and matric suction was highly significant (  $r = 0.97$  ).

Although disk did not differ significantly with mouldboard during vegetative growth stage of wheat, the matric suction under disk was significantly lower as compared to wedge, rotary tiller and untilled. Similarly mouldboard differed significantly with rotary tiller and untilled. There was no significant difference between wedge, rotary tiller and untilled (Table 4.5). Similar trend of soil moisture suction continued during vegetative, reproductive and grain formation phase of wheat growth. During grain ripening stage, water distribution was almost same in all treatments because of continuous rain in the first fortnight of March, 1973 ( Fig. 3.2 ).

The considerable decrease in porosity and increase in bulk density with irrigation was noted among all treatments. It appeared that the vaporization process ceased to remove soil water and capillarity played important role. Since bulk density was always lower under disk and mouldboard than other treatments and maximum in untilled plot, it is expected that pores under the tillage treatments will be more discontinuous and bigger which helped in retaining more water in disk and mouldboard. During

Table 4.5 Matric suction as influenced by various tillage practices (T) at different stages of wheat growth

Treatments	Matric suction, bar			
	Seedling emergence stage	Vegetative growth phase	Reproductive phase	Grain formation phase
<b>1971-72</b>				
T <sub>1</sub>	3.49	0.74	0.92	0.56
T <sub>2</sub>	3.20	0.80	1.06	0.64
T <sub>3</sub>	1.17	0.91	2.39	1.09
T <sub>4</sub>	2.04	0.87	1.42	0.86
T <sub>5</sub>	1.03	0.97	2.59	1.35
	**	**	**	**
S.Em ±	0.392	0.032	0.091	0.142
LSD <sub>0.05</sub>	1.18	0.08	0.27	0.43
LSD <sub>0.01</sub>	1.56	0.13	0.38	0.58
<b>1972-73</b>				
T <sub>1</sub>	3.75	0.99	1.17	0.81
T <sub>2</sub>	3.46	1.06	1.32	0.90
T <sub>3</sub>	1.43	1.17	2.35	1.35
T <sub>4</sub>	2.30	1.13	1.68	1.16
T <sub>5</sub>	1.29	1.21	2.65	1.59
	**	**	**	**
S.Em ±	0.477	0.021	0.082	0.085
LSD <sub>0.05</sub>	1.43	0.06	0.25	0.25
LSD <sub>0.01</sub>	1.92	0.09	0.32	0.34

\*\* significant at 1% level

later part of wheat growth mulching effect of better vegetal cover in plots tilled with disk or mouldboard appears to have contributed to retention of water for longer time.

It may be concluded that although loss of moisture from soil was faster during seedling emergence stage from plots tilled with disk and mouldboard, they helped in conserving moisture for longer period during the later phases of wheat growth.

#### 4.3.3.2 Infiltration

The infiltration data presented in Table 4.6 indicated that all tillage treatments differed significantly from each other. It is interesting to note that at seedling emergence stage the values of initial and final infiltration rates were higher than at later phases of growth. This difference in initial infiltration was noticeable but final infiltration did not change in the similar fashion. This may be attributed to the fact that the larger clods initially produced under different tillage treatments helped absorbing more water due to higher porosity and which then decreased due to settlement of particles and decreased the value of initial infiltration. The disk and mouldboard helped higher intake of water because of larger clods as compared to other treatments. This shows that the soil structure was better at all the growth stages under disk and mouldboard followed by wedge and rotary tiller. The untilled plot did not favour the higher rate of infiltration, thereby indicating the inability to absorb more moisture because of compacted soil surface due to irrigation.

Table 4.6 Infiltration as influenced by various tillage treatments (T) at different stages of wheat growth during 1972-73

Treatments	Infiltration rate, cm/hr											
	Seedling emergence stage		Vegetative growth phase		Reproductive phase		Grain formation phase					
	Initial	Final	Initial	Final	Initial	Final	Initial	Final				
T <sub>1</sub>	11.58	3.43	9.92	3.15	8.18	2.86	7.68	2.68				
T <sub>2</sub>	10.88	3.18	8.70	2.82	7.65	2.72	6.47	2.43				
T <sub>3</sub>	6.45	2.54	5.84	2.35	5.66	2.23	5.43	2.08				
T <sub>4</sub>	7.86	2.79	6.68	2.69	5.94	2.52	5.74	2.34				
T <sub>5</sub>	5.89	2.37	5.64	2.16	5.12	2.09	4.84	2.02				
	**	**	**	**	**	**	**	**				
S. Em ±	0.072	0.021	0.122	0.022	0.025	0.032	0.027	0.030				
LSD <sub>0.05</sub>	0.21	0.06	0.37	0.07	0.08	0.09	0.08	0.09				
LSD <sub>0.01</sub>	0.29	0.08	0.50	0.09	0.10	0.13	0.11	0.12				

\*\* significant at 1% level

#### 4.3.3.3 Hydraulic conductivity

The data in Table 4.7 indicated the influence of root growth on soil structure as reflected by hydraulic conductivity variations from seedling emergence to grain formation phase. Hydraulic conductivity varied significantly among all treatments. The higher values were noted under disk closely followed by mouldboard, wedge, rotary tiller and was minimum in uncultivated plots. These differences in hydraulic conductivity may be attributed to the differential proliferation of roots which was effected by the tillage depth. The results are in agreement with Dakshinamurti and Pradhan (1966), Reddy and Dakshinamurti (1971), Rane and Varade (1972), and Mallick and Rao (1972).

#### 4.3.4 Oxygen diffusion rate (ODR) and non-capillary porosity

The measurement of ODR immediately after tillage operation was not possible because moisture content of soil was too low to provide proper water film around micro-electrodes. Hence, the measurements were taken after first irrigation when the soil moisture content was about 11-12 per cent.

It is evident from Table 4.8 that oxygen diffusion rate was higher in tilled plots compared to untilled ones. The ODR values observed at vegetative phase were 78.38, 76.65, 65.97 and 53.20  $\times 10^{-8}$  g cm<sup>-2</sup> min<sup>-1</sup> during 1971-72 and 80.03, 79.50, 70.17 and 55.05  $\times 10^{-8}$  g cm<sup>-2</sup> min<sup>-1</sup> during 1972-73 under disk, mouldboard, wedge and rotary tiller respectively while it was 29.10 and 33.95  $\times 10^{-8}$  g cm<sup>-2</sup> min<sup>-1</sup> under untilled plots for the corresponding seasons. This indicated that ODR was 2 to 3.5 times

Table 4.7 Hydraulic conductivity as influenced by tillage treatments (T) at different stages of wheat growth during 1972-73

Treatments	Hydraulic conductivity, cm/hr			
	Seedling emergence stage	Vegetative growth phase	Reproductive phase	Grain formation phase
T <sub>1</sub>	2.88	4.86	5.45	6.56
T <sub>2</sub>	2.71	4.32	5.05	5.91
T <sub>3</sub>	2.34	3.66	4.08	5.10
T <sub>4</sub>	2.55	3.96	4.52	5.45
T <sub>5</sub>	2.16	3.28	3.76	4.69
	**	**	**	**
S. Em ±	0.046	0.003	0.041	0.039
LSD <sub>0.05</sub>	0.14	0.08	0.12	0.12
LSD <sub>0.01</sub>	0.19	0.11	0.17	0.16

\*\* significant at 1% level

Table 4.8 Oxygen diffusion rate (ODR) as influenced by various tillage practices (T) at different phases of wheat growth

Treatments	ODR, $10^{-8}$ g cm $^{-2}$ min $^{-1}$		
	Vegetative growth phase	Reproductive phase	Grain formation phase
<u>1971-72</u>			
T <sub>1</sub>	78.38	63.50	59.27
T <sub>2</sub>	76.65	61.46	56.38
T <sub>3</sub>	53.20	45.62	44.15
T <sub>4</sub>	65.97	56.15	53.32
T <sub>5</sub>	29.10	25.42	24.18
	**	**	**
S. Em $\pm$	2.172	1.455	1.225
LSD <sub>0.05</sub>	6.51	4.36	3.67
LSD <sub>0.01</sub>	8.68	5.81	5.06
<u>1972-73</u>			
T <sub>1</sub>	80.03	65.85	61.31
T <sub>2</sub>	79.50	63.81	59.11
T <sub>3</sub>	55.05	47.32	45.99
T <sub>4</sub>	70.17	58.00	55.17
T <sub>5</sub>	33.95	26.70	26.04
	**	**	**
S. Em $\pm$	1.581	1.495	1.283
LSD <sub>0.05</sub>	4.74	4.48	3.84
LSD <sub>0.01</sub>	6.53	5.96	5.12

\*\* significant at 1% level

greater in tilled plots as compared to untilled. From Fig.4.6 it is revealed that subsequent irrigation increased the bulk density and reduced the porosity which ultimately decreased the ODR after the second irrigation. Subsequently, a gradual decrease in ODR of untilled plot was also noted.

At grain formation phase i.e. 75th day after sowing, ODR was reduced to 32 per cent under tillage treatments, whereas, it was almost same in the untilled plot ( $24.18$  and  $26.04 \times 10^{-8}$   $\text{g cm}^{-2} \text{min}^{-1}$ ) during either seasons.

A thorough study of data presented in Table 4.8 shows that ODR decreased considerably as time elapsed under all tillage treatments. This trend of decrease in ODR under all tillage practices, however, remained same during various phases of wheat growth.

It is seen from Table 4.9 that non-capillary porosity was higher in tilled plots than untilled ones. The non-capillary porosity values at seedling emergence stage were 45.92, 38.12, 36.94, 28.57 and 13.51 per cent during 1971-72 and 48.08, 42.91, 37.10, 29.32 and 15.80 per cent during 1972-73 under disk, mould-board, wedge, rotary tiller and no-tillage plots respectively. The higher values of non-capillary porosity during 1972-73 is attributable to the bigger clods produced (Table 4.2). Furthermore, the non-capillary (aeration) porosity was reduced considerably as the time elapsed under all tillage treatments. This may be because of the settlement of particles or disintegration of larger clods by irrigation water. However, significantly higher

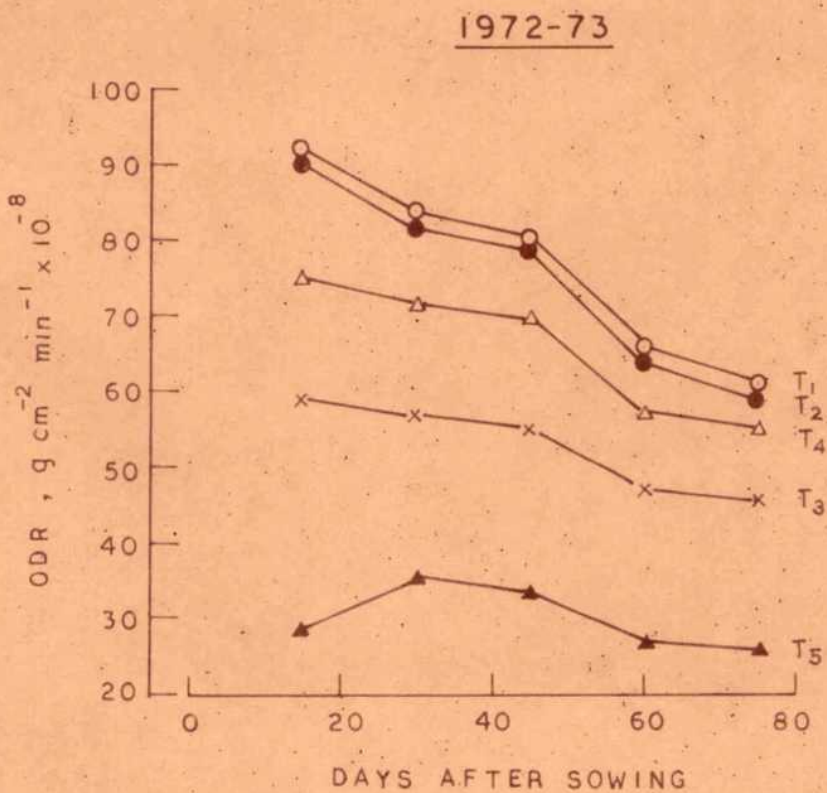
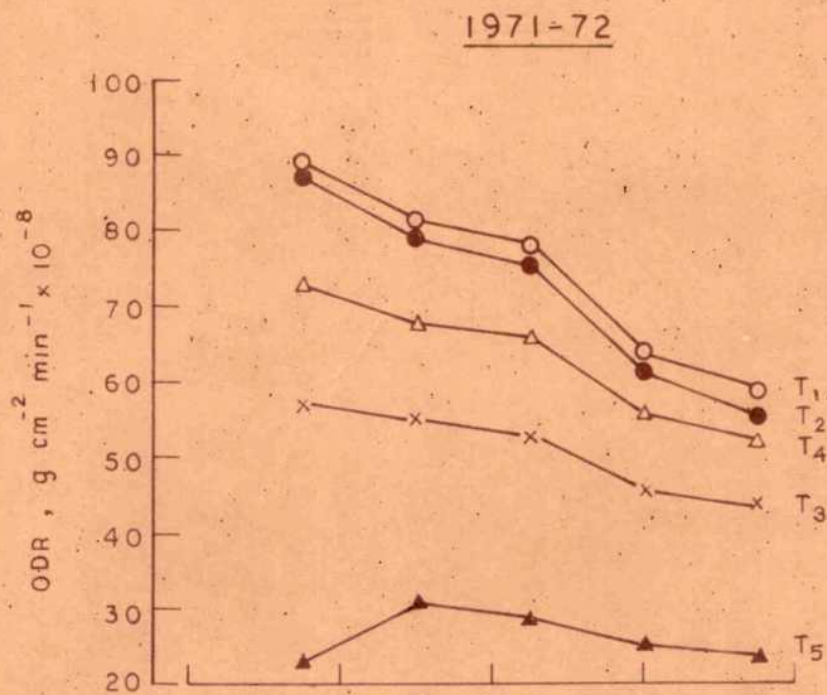


FIG.4.6 EFFECT OF TILLAGE PRACTICES ON OXYGEN DIFFUSION RATE.

Table 4.9 Non-capillary porosity as influenced by various tillage practices (T) at different growth phases of wheat

Treatments	Non-capillary porosity, per cent				
	Seedling emergence stage	Vegetative growth phase	Reproductive phase	Grain formation phase	Post harvest
<b>1971-72</b>					
T <sub>1</sub>	45.92	32.59	27.92	25.57	17.93
T <sub>2</sub>	38.12	28.59	25.58	20.88	15.12
T <sub>3</sub>	28.57	20.34	16.04	14.42	10.57
T <sub>4</sub>	36.94	25.27	23.44	17.80	12.80
T <sub>5</sub>	13.51	11.99	10.10	9.29	5.75
	**	**	**	**	**
S.Em ±	0.312	0.347	0.933	1.321	1.278
LSD <sub>0.05</sub>	0.93	1.04	2.80	3.96	3.83
LSD <sub>0.01</sub>	1.28	1.44	3.86	5.46	5.29
<b>1972-73</b>					
T <sub>1</sub>	48.08	34.88	28.81	26.15	19.81
T <sub>2</sub>	42.91	30.62	27.14	22.54	15.70
T <sub>3</sub>	29.32	22.02	16.98	15.59	12.22
T <sub>4</sub>	37.10	26.57	23.81	18.70	13.57
T <sub>5</sub>	15.80	15.25	13.63	10.35	7.62
	**	**	**	**	**
S.Em ±	0.289	0.557	1.013	0.927	1.133
LSD <sub>0.05</sub>	0.87	1.67	3.04	2.78	3.40
LSD <sub>0.01</sub>	1.19	2.23	4.21	3.84	4.69

\*\* significant at 1% level

values were noted under disk closely followed by mouldboard treatment. At grain formation phase, porosity was reduced to 50 per cent under tilled plots, whereas it did not change appreciably in untilled plots ( 9.29 and 10.35 per cent ) during either seasons.

Since oxygen diffusion rate is a function of non-capillary porosity, it is natural that ODR will increase with higher porosity and hence very high correlation was obtained at various stages of growth (Appendix N). As bulk density increased total porosity decreased and in most of the cases the reduction occurs at the cost of aeration (non-capillary) porosity (Veihmeyer and Hendrickson, 1948; Gill, 1959; Vomocil and Flocker, 1961; Meredith and Patrick, 1961; and Varade, 1965). Since non-capillary porosity was higher under disk and mouldboard, it is expected that aeration pores were more under these treatments which helped maintain higher oxygen diffusion rate throughout. Bertrand and Kohnke (1957) also found that oxygen diffusion decreased when bulk density increased at constant moisture content.

It may be concluded that use of disk and mouldboard provided better aeration than wedge and rotary tiller, there being minimum under rotary tiller throughout the growth period of wheat.

#### 4.3.5 Penetration resistance

The penetration resistance was measured after first irrigation when the moisture content of soil was 7 to 8 per cent.

The changes in penetration resistance at 5, 10 and 15 cm depth during the growth period of wheat are shown in Fig.4.7, 4.8 and 4.9 respectively and the data are given in Table 4.10. Penetration resistance was found higher under untilled plot compared to tilled plots. An increase in penetration resistance under all tillage practices was observed with the application of irrigation and lapse of time. The increase in resistance was observed with first two irrigations. However, subsequent increase was very sharp. After second irrigation, the increase of about 20-25 per cent in resistance was observed under all treatments except in untilled plot, wherein the resistance was reduced to some extent. However, this reduction was not remarkable at 15 cm depth (Fig.4.9). It is observed that on the 100th day after seeding, almost same resistance was recorded under all tillage treatments at 5 and 10 cm depth (Fig.4.7 and 4.8), whereas, in the case of 15 cm depth, the penetration resistance of soil tilled by rotary tiller tended to approach that of untilled plot (Fig. 4.9). The differences among disk, mouldboard and wedge were non-significant, though, significantly higher difference was noted when compared to rotary tiller. Penetration resistance increased with increasing depth.

Resistance to penetration is a function of bulk density and soil moisture content. Since observations were made at approximately constant moisture content, bulk density appears to be the only active soil property governing penetration resistance. Higher penetration resistance in uncultivated plots than tilled ones may, therefore, be attributed to higher bulk density. The

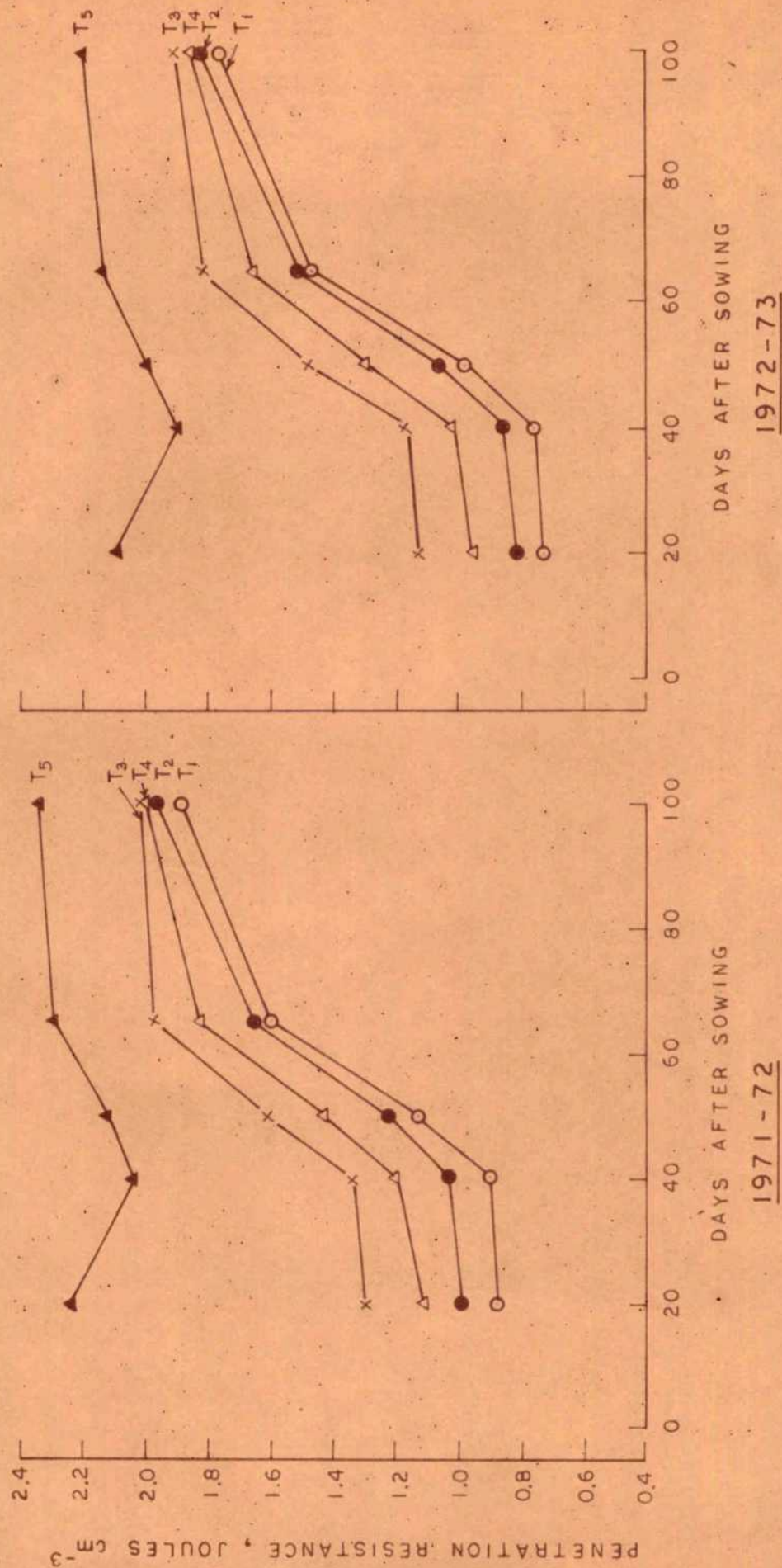


FIG.4.7 EFFECT OF TILLAGE PRACTICES ON PENETRATION RESISTANCE AT 5cm DEPTH

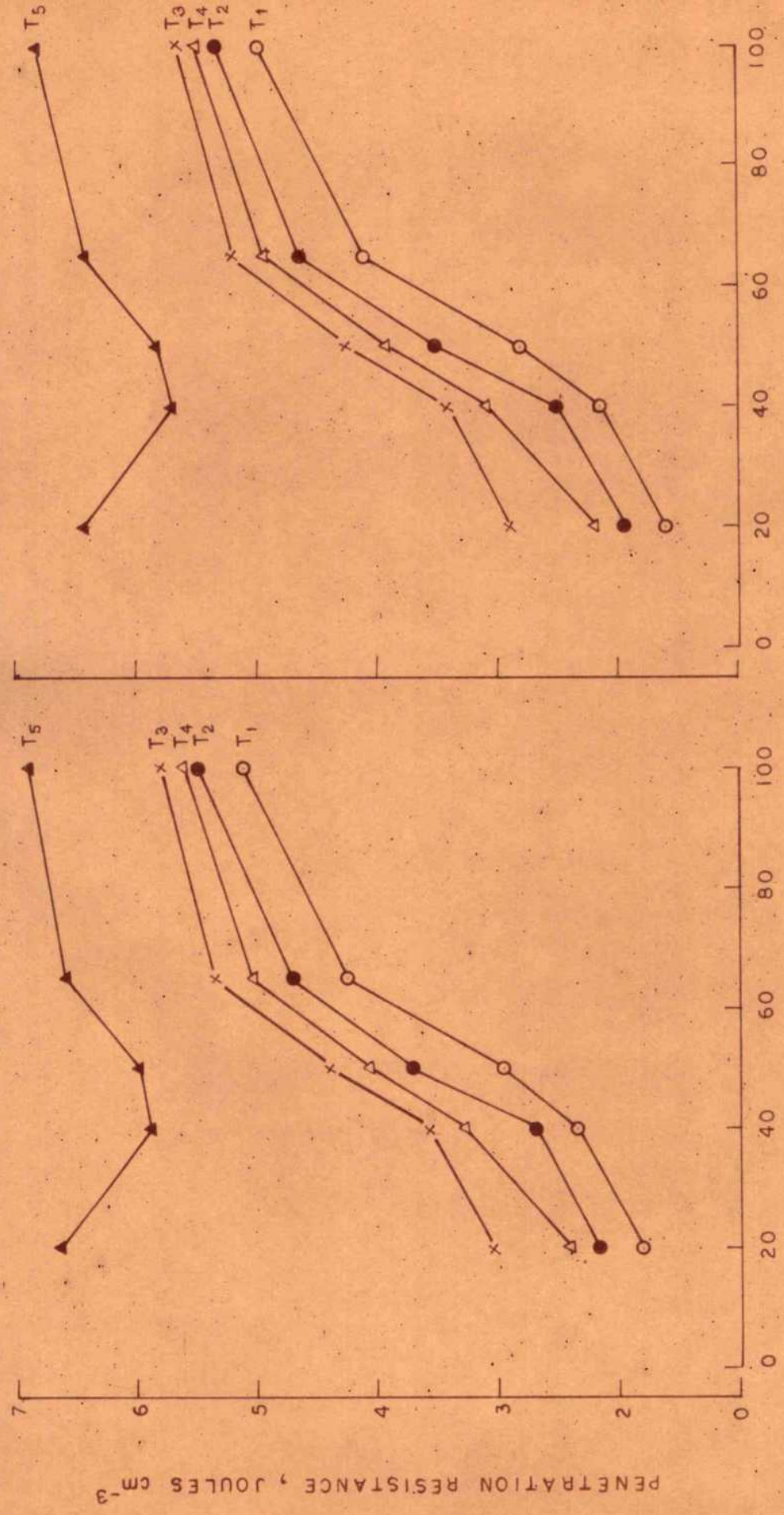
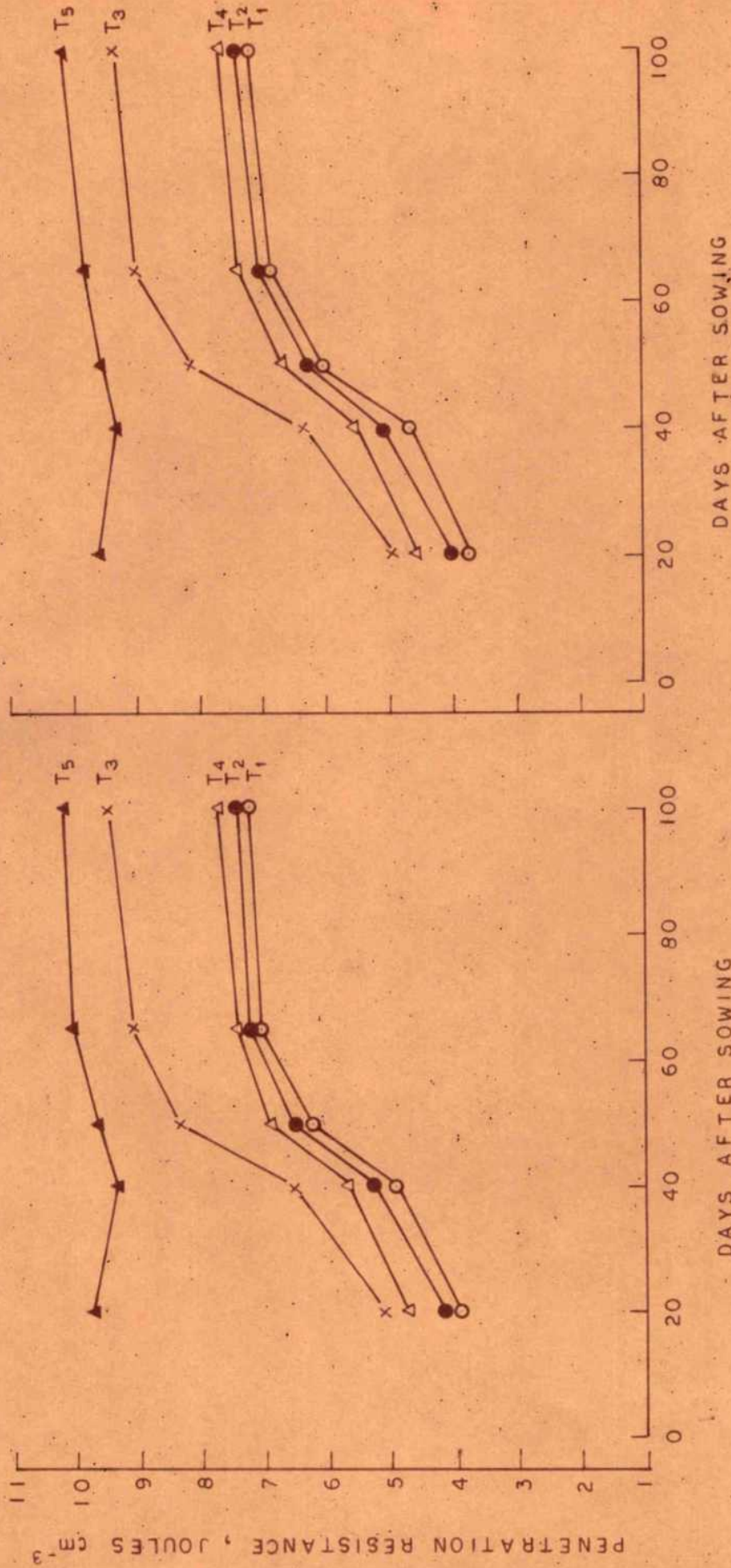


FIG.4.8 EFFECT OF TILLAGE PRACTICES ON PENETRATION RESISTANCE AT 10CM DEPTH



1971-72

1972-73

FIG.4.9 EFFECT OF TILLAGE PRACTICES ON PENETRATION RESISTANCE AT 15 cm DEPTH

Table 4.10 Penetration resistance as influenced by tillage treatments (T) at different stages of wheat growth

Treatments	Penetration resistance, joules/cm <sup>3</sup>											
	Vegetative phase			Reproductive phase			Grain formation phase			At harvest		
	5 cm depth	10 cm depth	15 cm depth	5 cm depth	10 cm depth	15 cm depth	5 cm depth	10 cm depth	15 cm depth	5 cm depth	10 cm depth	15 cm depth
<b>1971-72</b>												
T <sub>1</sub>	0.88	2.35	5.00	1.13	2.96	6.26	1.59	4.27	7.07	1.88	5.10	7.35
T <sub>2</sub>	0.99	2.68	5.27	1.22	3.67	6.46	1.64	4.69	7.12	1.96	5.50	7.42
T <sub>3</sub>	1.33	3.57	6.54	1.61	4.39	8.30	1.96	5.34	9.11	2.02	5.78	9.48
T <sub>4</sub>	1.19	3.28	5.78	1.44	4.08	6.95	1.83	5.06	7.50	2.01	5.62	7.76
T <sub>5</sub>	2.05	5.89	9.36	2.13	6.00	9.72	2.31	6.57	10.06	2.29	6.87	10.22
	*	*	*	**	**	**	**	**	**	**	**	**
S.E.m ±	0.027	0.241	0.352	0.071	0.491	0.407	0.092	0.197	0.172	0.013	0.241	0.297
LSD <sub>0.05</sub>	0.08	0.72	1.05	0.21	1.47	1.22	0.27	0.59	0.51	0.04	0.72	0.89
LSD <sub>0.01</sub>	0.11	0.95	1.42	0.28	1.96	1.63	0.38	0.78	0.67	0.05	0.96	1.18
<b>1972-73</b>												
T <sub>1</sub>	0.73	2.17	4.78	0.98	2.83	6.11	1.45	4.12	6.98	1.75	4.94	7.24
T <sub>2</sub>	0.82	2.53	5.08	1.06	3.55	6.33	1.50	4.58	6.99	1.82	5.35	7.30
T <sub>3</sub>	1.17	3.41	6.40	1.48	4.26	8.17	1.82	5.21	9.00	1.87	5.64	9.32
T <sub>4</sub>	1.03	3.12	5.62	1.30	3.98	6.81	1.66	4.94	7.36	1.87	5.48	7.63
T <sub>5</sub>	1.89	5.72	9.28	2.00	5.84	9.63	2.18	6.43	9.94	2.16	6.85	10.08
	NS	*	*	**	**	**	**	**	**	**	**	**
S.E.m ±	0.071	0.227	0.341	0.063	0.391	0.362	0.076	0.204	0.162	0.016	0.217	0.277
LSD <sub>0.05</sub>	0.21	0.68	1.02	0.19	1.17	1.08	0.23	0.61	0.48	0.05	0.65	0.83

correlation coefficients between bulk density and penetration resistance were highly significant (Appendix N). Lutz (1952), Gill and Miller (1956), Gill (1959), Swanson and Jacobson (1956), Meredith and Patric (1961), Phillips and Kirkham (1962), Parker and Taylor (1964) and Drew *et. al.* (1965) observed increase in mechanical strength with increase in bulk density. It is, of course, expected that porosity would have always a negative correlation (Appendix N) with penetration resistance.

It may be concluded that ploughing with a disk or mould-board plough produced less resistance to penetration indicating their beneficial effects in keeping the seedbed comparatively loose for longer duration. The penetration resistance was more or less doubled in all tillage treatments at harvest. It may, therefore, be suggested to adopt intercultural operations during the growth period of crop so as to keep the minimum resistance to penetration.

#### 4.4 Emergence of Seedlings as Influenced by Tillage Practices and Edaphic Factors.

Seedling emergence study was carried out in the field, cultivated with different tillage implements as described earlier. Seeds were sown at 8 cm depth and covered. Five replicates each of 50 seeds were used within each treatment. Seedlings were presumed to have emerged when the shoot tip was visible on the soil surface. First emergence incident was observed on the 4th day after sowing and continued for another 3-4 days. The results were expressed as emergence percentage. During the period of emergence, continuous depletion of soil moisture occurred due

to evaporation. Since emergence was completed in 8 days, average soil moisture was used for the correlation.

The effect of various tillage operations on seedling emergence of wheat is shown in Table 4.11. It is evident that seedling emergence was higher in untilled plot than in tilled ones. Although the influence of disk and mouldboard was not remarkable, seedling emergence was considerably lower under these two treatments compared to wedge and rotary tiller. The difference between rotary tiller and wedge was significant. However, non-significant difference occurred between rotary tiller and untilled treatment.

The seedbeds under disk and mouldboard were dominated by bigger clods closely followed by wedge plough. Rotary tiller also produced significantly higher percentage of smaller clods (Table 4.1). It can be examined from Fig.4.10 that as the clod MWD increased beyond 4.0 mm, seedling emergence of wheat was adversely affected and minimum emergence was recorded when the seedbed contained clods of 12.5 mm MWD under the disk. Seedbed of 4-6 mm diameter aggregates was also found conducive for seedling emergence by Johnson and Taylor (1960) and Johnson and Buchele (1961).

The influence of edaphic factors on seedling emergence is presented in Fig.4.10 and 4.11. The bulk density had significant positive correlation with seedling emergence, whereas, the emergence was affected adversely by the negative and significant correlation of porosity (Table 4.11). Porosity helped directly

Table 4.11 Seedling emergence of wheat as influenced by tillage treatments (T) and correlation coefficient between edaphic factors and seedling emergence

Treatments	Seedling emergence, per cent		Edaphic factors	Correlation coefficient	
	1971-72	1972-73		1971-72	1972-73
T <sub>1</sub>	56.53	53.50	Bulk density	0.85	0.87
T <sub>2</sub>	61.69	59.10		*	*
T <sub>3</sub>	76.53	74.28	Porosity	-0.94	-0.95
T <sub>4</sub>	72.03	69.15		**	**
T <sub>5</sub>	79.74	75.23	Matric suction	-0.99	-0.99
S. Em ±	1.644	1.581		**	**
LSD <sub>0.05</sub>	4.92	4.74			
LSD <sub>0.01</sub>	6.63	6.53			

\*\* significant at 1% level

\* significant at 5% level

○— 1971-72  
 ×— 1972-73

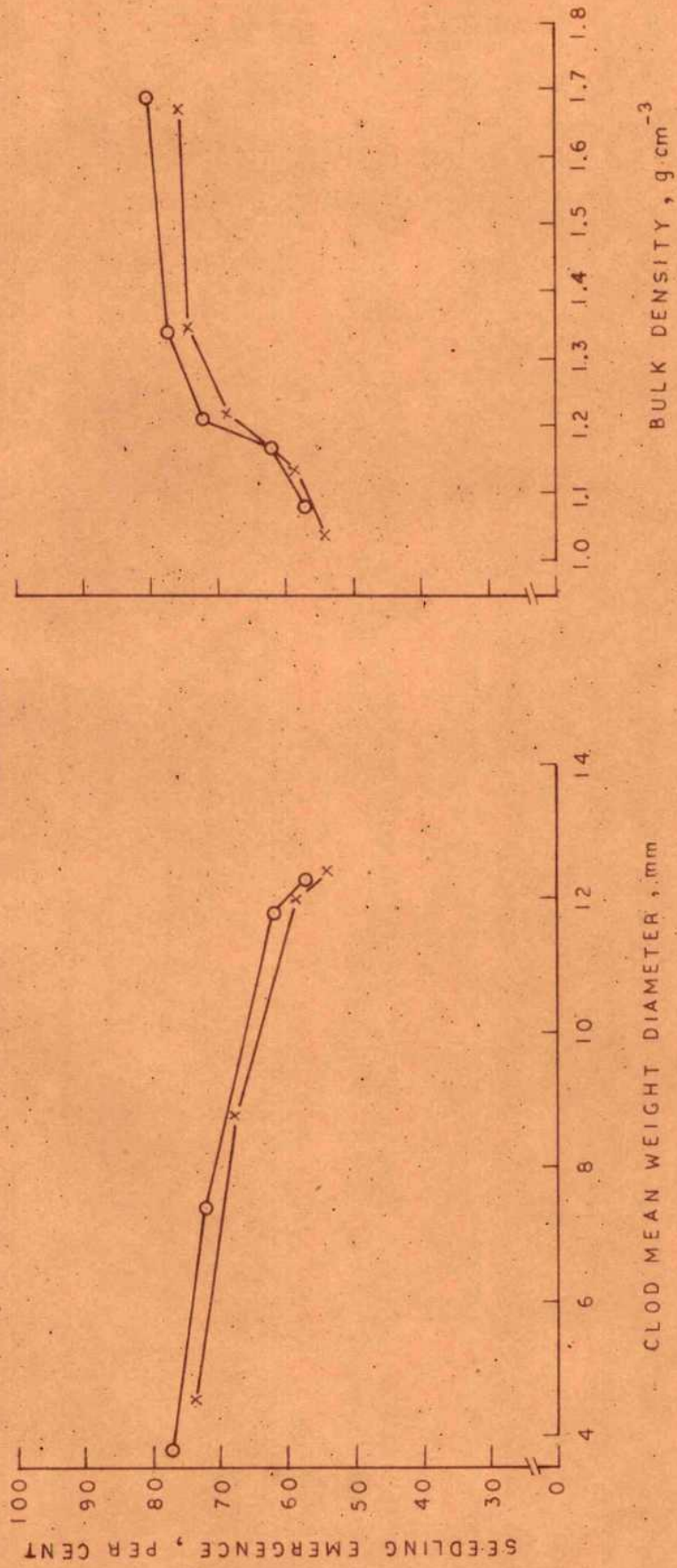


FIG.4.10 SEEDLING EMERGENCE OF WHEAT AS INFLUENCED BY CLOD SIZE AND BULK DENSITY

—○— 1971-72  
—x— 1972-73

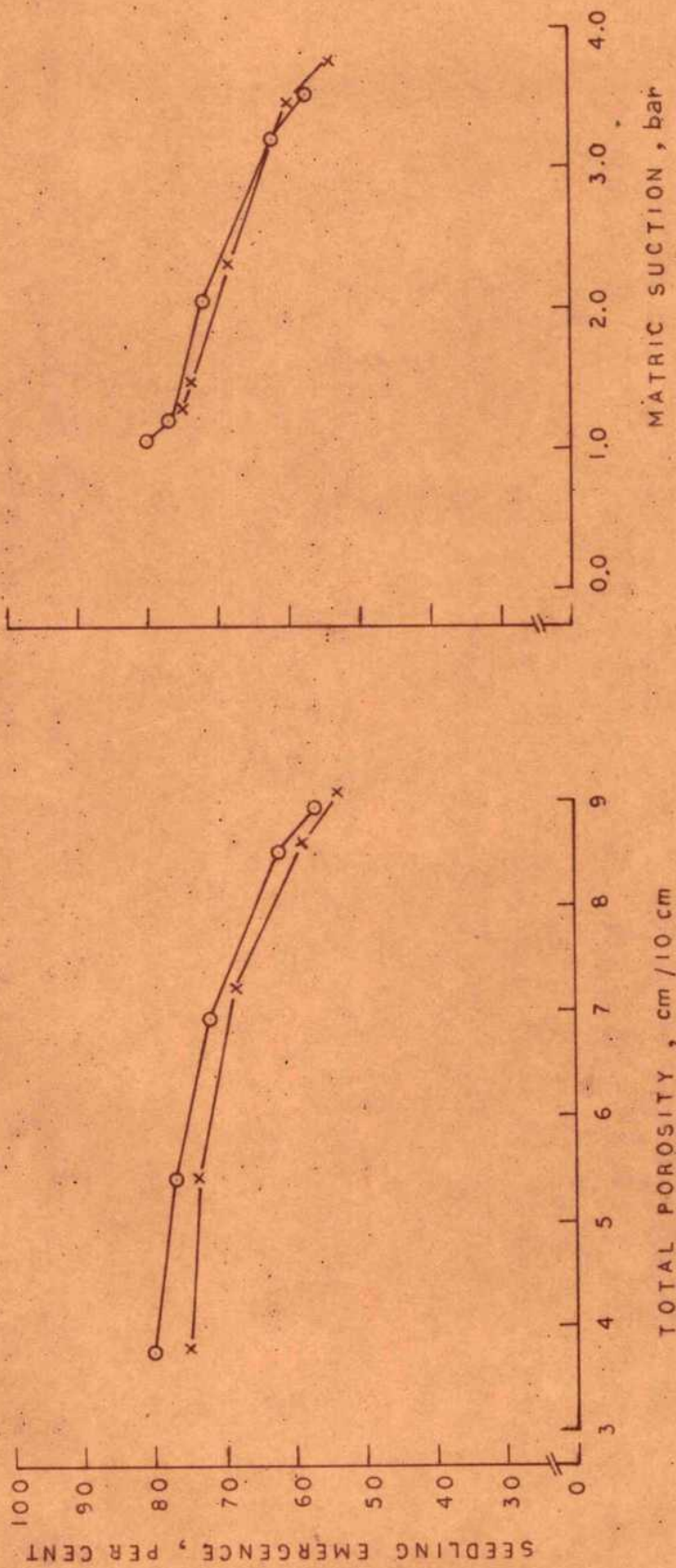


FIG. 4.11 SEEDLING EMERGENCE OF WHEAT AS INFLUENCED BY POROSITY AND MATRIC SUCTION

in lowering soil moisture and due to lower bulk density, soil was too loose inhibiting proper seed-soil-water contact. Stout and Snyder (1957) and Stout *et. al.*(1960) observed that a little compaction was found to be suitable for emergence.

Matric suction (Table 4.11) had highly significant and negative correlation with seedling emergence indicating that in wheat crop, moisture was the main limiting factor. Several workers reported that seeds emerged faster at higher moisture content (Hunter and Erickson, 1952; Bowen, 1966). The soil under disk and mouldboard dried fastly because of larger clods and high porosity.

It may be concluded from the results obtained that soil moisture became a limiting factor for proper emergence of wheat seeds in the lateritic soil of Kharagpur.

#### 4.5 Influence of Tillage Practices on Growth, Yield and Yield Attributes of Wheat (Culti-variety Kalyansona)

##### 4.5.1 Growth and growth parameters

4.5.1.1 Plant height : Plants under each of five tillage treatments attained maximum height at the age of about 80 days in either experiments (Fig.4.12) which corresponded to the milking stage of wheat growth. Plants were taller during 1972-73 than during 1971-72.

Plants in tilled seedbed were always taller than those in untilled plot. Among the tillage operations, disk and mouldboard

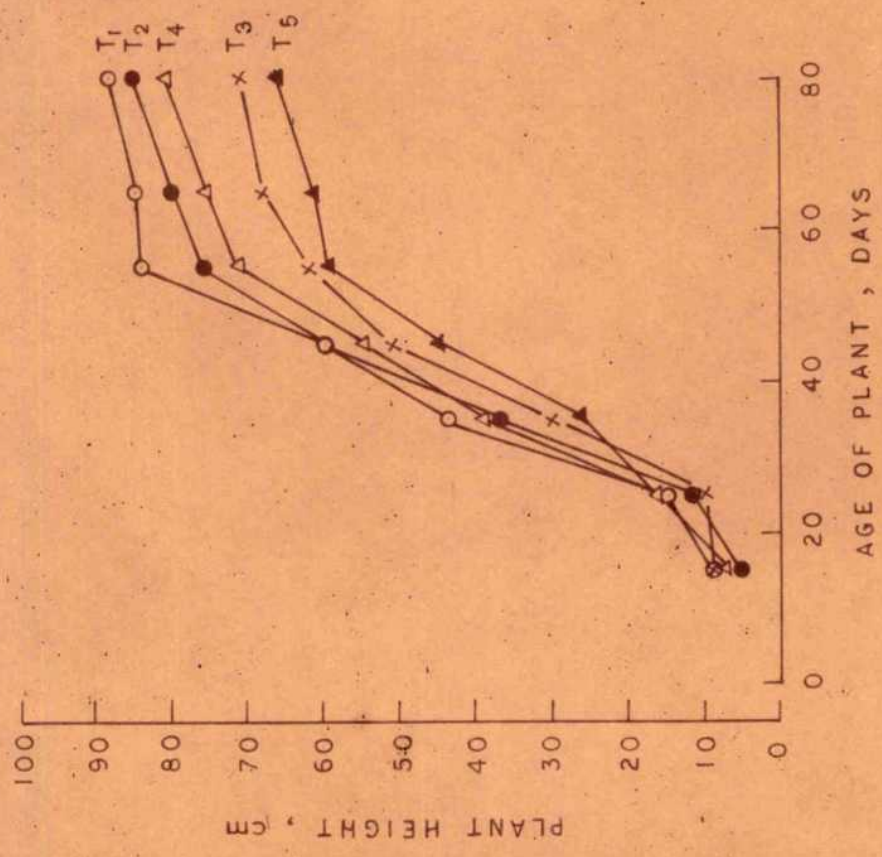
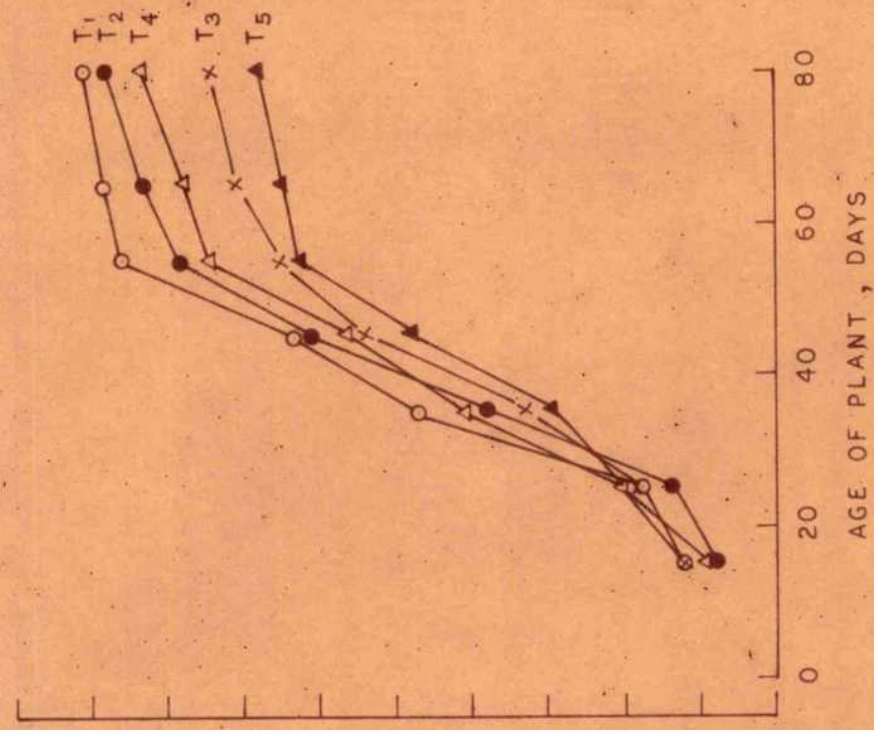


FIG.4.12 HEIGHT OF PLANTS AS INFLUENCED BY TILLAGE PRACTICES

proved better than wedge and rotary tiller. The differences among these treatments were significant at milking stage (Table 4.12).

4.5.1.2 Tiller number : Initiation of tiller formation was observed to occur on the 20th day of crop age, whereas, the maximum number reached in about 50 days in either experiments (Fig. 4.13). The number of viable tillers thereafter decreased under all treatments due to mortality of some of them. The reduction in number was noted even on the 80th day under disk and mouldboard while upto 70th day under wedge, rotary tiller and no-tillage treatments.

The data taken at maximum tillering stage showed that the crop plants in tilled plots produced significantly higher number of tillers than untilled plot. In either experiments, the rotary tiller produced significantly fewer tillers as compared to disk, mouldboard and wedge. The difference in tiller number under disk and mouldboard was non-significant. Similarly there was no difference between rotary tiller and untilled plot. The tiller production under wedge was better than rotary tiller but lesser than disk and mouldboard. The performance of crop was found better in the following order :

disk > mouldboard > wedge > rotary tiller-  
>untilled treatment.

4.5.1.3 Leaf area index (LAI) : Maximum leaf area index was observed in about 60-70 days after sowing during 1971-72 and

Table 4.12 Growth and growth attributes of wheat as influenced by various tillage treatments (T)

Treatments	Maximum plant height cm	Maximum tiller/30 cm drill	Maximum leaf area index (LAI)	Maximum dry matter/30 cm drill g	Straw yield kg/ha
<b>1971-72</b>					
T <sub>1</sub>	89.63	40.82	4.91	56.88	4356.78
T <sub>2</sub>	88.45	38.25	4.53	54.45	4348.51
T <sub>3</sub>	60.92	26.30	2.19	30.13	3268.50
T <sub>4</sub>	71.38	35.01	2.94	39.28	3499.62
T <sub>5</sub>	56.49	23.21	1.14	18.51	3233.46
	**	**	**	**	**
S. Em ±	0.994	2.279	0.240	1.455	165.324
LSD <sub>0.05</sub>	2.98	6.83	0.72	4.36	485.28
LSD <sub>0.01</sub>	3.84	9.12	0.97	5.80	647.04
<b>1972-73</b>					
T <sub>1</sub>	92.15	51.80	5.63	65.21	4547.85
T <sub>2</sub>	89.95	50.00	5.58	62.90	4534.98
T <sub>3</sub>	71.05	29.80	3.12	39.37	3433.22
T <sub>4</sub>	74.60	37.20	3.87	47.77	3678.97
T <sub>5</sub>	66.05	26.00	2.19	27.68	3393.63
	**	**	**	*	**
S. Em ±	1.061	2.422	0.250	1.545	169.716
LSD <sub>0.05</sub>	3.18	7.26	0.75	4.63	508.67
LSD <sub>0.01</sub>	4.25	9.68	1.02	6.16	798.24

\*\* significant at 1% level

\* significant at 5% level

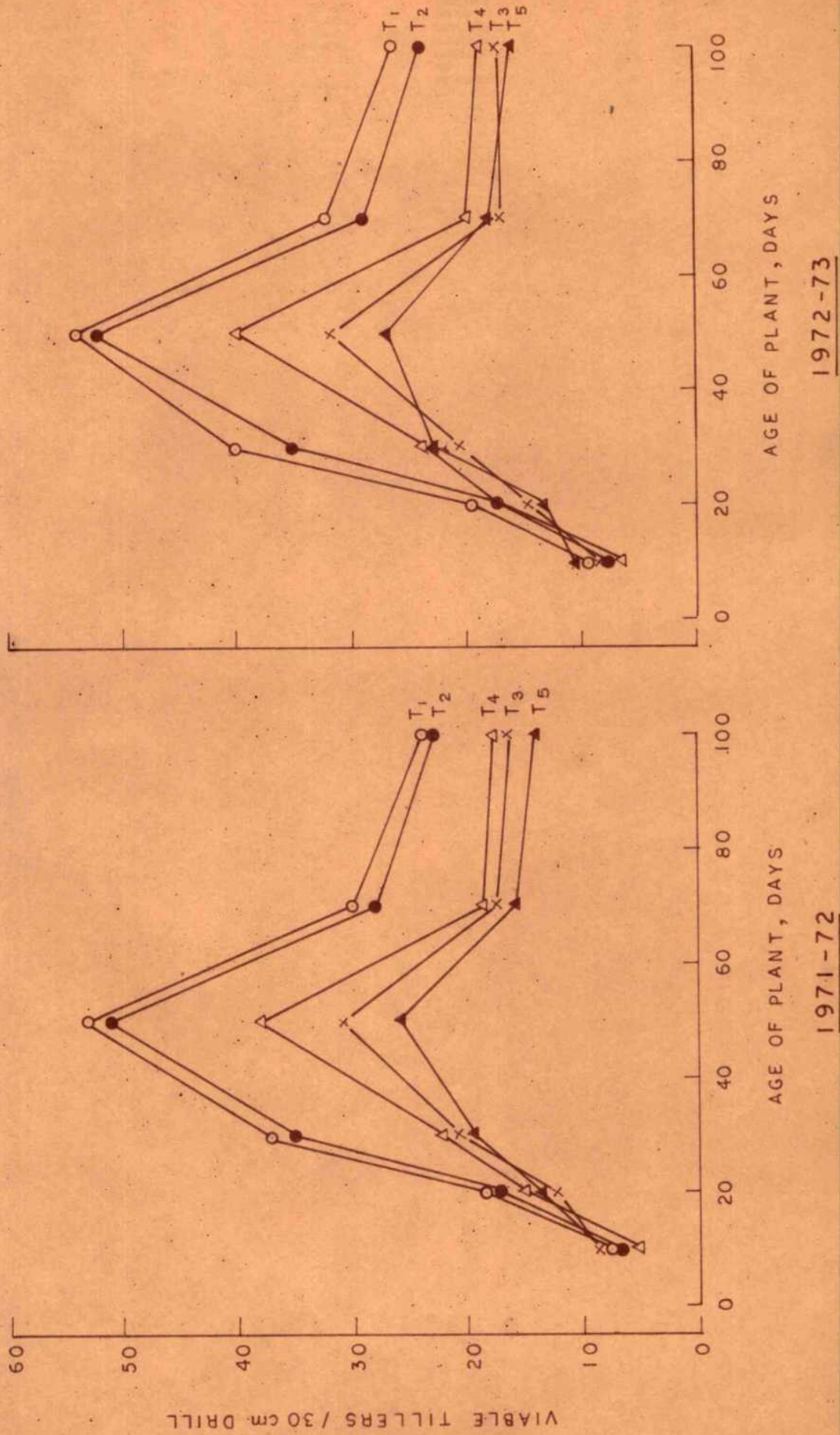


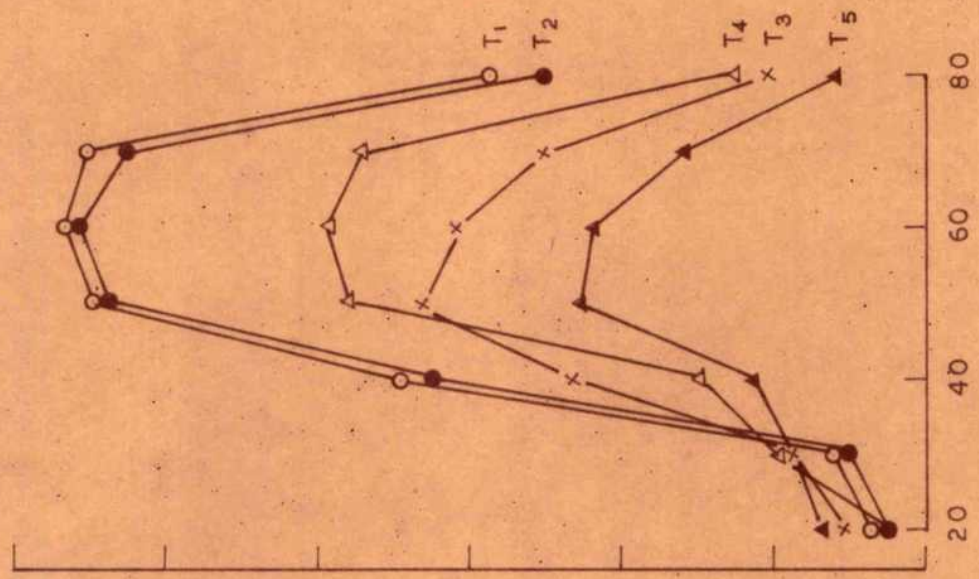
FIG.4.13 TILLER PRODUCTION OF PLANTS AS INFLUENCED BY TILLAGE PRACTICES

50-60 days during 1972-73. The LAI reached maximum value in plot tilled with rotary tiller and no-tillage treatment a few days earlier than other tillage practices (Fig. 4.14).

The data presented in Table 4.12 reveal a significant decrease in LAI in untilled plot as compared to tilled plots. Maximum LAI was 4.91, 4.53, 2.94, 2.19 during 1971-72 and 5.63, 5.58, 3.87 and 3.12 during 1972-73 under disk, mouldboard, wedge and rotary tiller respectively. It is evident that tillage treatments differed significantly among themselves except disk and mouldboard. However, it is clear that the use of disk and mouldboard produced significantly greater LAI compared to other tillage operations. Leaf area index was significantly higher under wedge than under rotary tiller.

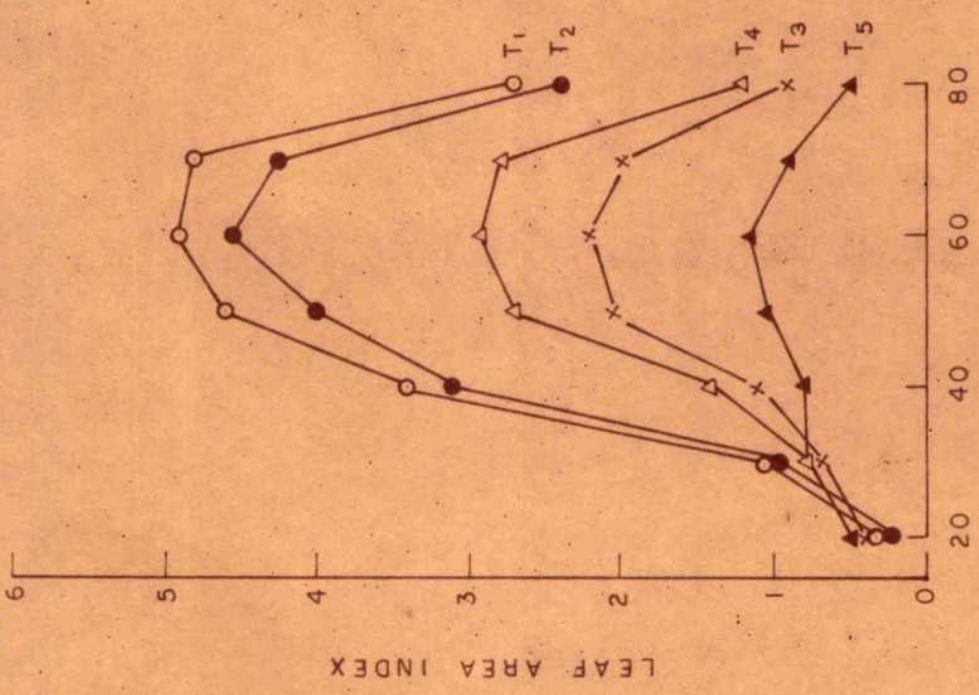
4.5.1.4 Dry matter accumulation : Dry matter accumulation was better during 1972-73. There was an appreciable increase in the rate of dry matter accumulation by plants from 50 to 65 days, thereafter, it slowed down gradually. No appreciable addition was recorded after 85 days (Fig. 4.15).

Tillage treatments proved far superior over no-tillage in dry matter accumulation. The results (Table 4.12) indicate that performance of crop was equally good under disk and mouldboard in either experiments. However, significantly higher dry matter accumulation was noted under these two tillage treatments as compared to wedge and rotary tiller. There was significant difference in dry matter accumulation under wedge, rotary tiller and no-tillage plots.



AGE OF PLANT, DAYS

1972-73



AGE OF PLANT, DAYS

1971-72

FIG.4.14 LEAF AREA INDEX AS INFLUENCED BY TILLAGE PRACTICES

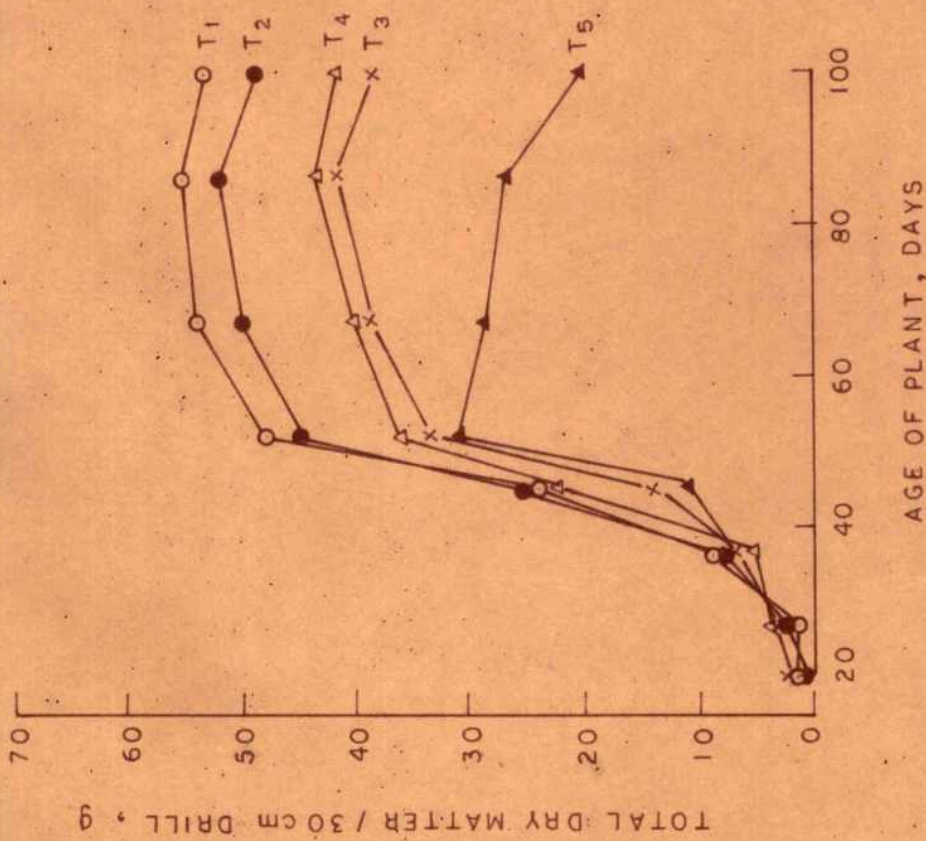
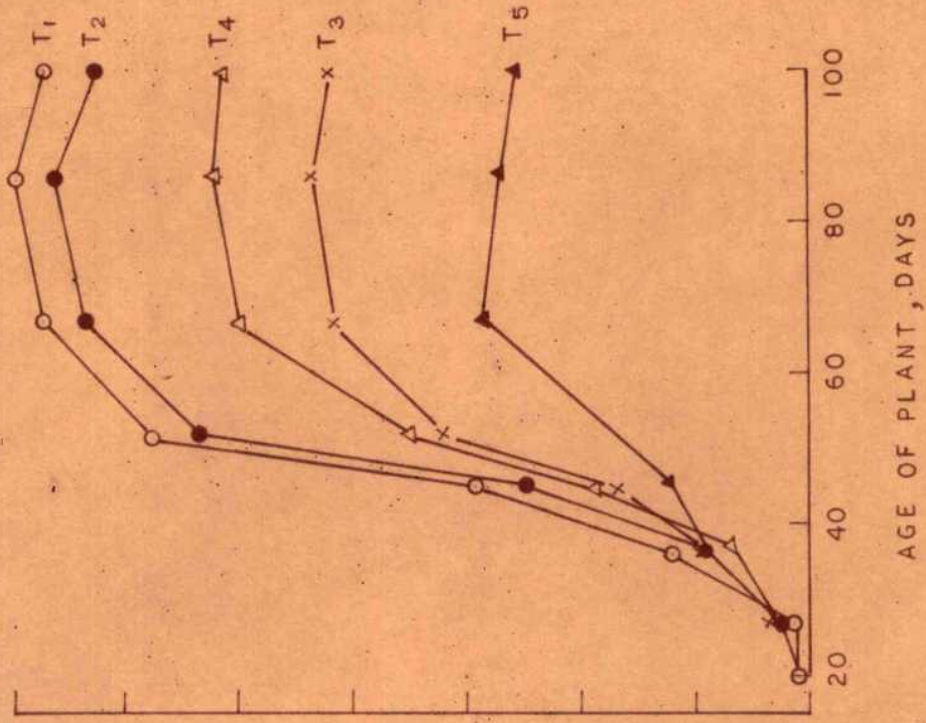


FIG.4.15 TOTAL DRY MATTER AS INFLUENCED BY TILLAGE PRACTICES

4.5.1.5 Straw yield : In both the experiments, straw yield was significantly lower in untilled plots than tilled plots. There was no appreciable difference between disk and mouldboard but they produced significantly higher yield of straw than other treatments. The tillage treatments namely : disk, mouldboard, wedge and rotary tiller produced 34.0, 33.6, 8.4 and 1.2 per cent higher straw yield as compared to untilled plots, respectively. Straw production was maximum under disk which proved better than wedge and rotary tiller. Minimum straw yield was noted in untilled plot. The lower straw yield in untilled plot was non-significant when compared with wedge and rotary tiller. Among all tillage treatments, straw yield was found better during 1972-73 (Table 4.12).

#### 4.5.2 Grain yield and yield attributes

4.5.2.1 Grain yield : The data in Table 4.13 indicate that significantly lower grain yield was obtained in untilled plot than under tillage treatments . The grain yield increased by 80.3, 69.9, 47.8 and 16.0 per cent under tilled plots, namely : disk, mouldboard, wedge and rotary tiller respectively, as compared to uncultivated plots. However, the difference between untilled and rotary tiller was non-significant. Maximum yield was recorded under disk closely followed by mouldboard. There was no significant difference between wedge and mouldboard. However, the grain yield under wedge differed significantly than under untilled plot. The grain yield during 1972-73 was reported

Table 4.13 Grain yield attributes of wheat as influenced by various tillage practices (T)

Treatments	Fertile tillers/ 30 cm drill	Spike length	Number of grains/ spike	1000 grains weight	Grain yield
		cm		g	kg/ha
<u>1971-72</u>					
T <sub>1</sub>	24.18	9.83	62.00	34.39	3311.42
T <sub>2</sub>	23.06	9.81	59.42	33.33	3104.72
T <sub>3</sub>	16.60	7.86	53.04	30.15	2063.89
T <sub>4</sub>	18.00	8.82	54.63	32.35	2680.23
T <sub>5</sub>	14.80	7.29	46.96	29.96	1747.83
	**	*	**	**	**
S. Em $\pm$	1.225	0.731	1.272	0.427	165.518
LSD <sub>0.05</sub>	3.67	2.19	3.81	1.28	496.15
LSD <sub>0.01</sub>	4.89	2.93	5.08	1.71	661.52
<u>1972-73</u>					
T <sub>1</sub>	25.13	9.89	62.41	35.02	3496.63
T <sub>2</sub>	24.22	9.84	60.33	34.64	3292.87
T <sub>3</sub>	16.93	7.93	53.03	30.78	2249.10
T <sub>4</sub>	18.95	9.12	54.17	32.18	2865.45
T <sub>5</sub>	15.88	7.48	47.55	29.41	1938.04
	**	**	**	**	**
S. Em $\pm$	1.288	0.577	1.254	0.484	193.106
LSD <sub>0.05</sub>	3.86	1.73	3.76	1.45	578.22
LSD <sub>0.01</sub>	5.16	2.33	5.01	1.92	771.08

\*\* significant at 1% level

\* significant at 5% level

to be higher than during 1971-72, there being similar trend of differences among tillage treatments.

**4.5.2.2 Fertile tillers :** The maximum fertile tillers occurred under disk which was significantly higher as compared to untilled plot. However, the differences between disk and mouldboard, and wedge and rotary tiller were non-significant. The tillage treatments except disk and mouldboard neither differed among themselves nor they could produce better results than untilled plot. The data in Table 4.13 clearly indicate that tillage treatments, namely : wedge and rotary tiller failed to establish their superiority over no-tillage treatments.

**4.5.2.3 Spike length :** It is seen from Table 4.13 that significantly longer spikes were produced under tilled plots than untilled one. Spike length was longest under disk which was also significantly longer than other tillage practices. However, in either experiments, the performance of disk and mouldboard was equally good and better than other tillage treatments. The difference in spike length due to the use of wedge, rotary tiller or in untilled plot was non-significant during 1971-72 but the remarkable difference was noticed between wedge and rotary tiller during 1972-73.

**4.5.2.4 Number of grains per spike :** All the tillage treatments significantly produced higher number of grains per spike than untilled plot. The number of grains per spike was significantly higher under disk in either experiments. The use of wedge and

rotary tiller did not produce significant results, however, they varied significantly when compared to untilled plot (Table 4.13).

4.5.2.5 Thousand grains weight : There was no appreciable difference in thousand grain weight among different tillage practices, however it was significantly higher than under untilled plot. The difference between disk and mouldboard, wedge and rotary tiller was found to be non-significant. Disk plough produced significantly higher thousand grain weight than other treatments and significantly lower weight was recorded under untilled plot closely followed by rotary tiller (Table 4.13).

#### 4.5.3 Root development

4.5.3.1 Root length : It was observed that maximum root length was obtained among all treatments at the age of 70 days in either experiments (Fig.4.16). However, the root length was slightly better during 1972-73. The longest roots were observed under disk closely followed by mouldboard (Table 4.14). The disk and mouldboard ploughs created conducive soil environment which helped roots to grow and penetrate the soil to a greater depth than other tillage treatments. Similar findings were reported by Reddy and Dakshinamurti (1971). They found better root penetration under deep ploughing because of improvement in the soil structure in the rhizosphere, and noted a significant correlation between root growth and soil structure. The shortest roots were noted under untilled plot. The root length varied significantly among tillage treatments during 1972-73, however, results obtained during 1971-72 did not show any significant effect with the

Table 4.14 Length and weight of roots as influenced by various tillage practices (T) at different phases of wheat growth

Treatments	Root length, cm					Root weight, g						
	Seedling stage	Vegetative growth phase	Reproductive phase	Grain formation phase	Seedling stage	Vegetative growth phase	Reproductive phase	Grain formation phase	Seedling stage	Vegetative growth phase	Reproductive phase	Grain formation phase
<u>971-72</u>												
T <sub>1</sub>	20.12	25.72	33.28	38.00	13.63	21.58	26.02	27.26				
T <sub>2</sub>	18.78	21.68	30.98	37.12	12.54	16.13	24.82	26.94				
T <sub>3</sub>	16.65	18.89	23.12	24.96	6.96	8.77	14.67	15.78				
T <sub>4</sub>	18.08	20.23	25.18	26.30	9.48	12.16	21.94	22.13				
T <sub>5</sub>	14.56	18.63	22.87	23.31	6.03	7.88	11.65	11.85				
	**	**	**	**	**	**	**	**				**
-Em ±	0.548	0.518	0.432	0.914	0.528	0.608	0.518	0.724				
D <sub>0.05</sub>	1.65	1.54	1.30	2.74	1.58	1.82	1.54	2.17				
D <sub>0.01</sub>	2.19	2.07	1.73	3.78	2.26	2.43	2.05	2.99				
<u>72-73</u>												
T <sub>1</sub>	22.38	26.38	35.10	39.14	15.33	21.62	27.94	29.45				
T <sub>2</sub>	19.35	22.36	32.15	37.50	12.99	16.48	26.26	28.43				
T <sub>3</sub>	17.20	20.18	24.20	27.06	7.17	9.55	15.82	17.15				
T <sub>4</sub>	18.23	21.29	26.25	30.17	10.58	12.43	23.18	23.38				
T <sub>5</sub>	15.13	19.40	23.12	25.08	6.15	8.08	12.85	12.32				

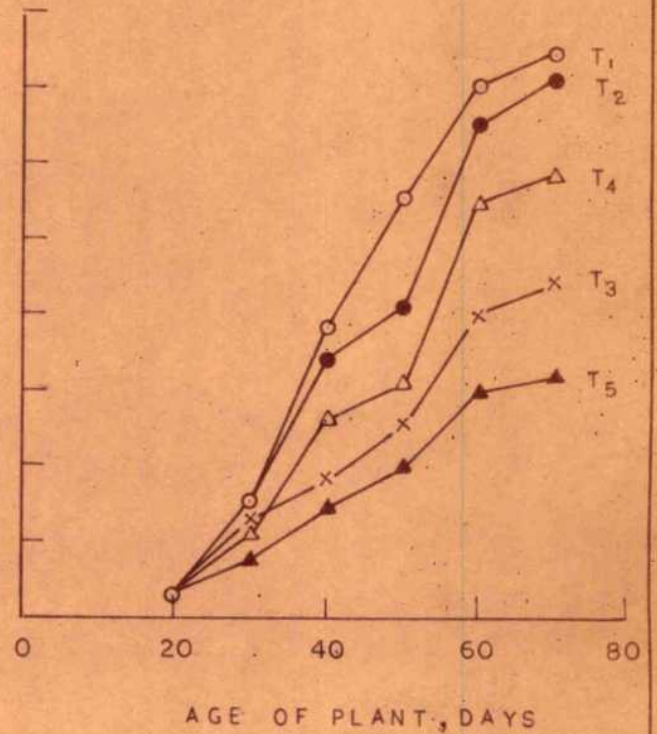
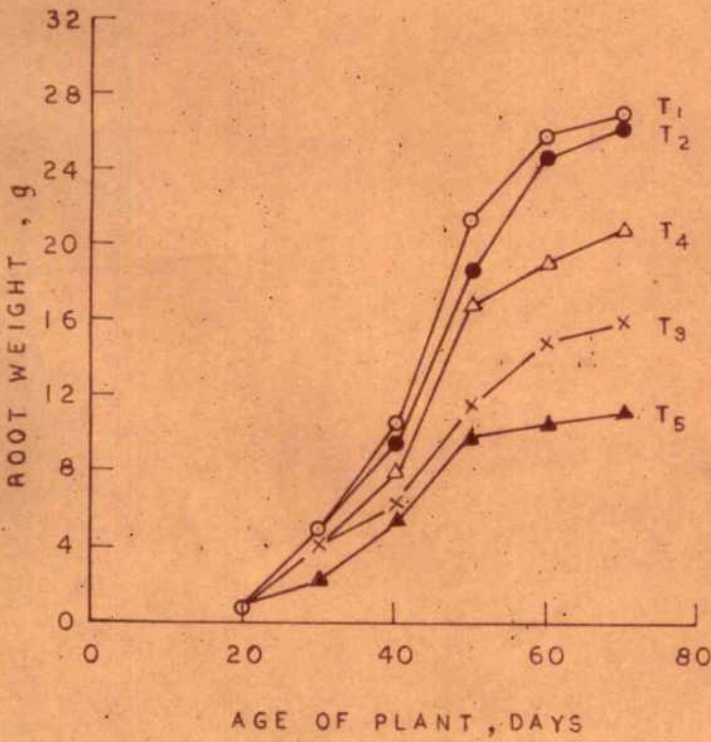
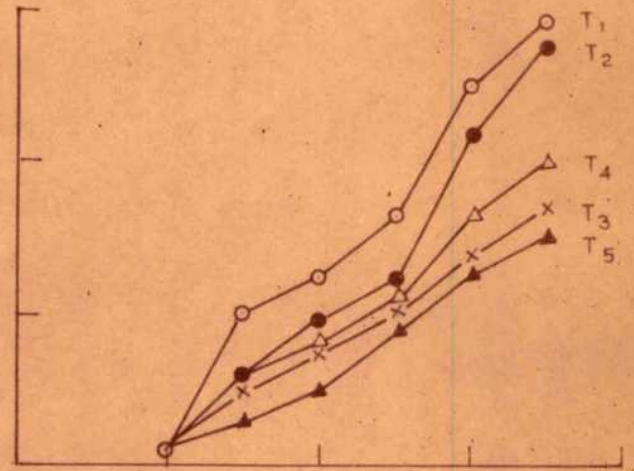
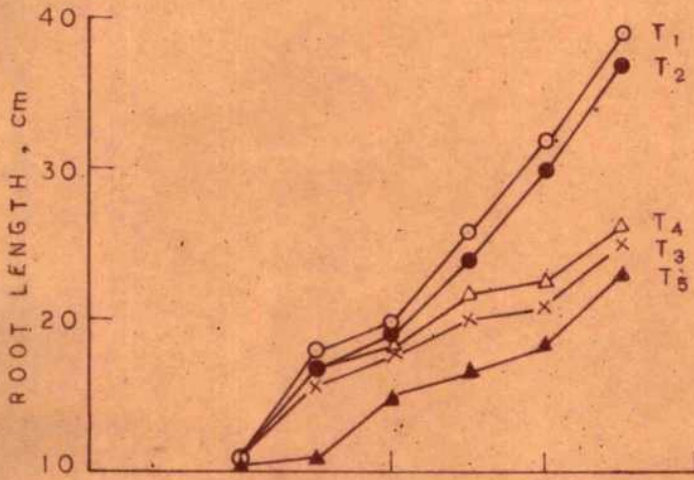


FIG.4.16 LENGTH AND WEIGHT OF ROOTS AS INFLUENCED BY TILLAGE PRACTICES

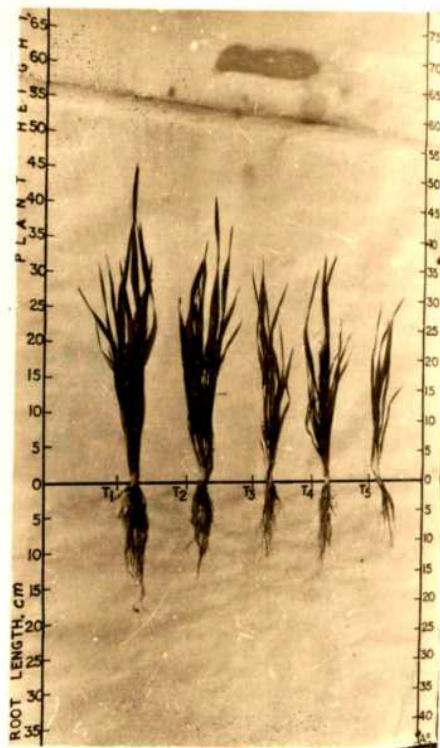
use of wedge and rotary tiller. But the wedge produced significantly longer roots than uncultivated plot.

4.5.3.2 Root weight : The root weight, as expected, was closely associated with the length of roots. The results of root weight, therefore, revealed a similar trend as that of root length among all tillage practices (Fig. 4.16). The maximum root weight was recorded under disk and mouldboard. They produced 2.5 times as much roots than untilled treatment. During 1971-72, disk and mouldboard showed no significant difference among themselves, however, they differed significantly as compared to other treatments. The results of wedge and rotary tiller also differed significantly than untilled plot. Rotary tiller produced less root weight than wedge. During 1972-73, the influence of tillage operations proved to be highly significant for all tillage practices. The similar trend was noted as that of previous experiment (Table 4.14).

#### GENERAL DISCUSSION

The results clearly indicate that grain yield was higher in tilled plots than in untilled one. Disk and mouldboard proved superior in their performance to other tillage treatments. Better performance of wheat under tilled plots is ascribed to the improved soil physical environment through tillage operations. The results reported by Reddy and Dakshinamurti (1971) also lend a support to these findings.

The highest grain yield was recorded under disk but it was on par with mouldboard. Wedge, however, gave the lowest yield

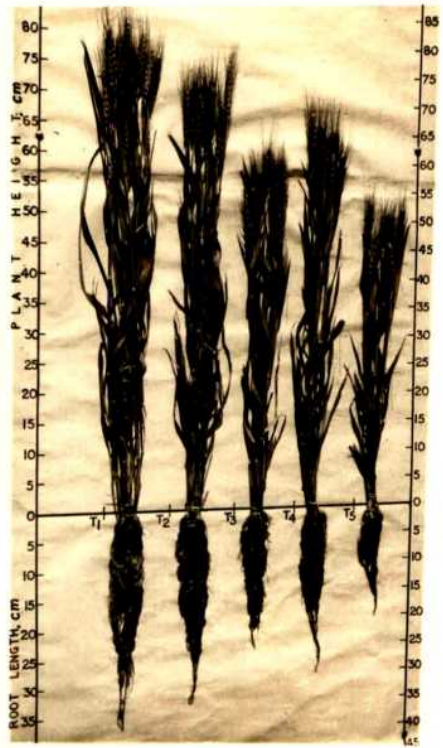


SEEDLING STAGE  
(15 DAYS AFTER SOWING)

VEGETATIVE STAGE  
(35 DAYS AFTER SOWING)



PLATE 9A. GROWTH OF WHEAT UNDER DIFFERENT  
TILLAGE PRACTICES



GRAIN FORMATION STAGE

( 75 DAYS AFTER SOWING )

MAXIMUM ROOT GROWTH

( AT HARVEST )

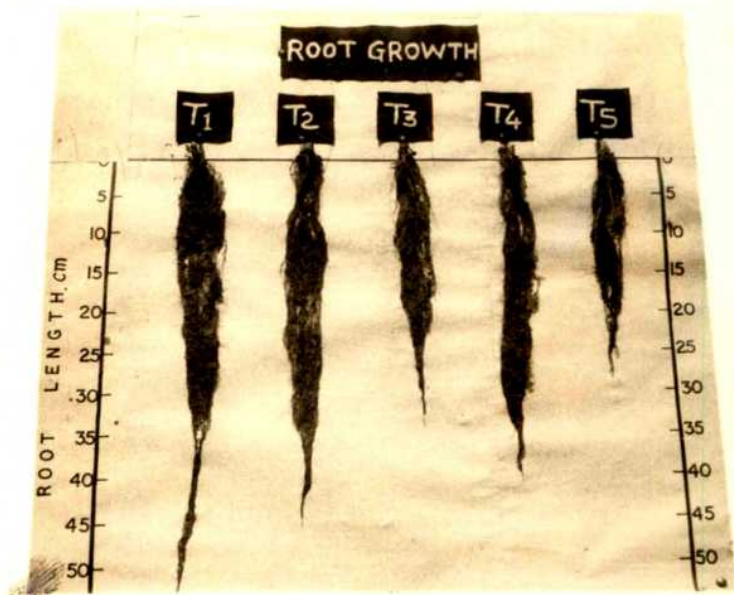


PLATE 9B. GROWTH OF WHEAT UNDER DIFFERENT TILLAGE PRACTICES

compared to disk and mouldboard but it was also statistically on a par at 1 per cent level with yield obtained in rotary tiller. The observed beneficial effects of deep ploughing (disk) of this region confirm the earlier findings of Moolani and Hukkeri (1965) and Bhushan *et. al.* (1973) for maize and wheat crops respectively. The variation in performance of wheat in either seasons is obviously due to the changes brought about in the rhizosphere of soil environment by tillage. It is, therefore, imperative to attribute the higher yield of wheat to conducive soil physical edaphic factors produced by tillage practices.

It is evident from the correlation studies that grain yield had significant relationship with different growth parameters and yield attributes (Fig. 4.17 and 4.18). It may be mentioned that every increase in leaf area index, number of tillers and in root weight within a certain range was accompanied by increase in grain yield. Grain yield had strong relationship with leaf area index (  $r = 0.97$  ), tiller number (  $r = 0.99$  ), root weight (  $r = 0.99$  ) and with various yield attributes as given in Appendix L.

Crop performance was better in plot of lower bulk density and higher porosity as indicated by the various growth parameters. Better performance of wheat crop in tilled plots may be attributed to increased root development : as a result the roots could absorb more moisture and plant nutrients from a greater soil volume which was favourably influenced by adequate aeration, lower penetration resistance and lower matric suction (Fig. 4.19 and

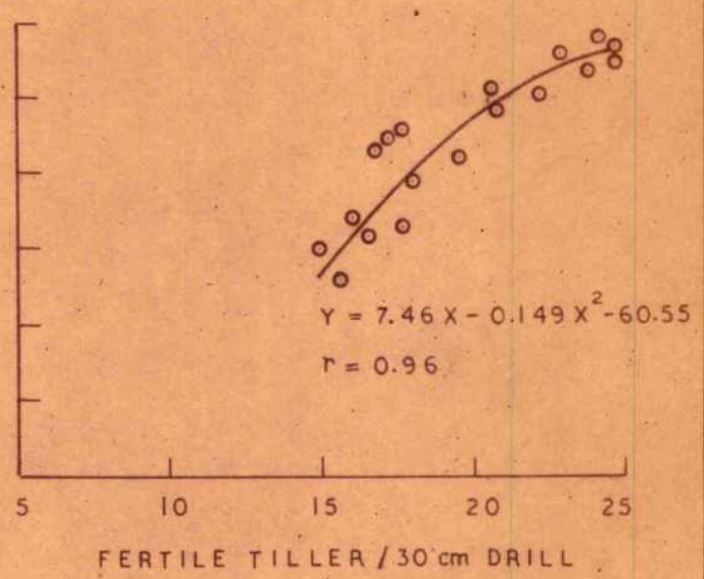
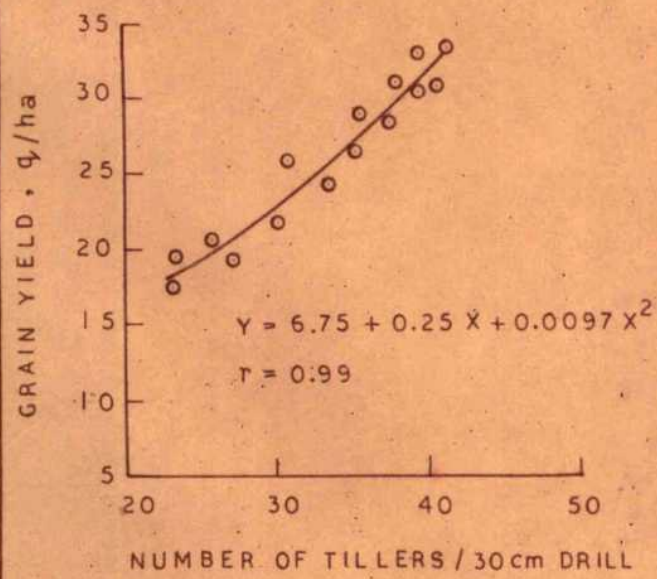
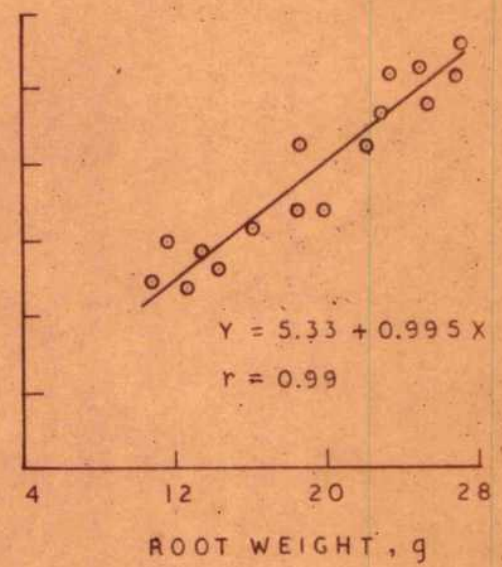
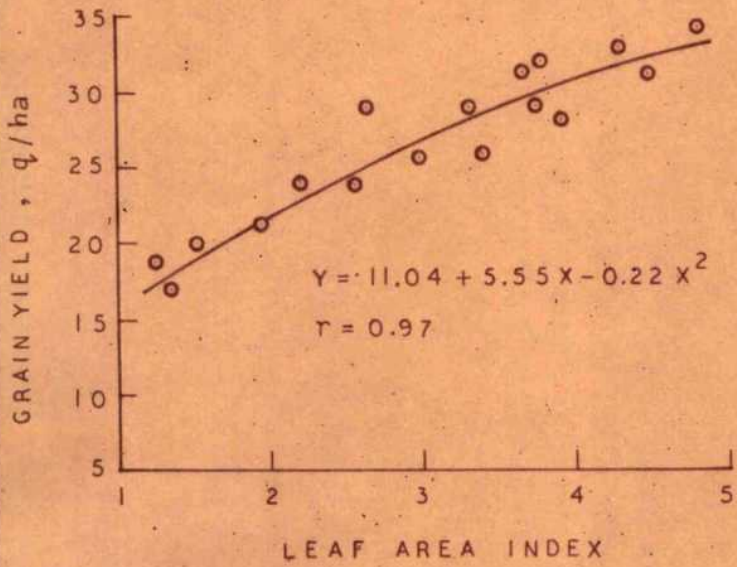


FIG.4.17 GRAIN YIELD AS INFLUENCED BY ROOT AND SHOOT GROWTH DURING 1971-72

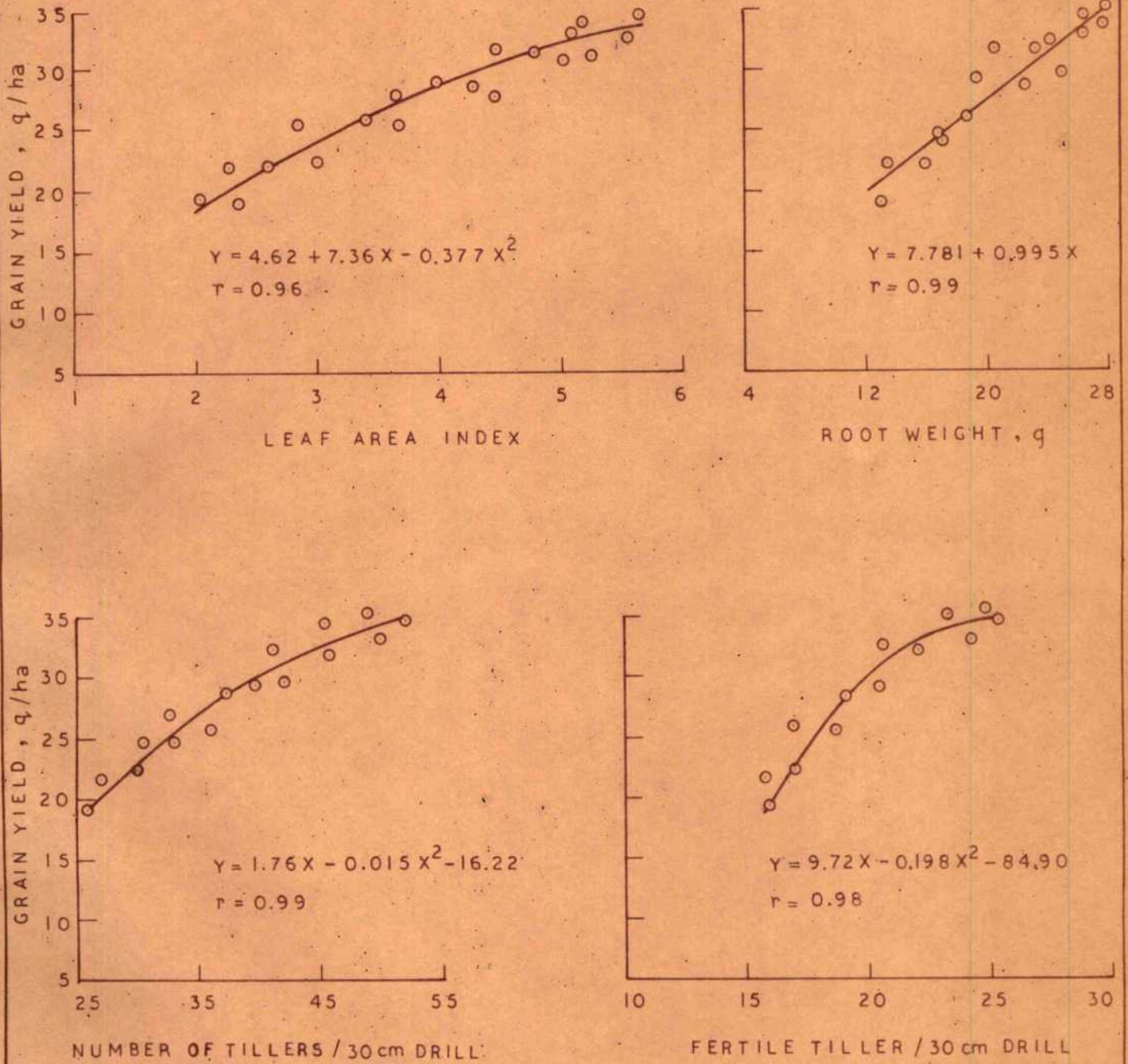


FIG.4.18 GRAIN YIELD AS INFLUENCED BY ROOT AND SHOOT GROWTH DURING 1972-73

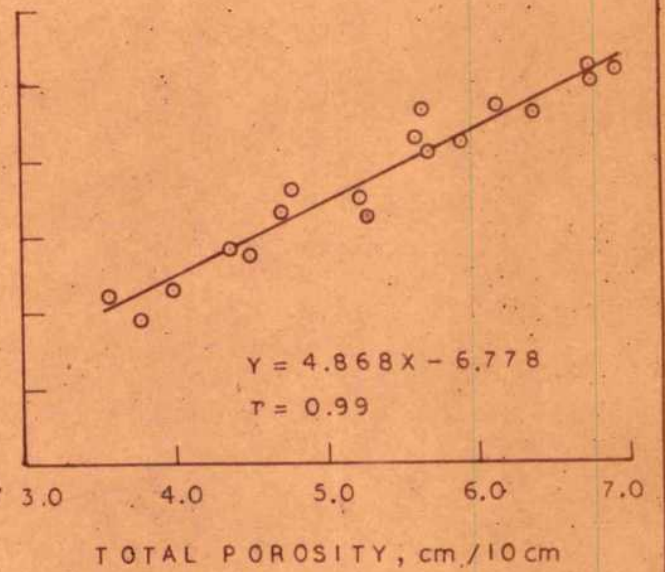
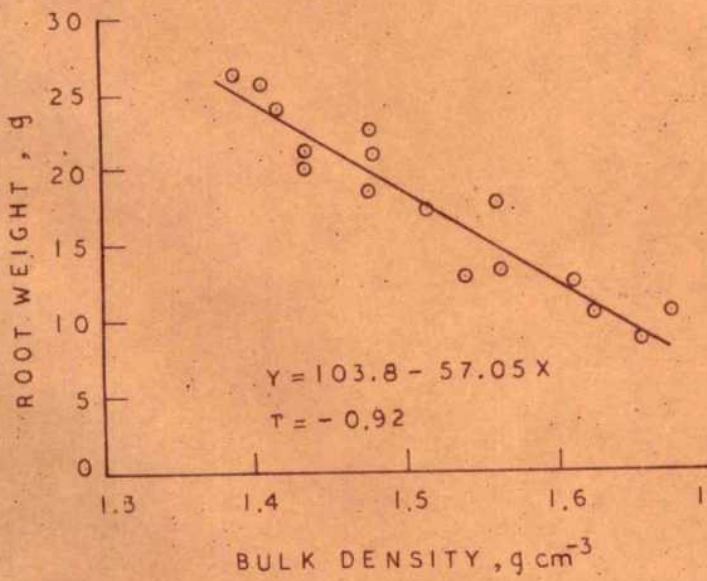
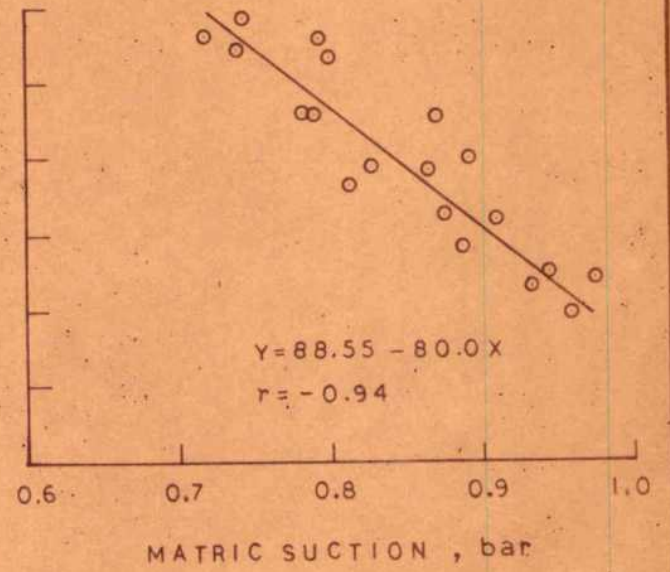
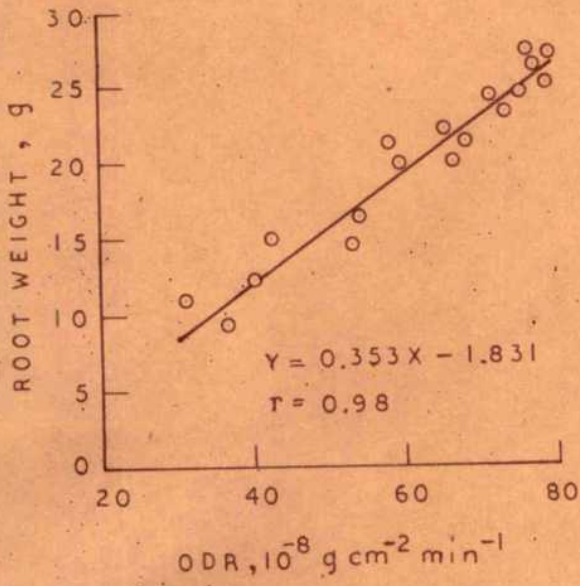


FIG.4.19 RELATION BETWEEN ROOT WEIGHT AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1971-72

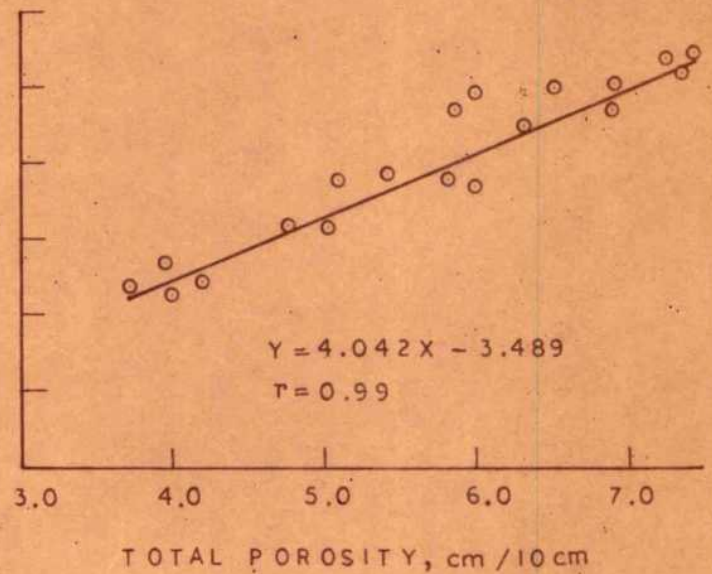
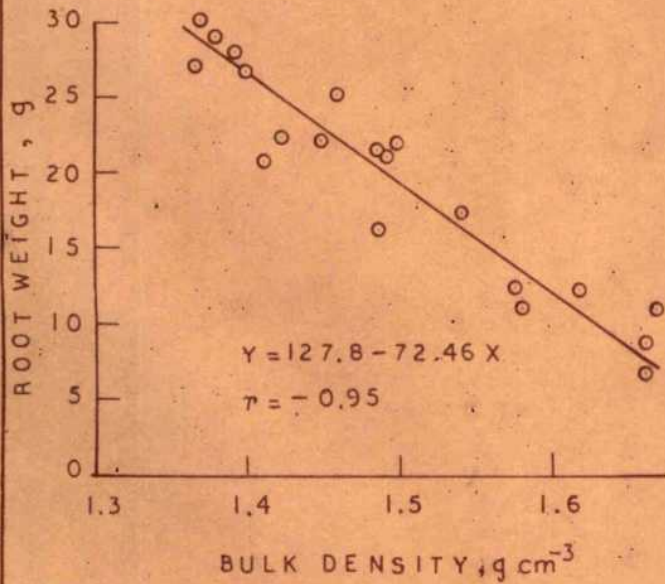
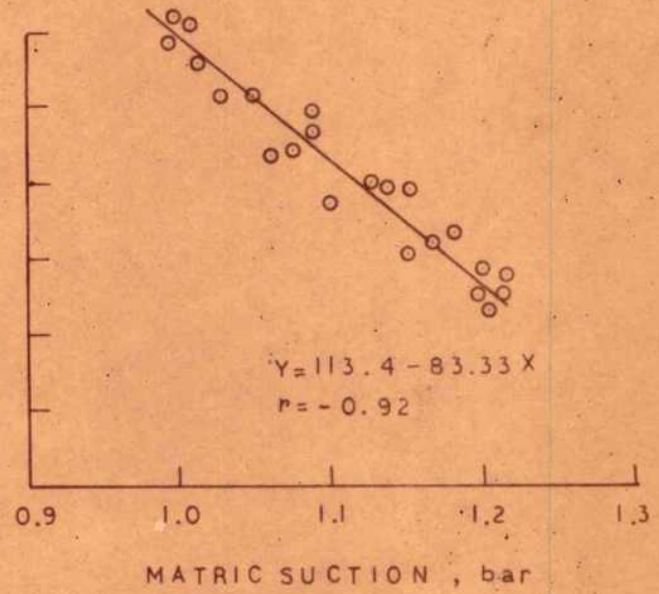
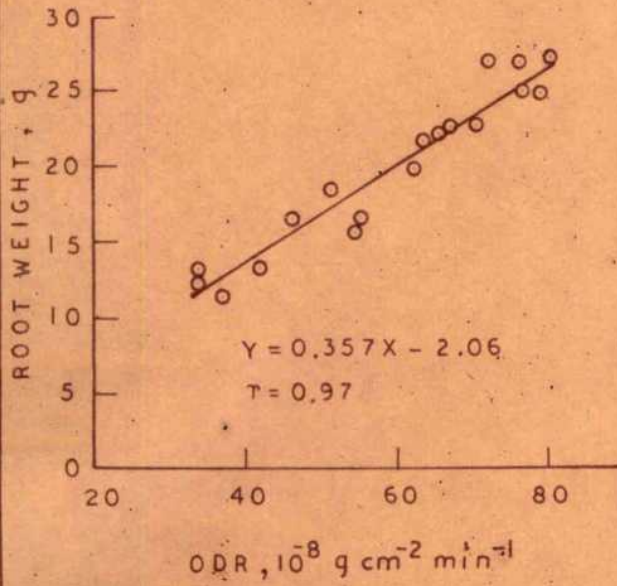


FIG.4.20 RELATION BETWEEN ROOT WEIGHT AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1972-73

4.20). The leaf area index and tiller formation also consequently had a similar relationship with edaphic factors (Fig. 4.21, 4.22, 4.23 and 4.24).

It is seen from the results that lower matric suction occurred in tilled plots during the critical moisture requirement phase of wheat i.e. reproductive phase (Table 4.5). The increased moisture stress decreased root development and prevented normal wheat plant growth (Kramer, 1963; Salim *et. al.*, 1965). From the findings of Johnson (1953), Robins and Domingo (1962) and Day and Intalap (1970), it is evident that wheat crop did not tolerate water stress at flowering stage because maximum leaf development took place during this stage. The tillage treatments, namely : wedge, rotary tiller and no-tillage plot, therefore, resulted in lower grain yield, fewer head per unit area and few grains per ear head. This high matric suction may be because of highest consumptive use of wheat during this phase of growth.

Above discussion clearly brings about the importance of soil moisture and explains the reason of higher yield under disk and mouldboard as compared to rotary tiller, wedge and untilled plot. The grain yield was highest under disk because disk plough (deep) opens up the sub-surface soil and allows easy infiltration of water (Table 4.6). Thus the soil absorbs more water, and a favourable soil-water relationship is maintained under disk ploughing. Furthermore, this enables us to know the soil physical condition that should be provided in order to reduce the frequency

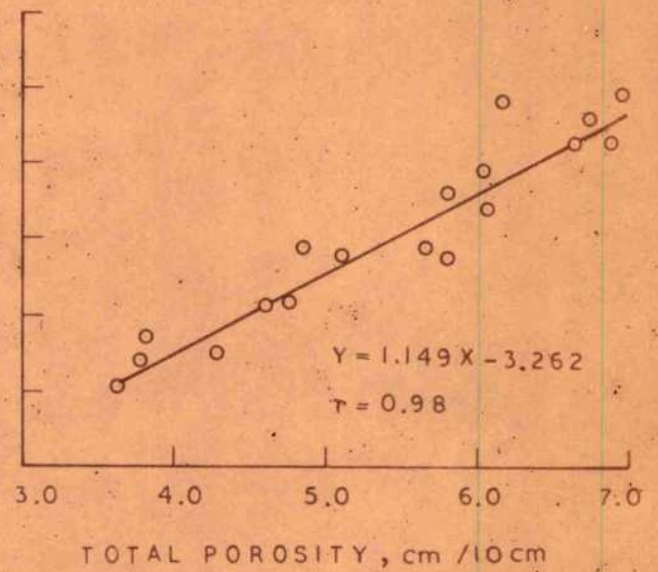
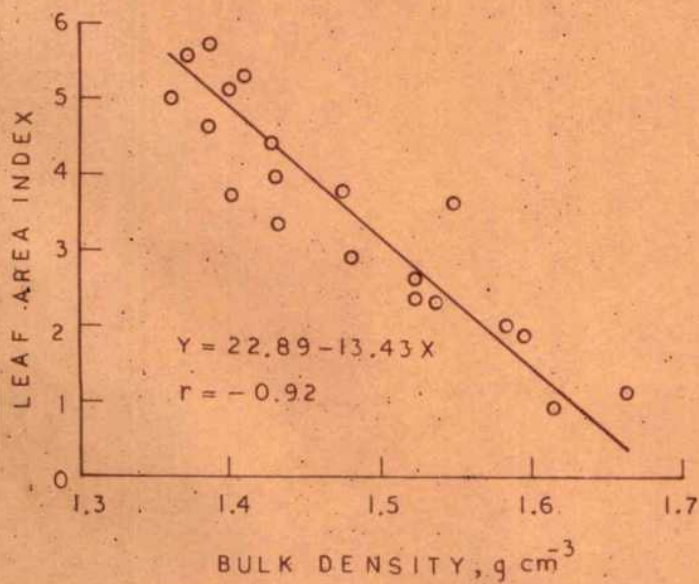
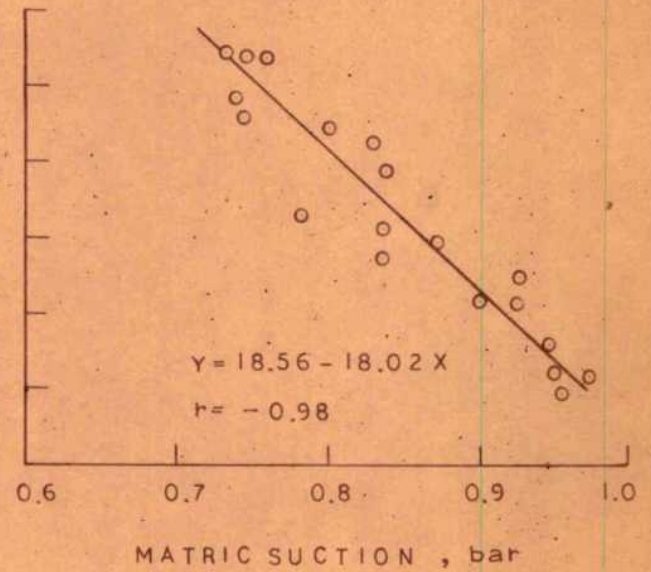
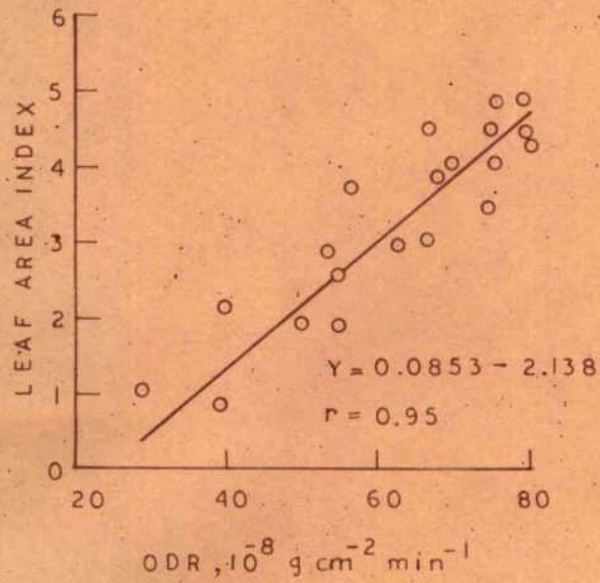


FIG.4.21 RELATIONSHIP BETWEEN LEAF AREA INDEX AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1971-72

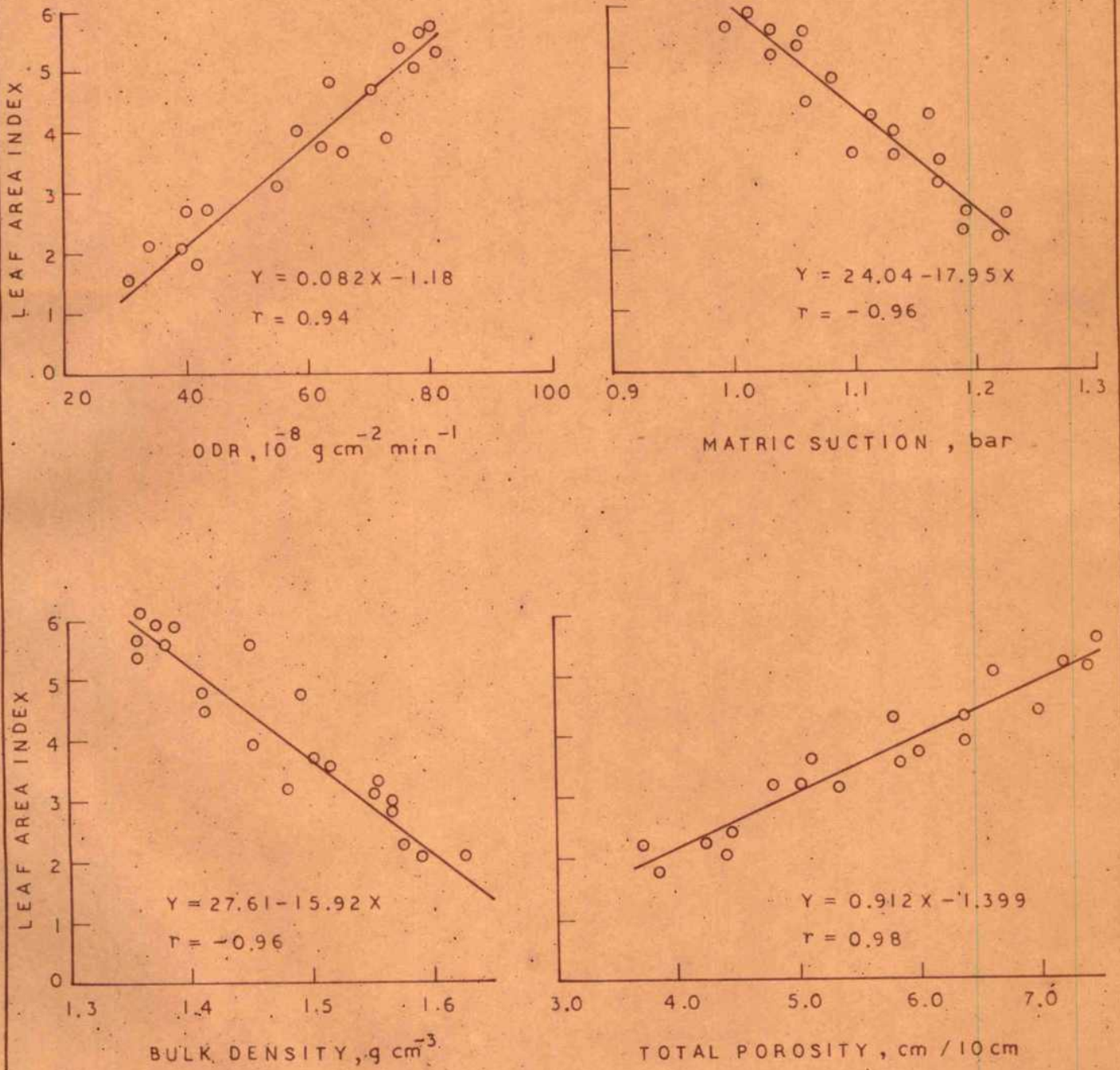


FIG.4.22 RELATIONSHIP BETWEEN LEAF AREA INDEX AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1972-73

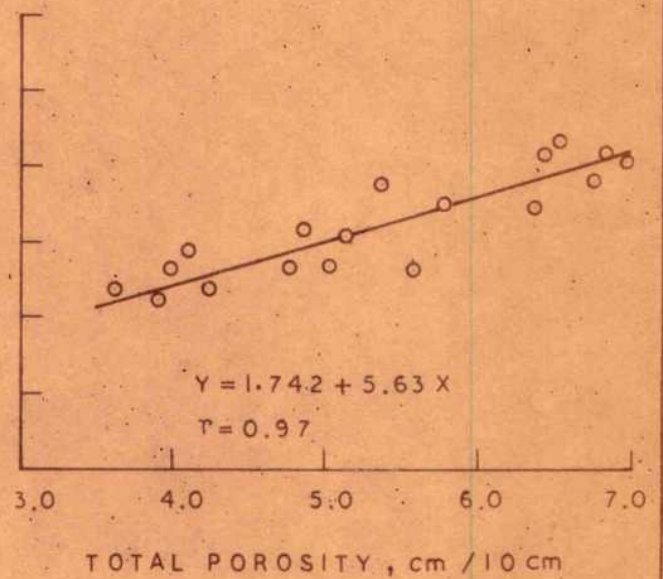
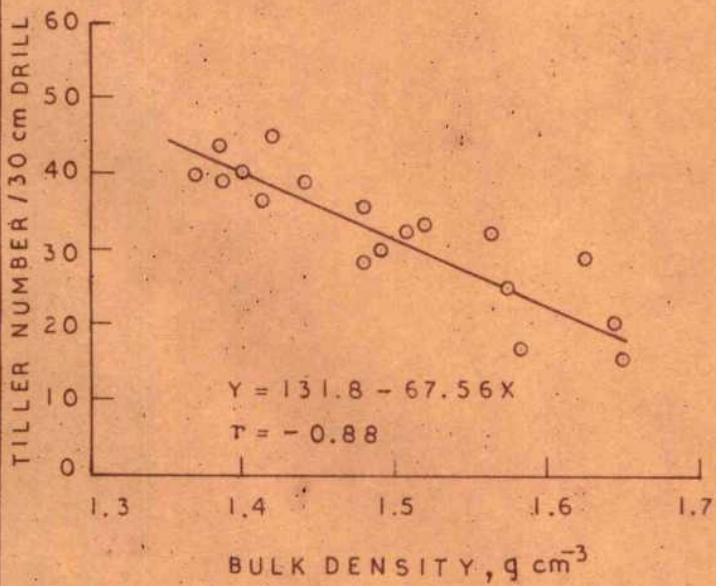
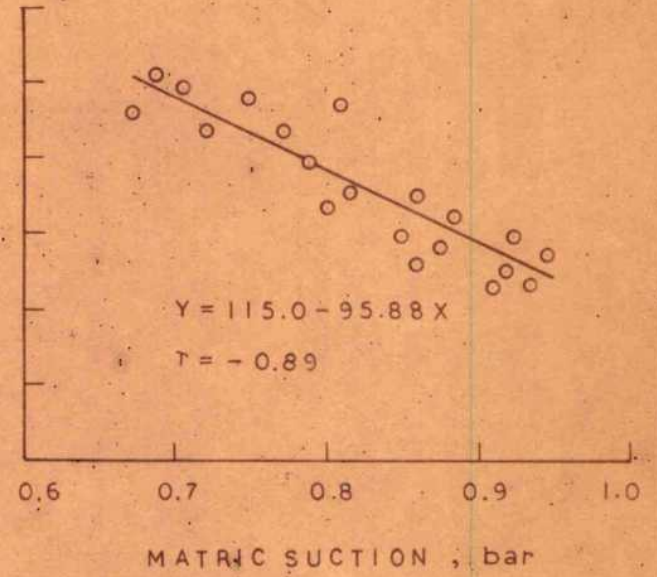
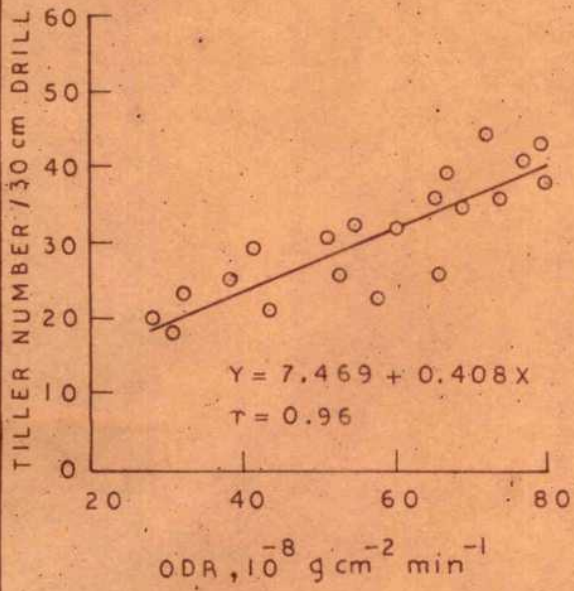


FIG.4.23 RELATIONSHIP BETWEEN TILLER NUMBER AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1971-72

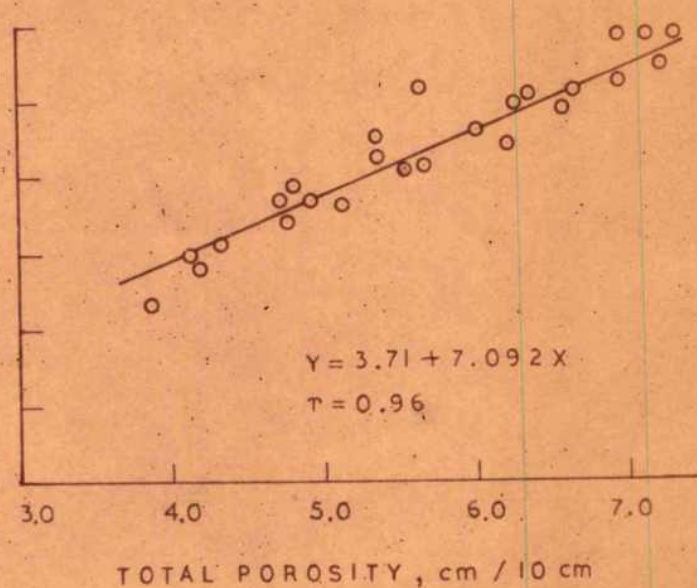
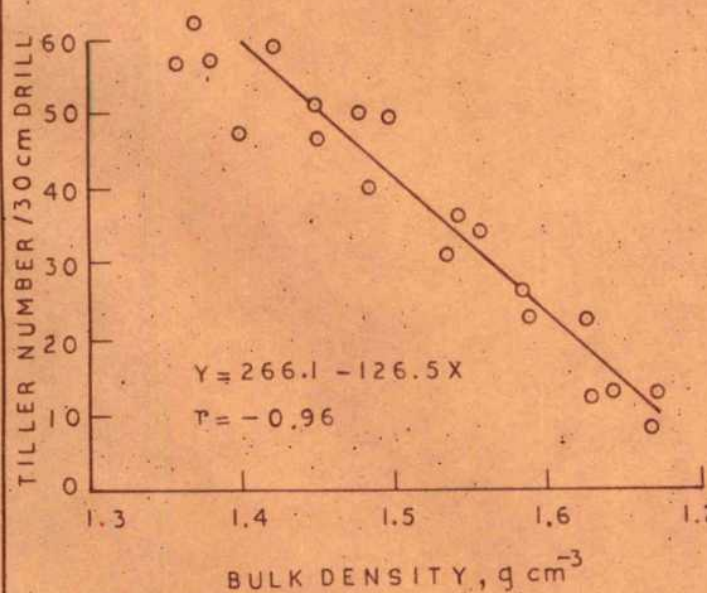
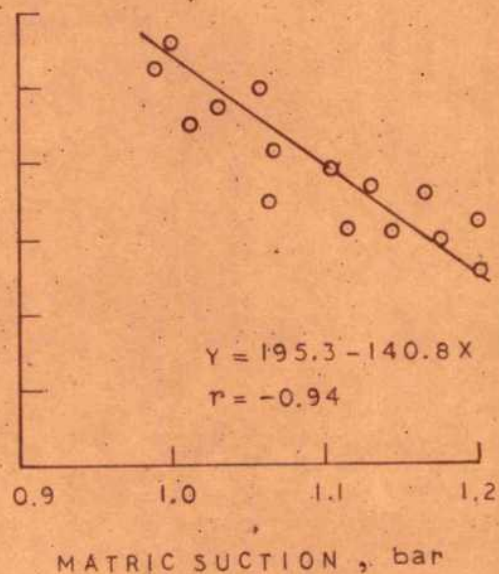
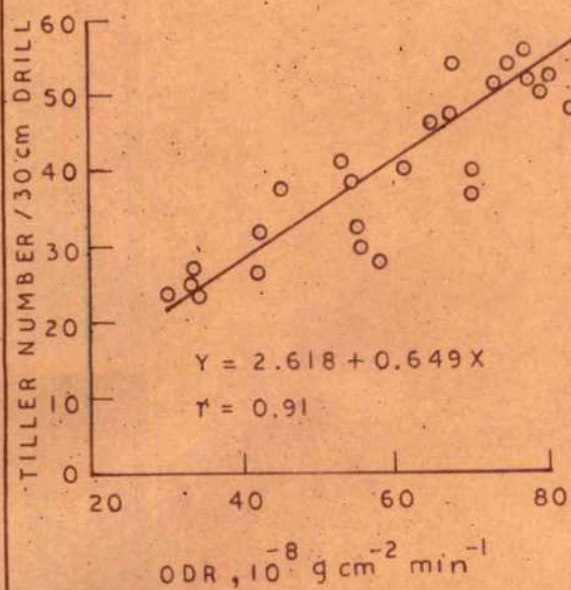


FIG. 4.24 RELATIONSHIP BETWEEN TILLER NUMBER AND EDAPHIC FACTORS AT VEGETATIVE GROWTH PHASE DURING 1972-73

of irrigation and the soil manipulation practice that should be adapted under restrained condition of irrigation water. This in fact would help to increase the water use efficiency.

The ODR values at various growth phases of wheat crop were significantly higher in plots tilled with disk or mouldboard as compared to wedge, rotary tiller and untilled plot (Table 4.8). The ODR values were always below  $30 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$  in untilled plot except vegetative growth phase during 1972-73. Stolzy and Letey (1964) emphasized that ODR played an important role in restricting the root development and, therefore, if the ODR is less than  $30 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ , the resultant grain yield is affected adversely. Lower grain yield in untilled plots is ascribed to the adverse effect of lower ODR values (Table 4.8).

The quantity of roots were related to the depth of ploughing and the roots were highest under disk followed by mouldboard, wedge and rotary tiller (Table 4.14). Thus disk and mouldboard ploughing facilitated the penetration of roots to lower depths. A positive correlation existed between root distribution and grain yield. Under wedge and rotary tiller, there was a relative concentration of roots in the surface layer as compared to other treatments. This suggests the possibility of accumulation of finer roots in the sub-surface soil under shallow ploughing.

Apart from higher penetration resistance throughout the growth period, poor aeration in untilled plots seems to have affected the root development very adversely.

Figures 4.25 and 4.26 show the relationship between number of fertile tillers and edaphic factors at reproductive phase. Greater number of fertile tillers at lower bulk density was influenced by profuse tillering during vegetative phase and compensated the poor emergence in plots of lower bulk density especially under disk and mouldboard treatments.

The grain yield of crop depends on root and shoot growth. The straight line relationship with root weight indicates that root growth is vital for better harvest. The curvilinear relationship of grain yield with leaf area index and number of tillers clearly indicates that yield can not go on increasing with the increase in the above three factors, rather there lies an optima for an individual factor and combination of all, from the point of view of grain yield. From Fig.4.18, it appears that during 1972-73, if the number of tillers/30 cm drill, leaf area index and fertile tillers/30 cm drill exceed respectively 52, 5.54 and 25, the yield may be adversely affected. Grain yield had similar relationship with edaphic factors as was exhibited by various growth parameters and yield attributes. Almost all the growth factors studied in both the seasons had higher values in disk (deep) ploughing operation followed closely by mouldboard ploughing than those in other treatments.

It appears from the results obtained that soil physical environment at various growth phases should be created in such a way that would be conducive to produce the optimum number of tillers and leaf area index. From Fig. 4.21, 4.22, 4.23, 4.24,

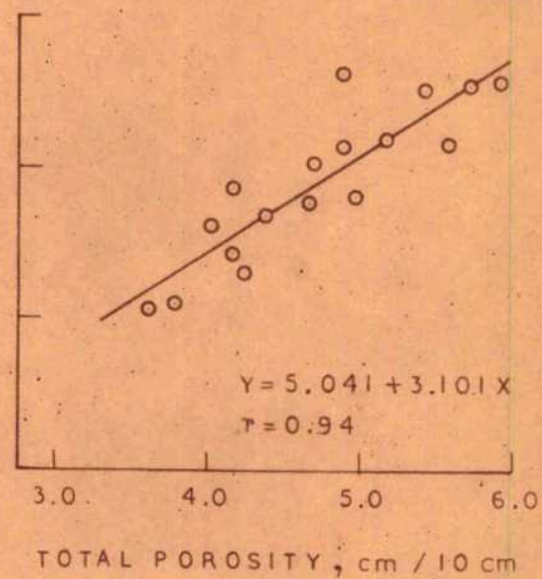
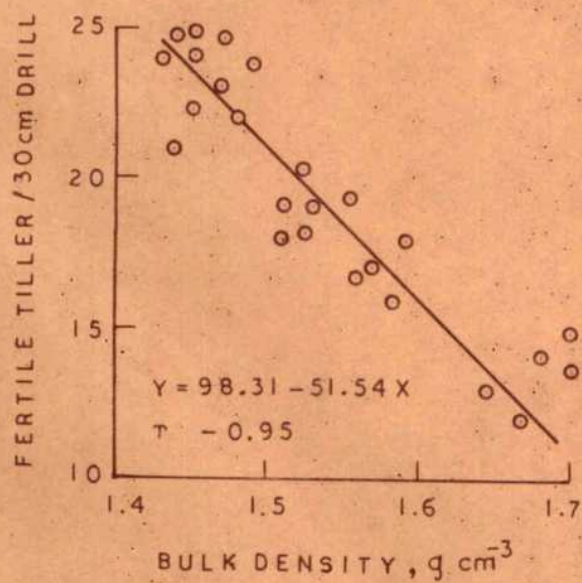
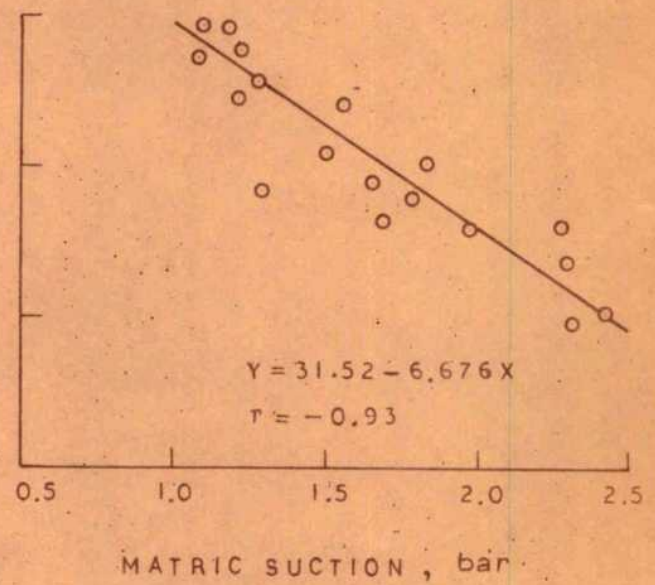
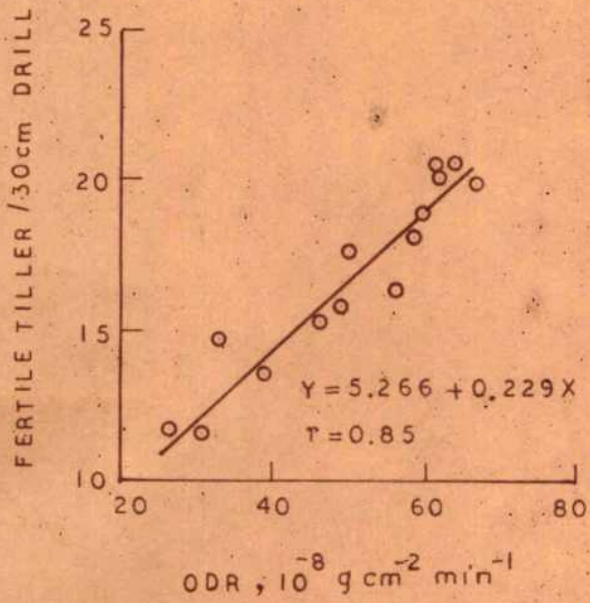


FIG.4.25 NUMBER OF FERTILE TILLERS AS INFLUENCED BY EDAPHIC FACTORS AT REPRODUCTIVE PHASE DURING 1971-72

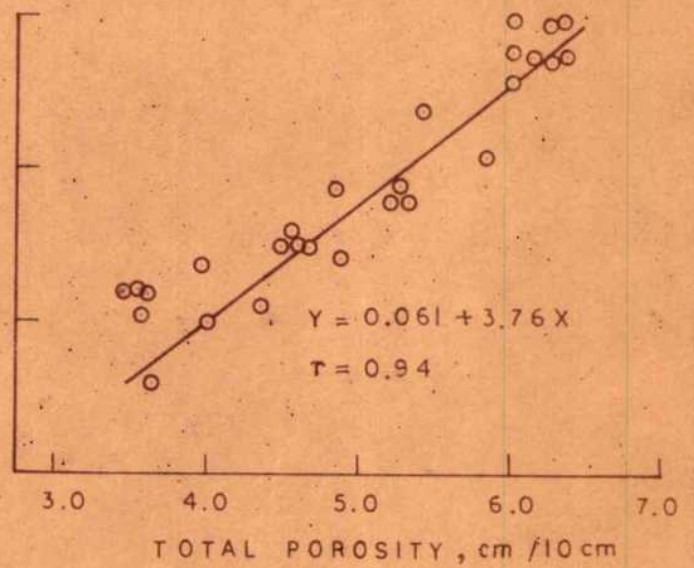
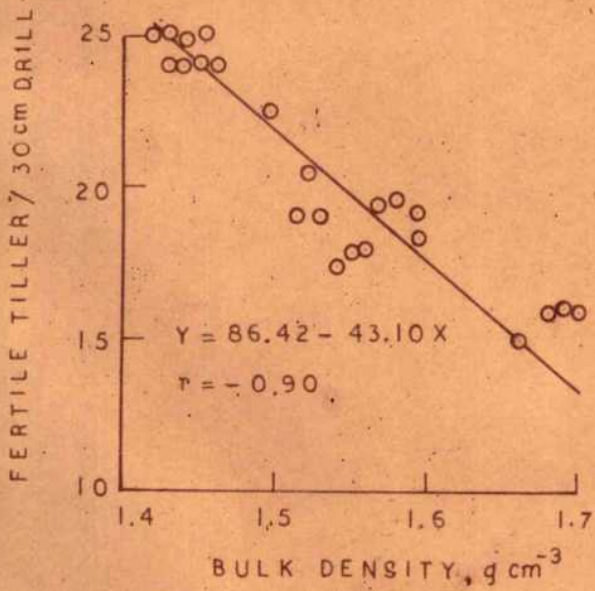
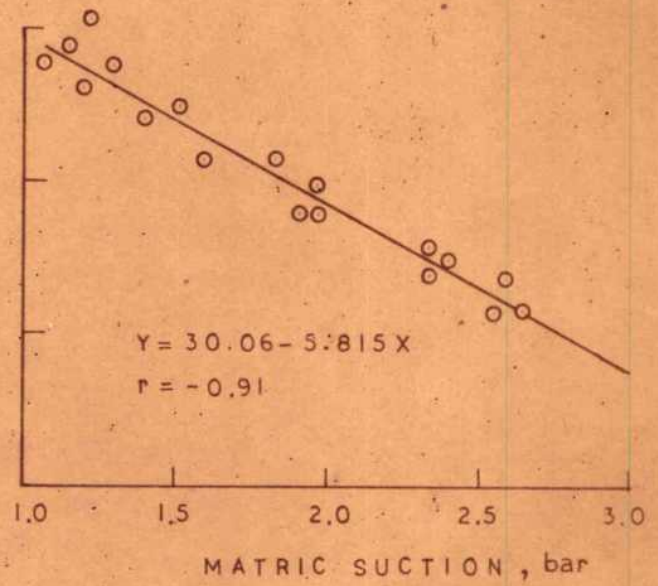
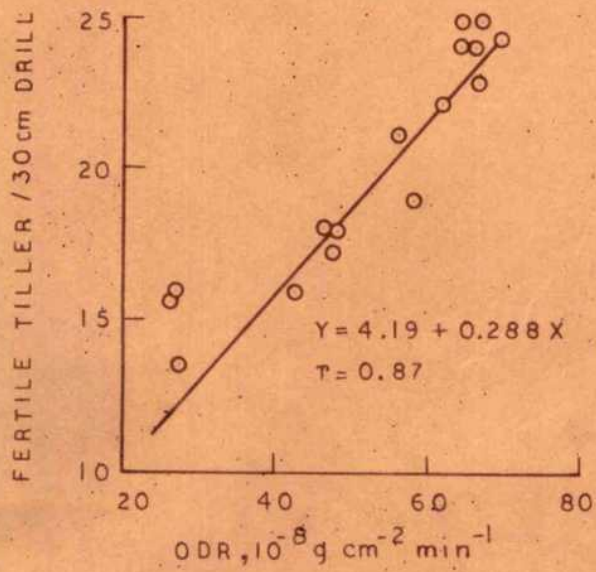


FIG.4.26 NUMBER OF FERTILE TILLERS AS INFLUENCED BY EDAPHIC FACTORS AT REPRODUCTIVE PHASE DURING 1972-73

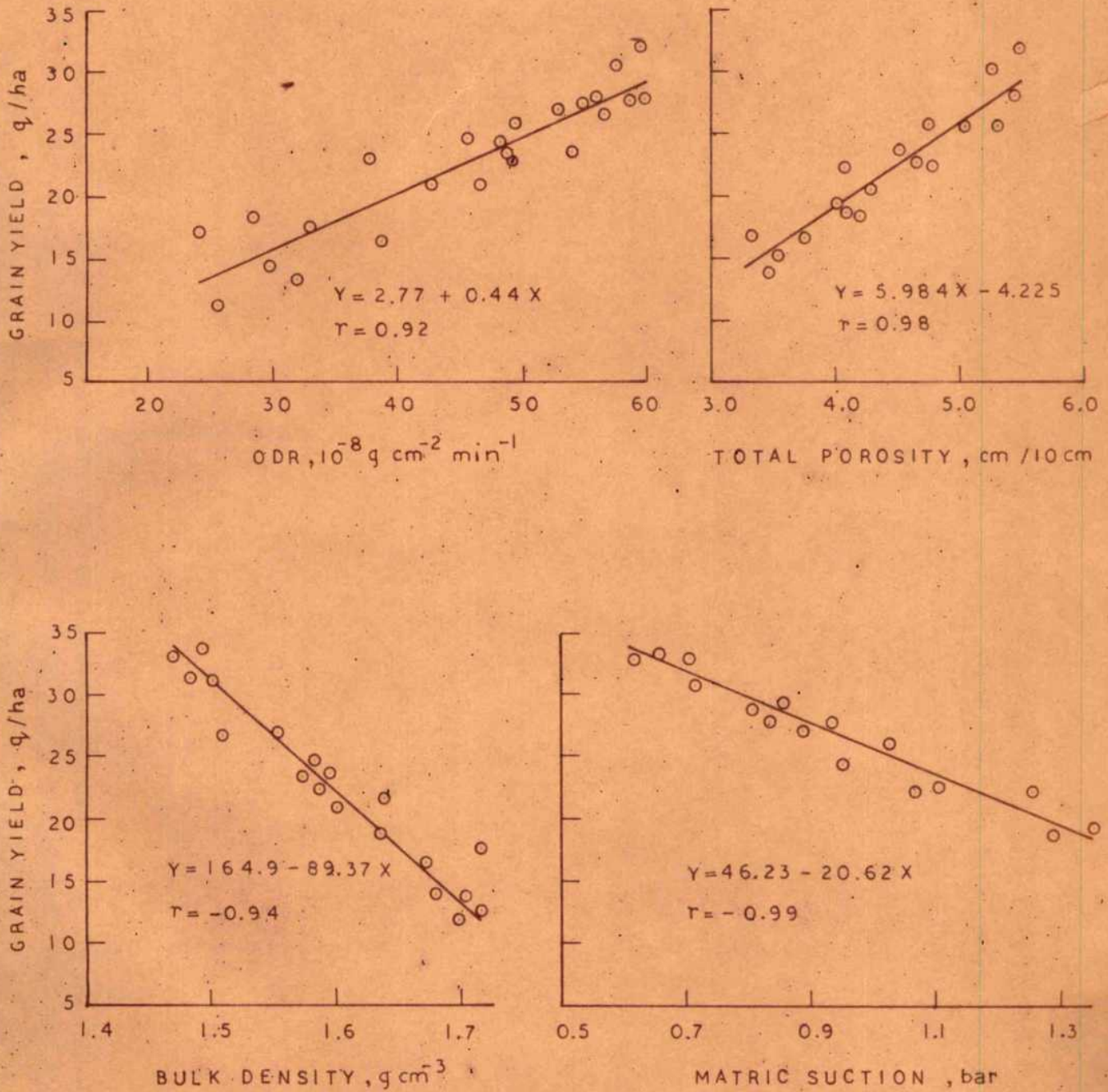


FIG.4.27 GRAIN YIELD AS INFLUENCED BY EDAPHIC FACTORS AT GRAIN FORMATION PHASE DURING 1971-72

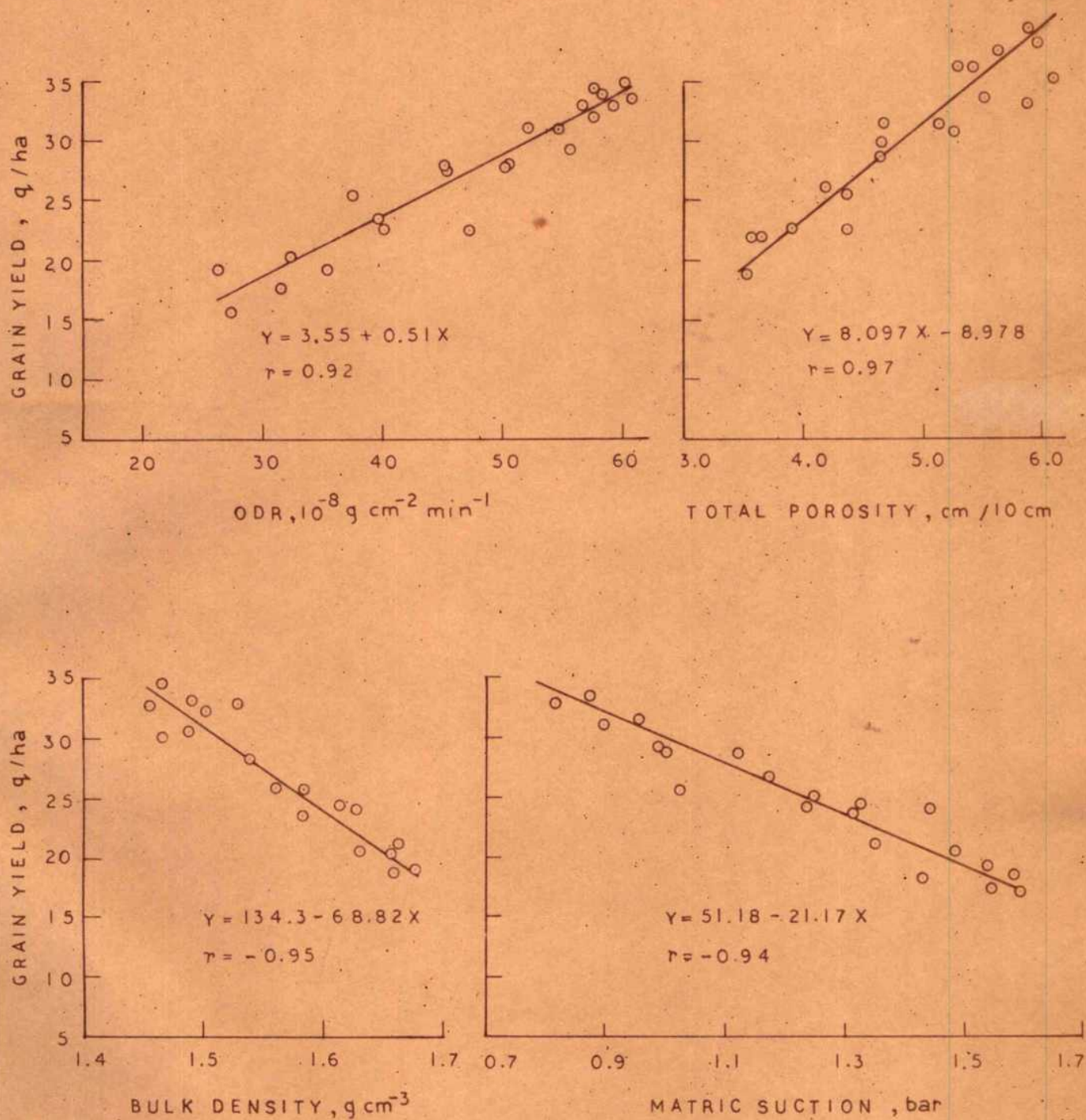


FIG.4.28 GRAIN YIELD AS INFLUENCED BY EDAPHIC FACTORS AT GRAIN FORMATION PHASE DURING 1972-73

4.25 and 4.26, it may be concluded that bulk density of 1.35 - 1.40 g cm<sup>-3</sup> during vegetative growth phase created favourable soil environment which produced the desired leaf area and number of tillers. At reproductive phase, the most conducive bulk density, however, would be 1.40 - 1.45 g cm<sup>-3</sup>. It may be concluded from Fig.4.27 and 4.28 that during grain formation phase, bulk density in the range of 1.45 - 1.50 g cm<sup>-3</sup> favoured the maintenance of the most desired soil environment.

In the present investigations, the above mentioned conducive soil physical environment was found to be created by the disk and mouldboard plough treatments in the seedbeds of which the initial clod size was in the range of 11 to 12.50 mm MWD in lateritic soils of Kharagpur.

## Part II

### Physical Properties of Soil Aggregates

#### 4.6 Distribution of Dry Aggregates

The distribution of dry aggregates in the various size groups (Table 4.15) shows that higher weight fraction was observed for larger clods in the order of disk, mouldboard, wedge and rotary tiller. The rotary tiller produced more clods having smaller diameter and very few clods having bigger diameter. The percentage clods smaller than 1.19 mm diameter was higher in the case of rotary tiller and wedge as compared to mouldboard and disk. Very recently, Bhushan *et. al.* (1973) found similar results while working on the same soil.

Table 4.15 Observed and cumulative weight fraction of soil aggregates as influenced by various tillage treatments(T)

Sieve classes	T <sub>1</sub>		T <sub>2</sub>		T <sub>3</sub>		T <sub>4</sub>	
	Observed values	Cumulative values	Observed values	Cumulative values	Observed values	Cumulative values	Observed values	Cumulative values
<u>1971-72</u>								
I	0.363	0.981	0.312	0.985	0.119	0.987	0.230	0.986
II	0.154	0.618	0.128	0.673	0.116	0.868	0.131	0.756
III	0.172	0.464	0.139	0.545	0.228	0.752	0.191	0.625
IV	0.066	0.292	0.072	0.406	0.133	0.524	0.113	0.454
V	0.041	0.226	0.057	0.334	0.091	0.391	0.074	0.321
VI	0.046	0.185	0.063	0.227	0.076	0.300	0.065	0.247
VII	0.139	0.139	0.214	0.214	0.224	0.224	0.182	0.182
<u>1972-73</u>								
I	0.351	0.993	0.324	0.993	0.050	0.991	0.161	0.995
II	0.173	0.647	0.172	0.669	0.109	0.941	0.148	0.834
III	0.206	0.474	0.187	0.497	0.263	0.832	0.284	0.686
IV	0.124	0.263	0.115	0.310	0.249	0.569	0.183	0.402
V	0.049	0.144	0.053	0.195	0.103	0.320	0.054	0.219
VI	0.048	0.085	0.048	0.142	0.089	0.217	0.053	0.165
VII	0.047	0.047	0.094	0.094	0.128	0.128	0.112	0.112

The data on clod mean weight diameter (MWD) reveal that the effect of different tillage treatments on MWD of clod was highly significant (Table 4.16). The clod MWD was statistically lower under rotary tiller compared to other tillage practices. The maximum MWD of clod was found under disk closely followed by mouldboard, wedge and rotary tiller. This is attributed to the predominance of clods larger than 12.70 mm diameter under disk and mouldboard treatments. Since rotary tiller produced higher percentage of clods smaller than 2.38 mm diameter, the MWD of clods was minimum.

The geometric mean diameter (GMD) of clods had also the similar trend as that of MWD. However, during 1971-72, no significant difference was noted between mouldboard and wedge, but it is worth noting that these two treatments produced significantly higher GMD of clods than rotary tiller (Table 4.16). The clods of highest GMD were produced by disk ploughing.

#### 4.7 Estimation of $\log$ GMD and $\sigma \log d$

Logarithm of geometric mean diameter is a simple method of representing a soil aggregate-size distribution by an analytical expression (Gardner, 1956). From the air-dry weights of the sieve fractions of a sample from 0 to 8 cm layer, two parameters were estimated viz. (a) the logarithm of the geometric mean diameter (  $\log$  GMD ) and (b) an index of the dispersion of the aggregate diameters (  $\sigma \log d$  ). Estimation of these parameters requires that the proportion of soil aggregates by weight in the sample be distributed approximately normally as the logarithm of the diameter. The two parameters were computed mathematically,

but the computation was conformed to the graphical estimation illustrated in Fig.4.29. Using the logarithm of the diameter of average limit for sieve classes shown in Table 3.4 and the proportion by weight in the sieve classes, an array of fraction-undersize versus logarithm of aggregate diameter was calculated. The fraction-undersize was then transformed as cumulative weight fraction. Under the assumption of a log normally distributed aggregate diameters, a linear relation was expected between the cumulative weight fraction-undersize and the logarithm of the aggregate diameter. The estimated GMD for treatment 2 during 1971-72 was 3.896 mm (Table 4.16) and the estimate of  $\sigma \log d$  was 1.526 mm specified that 67 per cent of the sample contained aggregates having a diameter within the range of 0.618 to 13.420 mm, i.e.  $\text{antilog}(1.354 \pm 1.526)$ . And if for instance, the value of  $\sigma \log d$  is 1.032 which is used as an index of dispersion, 50 per cent of the sample (Fig. 4.29) would fall in the range of 1.036 to 9.180 mm, i.e.  $\text{antilog}(1.354 \pm 1.032)$ . The changes in log GMD and  $\sigma \log d$  due to sieving were estimated by sieving several randomly selected samples.

The validity of the assumed log normal distribution of aggregate diameter was judged qualitatively from comparison of observed and estimated weight fractions (Fig.4.29). There appears to be no rigorous and yet facile manner to check the assumption when there is a small number of sieve sizes, and when the weights are observed rather than number of particles. Figure 4.29 (Treatment 2) represents one of the poorest fit of a linear relation between cumulative weight fraction and the logarithm of the diameter.

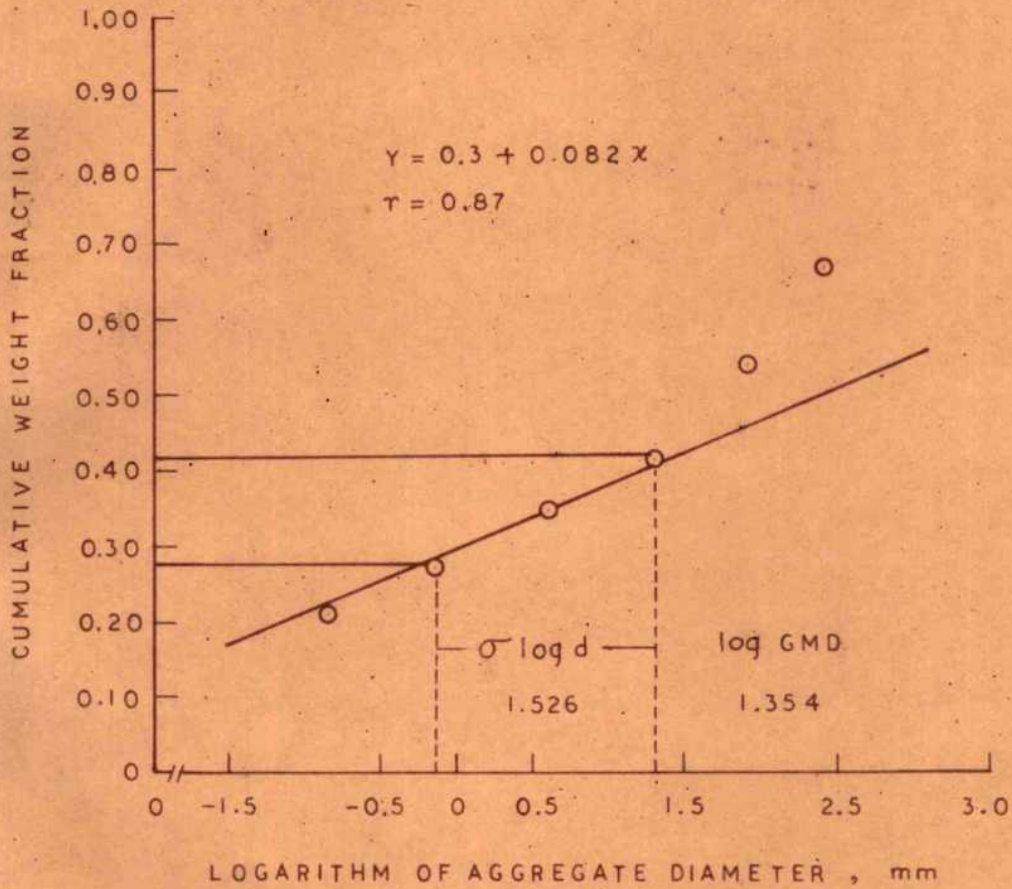


FIG.4.29 GRAPHICAL ILLUSTRATION OF DETERMINATION OF log GMD AND  $\sigma \log d$  FOR SELECTED AGGREGATE SAMPLE ( $T_2$ ) DURING 1971-72

## 4.8 Aggregates and Related Soil Physical Properties

### 4.8.1 Water retention

The data on water retention at 0.06 bar tension, bulk density and volume loss upon mixing are presented in Table 4.16. The results of water retention at 0.06 bar tension indicated that the tillage treatment which produced larger clods retained more moisture than the tillage practice producing smaller clods. Even though the water retained by weight was more in tillage induced larger clods than those producing smaller ones, there appears to be very less difference in the water retained on volumetric basis because the larger clods had the lesser bulk density which ultimately reduced its water content by volume while in case of rotary tiller producing smaller clods of which the bulk density was comparatively higher than the larger clods which ultimately increased water content on volume basis. Water retained at 0.06 bar tension varied significantly among the tillage treatments, there being no significant differences between disk and mouldboard (Table 4.16).

It is interesting to note that with decrease of  $\sigma \log d$  (Table 4.16) there was also a decrease in the quantity of water retained at 0.06 bar tension. Amemiya (1965) found differences of capillary conductivity in beds of mixture of aggregate-diameter separates when the suction moisture curves for these beds differed. Hence, alterations of interaggregate void space may also affect water movement relations in beds of aggregates in the row zone of tillage.

Table 4.16 Physical properties of soil aggregates as influenced by various tillage treatments (T)

Treatments	Mean weight diameter (MWD)	Geometric mean diameter (GMD)	Log GMD	Standard deviation of log d ( $\sigma \log d$ )	Weight fraction of water retained at 0.06 bar tension, by volume	Dry density of aggregate mixture (D <sub>B</sub> )	Dry density of aggregate mixture (cm <sup>3</sup> /100 cm <sup>3</sup> initial volume)
	mm	mm	mm	mm	cc	g cm <sup>-3</sup>	cm <sup>3</sup> /100 cm <sup>3</sup>
<b>1971-72</b>							
T <sub>1</sub>	9.198	5.458	1.691	1.636	0.223	1.12	21.28
T <sub>2</sub>	8.135	3.896	1.354	1.526	0.221	1.13	18.50
T <sub>3</sub>	5.762	2.933	1.072	1.488	0.209	1.15	16.36
T <sub>4</sub>	7.325	3.498	1.252	1.505	0.216	1.14	17.68
	**	**	**	**	**	**	**
S. Em ±	0.1493	0.1523	0.0368	0.0101	0.0009	0.0015	0.926
LSD <sub>0.05</sub>	0.457	0.469	0.113	0.031	0.003	0.005	2.85
LSD <sub>0.01</sub>	0.641	0.657	0.158	0.044	0.004	0.007	4.01
<b>1972-73</b>							
T <sub>1</sub>	9.524	5.202	1.649	1.721	0.243	1.11	23.43
T <sub>2</sub>	8.940	5.135	1.636	1.694	0.238	1.13	21.84
T <sub>3</sub>	5.221	4.133	1.419	1.547	0.204	1.16	16.51
T <sub>4</sub>	6.984	4.918	1.593	1.596	0.212	1.14	17.17
	**	**	**	**	**	**	**
S. Em ±	0.0367	0.0093	0.0325	0.0039	0.0016	0.0008	0.812

#### 4.8.2 Volume loss upon mixing

From the synthesised mixtures of aggregate-diameter separates, the volume loss upon mixing these aggregates was noted in the laboratory. It is evident from Table 4.16 that the volume loss upon mixing decreased with decreasing  $\sigma \log d$ . There was a greater decrease in volume loss with decreasing  $\sigma \log d$  at the smaller values of  $\log GMD$ . This clearly indicates that because of the smaller clods produced by rotary tiller in which inter-aggregate void space was much less compared to clods produced under disk and mouldboard which settled firmly and resulted in lesser loss of volume upon mixing. The maximum volume loss was noted under disk. The volume loss after mixing differed non-significantly among mouldboard, wedge and rotary tiller during 1971-72. However, during 1972-73, significant difference was noted between mouldboard and rotary tiller.

As the measurements of volume loss deal with interaggregate void space, the associated changes in bulk density;  $D_B$  were, therefore, brought about mainly by the changes in the interaggregate void space. A close inspection of Table 4.16 indicates a volume loss about 16 to 23  $\text{cm}^3/100 \text{ cm}^3$  initial volume. It is likely that there was more mixing of aggregate-diameter separates in the laboratory as compared to field conditions.

#### 4.8.3 Aggregate densities

The results of dry density of soil aggregate mixture presented in Table 4.16 reveal that the bulk density under disk and mouldboard was lower than wedge and rotary tiller. Although the density under rotary tiller was quite high, difference in

bulk density obtained by rotary tiller and wedge plough was little. The dry density of mixture varied between 1.12 to 1.14  $\text{g cm}^{-3}$ . All the tillage treatments differed significantly. The maximum density was noted under rotary tiller because of the smaller clods produced with its operation which helped close packing of the aggregates whereas in the case of disk and mould-board, the clods were bigger and because of more interaggregate void space, the packing was loose resulting in lower bulk density of mixture.

The results of particle density, density of individual aggregate and density of bulk volume of aggregates as indicated in Table 4.17 show that the aggregate density increased with the decrease in aggregate diameter. The aggregates of diameter 15.87 mm had the density of  $1.57 \text{ g cm}^{-3}$  while the smaller aggregates of 3.57 mm diameter possessed a density of  $1.63 \text{ g cm}^{-3}$ . Similarly density of bulk of aggregates varied from 0.76 to  $1.11 \text{ g cm}^{-3}$  for largest and smallest diameter respectively. But the particle density of the aggregates in the various size groups had nearly an uniform value of  $2.65 \text{ g cm}^{-3}$ . Thus it may be stated that the smaller aggregates were not as porous as those of larger diameter aggregates. The results are in agreement with the observations made by Wittmuss and Mazurak (1958), Larson (1964), and Allmaras *et. al.* (1965).

The significance of the aggregate-diameter distribution for describing packing arrangement was evaluated from the changes in bulk density;  $D_B$  (also from the volume loss upon mixing aggregate-diameter separates) as predicted by the changes in  $\log \text{GMD}$  and  $\sigma \log d$ . The larger values of  $\sigma \log d$  were expected for

Table 4.17 Bulk density, aggregate density and particle density of soil aggregates

Sieve classes	Bulk density g cm <sup>-3</sup>	Aggregate density g cm <sup>-3</sup>	Particle density g cm <sup>-3</sup>
<u>1971-72</u>			
I	0.76	1.57	2.64
II	0.82	1.60	2.65
III	0.83	1.62	2.64
IV	0.86	1.63	2.65
V	0.91	-	2.65
VI	0.95	-	2.64
VII	1.11	-	2.65
	**	**	**
S. Em ±	0.0021	0.0013	0.0017
LSD <sub>0.05</sub>	0.006	0.004	0.005
LSD <sub>0.01</sub>	0.009	0.006	0.007
<u>1972-73</u>			
I	0.80	1.57	2.65
II	0.85	1.61	2.66
III	0.87	1.62	2.65
IV	0.89	1.64	2.66
V	0.94	-	2.65
VI	1.04	-	2.65
VII	1.16	-	2.66
	**	**	**
S. Em ±	0.0047	0.0012	0.0021
LSD <sub>0.05</sub>	0.018	0.004	0.007
LSD <sub>0.01</sub>	0.025	0.005	0.009

\*\* significant at 1% level

larger values of log GMD. The larger values of log GMD and  $\sigma \log d$  (Table 4.16) were observed in disk and mouldboard than in wedge and rotary tiller. The change of  $D_B$  was observed concomitantly with changes in  $\sigma \log d$ . Some change in log GMD was also noted. These relations were examined more comprehensively. For each of 25 locations, the measurements of log GMD,  $\sigma \log d$  and  $D_B$  were taken. For a given location, the mean of each of the measurements was taken as a reference point. The equation based on these measurements as suggested by Allmaras *et. al.* (1965) was then used to predict the bulk density of soil under various tillage practices.

It is evident from Table 4.16 that each of both i.e. log GMD and  $\sigma \log d$  made only a linear contribution to  $D_B$ . The values of constants  $\beta_1$  and  $\beta_2$  were computed as suggested by Allmaras *et. al.* (1965) and the constants for this soil were found to be of interest in predicting the bulk density of the soil immediately after tillage operation. The equation, established, therefore, can be stated as :

$$\Delta(D_B) = \beta_1 [\Delta(\log \text{GMD})] + \beta_2 [\Delta(\sigma \log d)] \dots\dots$$

Allmaras *et. al.*, 1965

$$\Delta(D_B) = -0.66 [\Delta(\log \text{GMD})] + 1.34 [\Delta(\sigma \log d)]$$

Once the values of log GMD and  $\sigma \log d$  after tillage are known along with  $\beta_1$  and  $\beta_2$ , it is possible to predict the bulk density of cloddy surface immediately after tillage which in practice poses a serious problem of bulk density measurements.

## Part III

## Soil Bin Experiments

A laboratory study was conducted to evaluate the influence of bulk density, soil moisture content and speed of operation on tillage tool draft and cloddiness potential of the seedbed.

## 4.9 Clod Size Distribution

Table 4.18 shows clod size distribution as influenced by the combinations of the experimental variables, namely : bulk density, soil moisture and speed. It may be observed that higher percentage of clods larger than 50 mm diameter was recorded at the highest values of bulk density, soil moisture and speed ( $D_3M_2S_2$ ) closely followed by the treatment combination  $D_3M_2S_1$  thereby indicating the reduction in clod sizes with the decrease in speed from 1.25 to 0.25 m/sec. The data reveal that clod size distribution was affected by the change in bulk density of soil to a great extent. It is seen that the percentage of clods larger than 4.76 mm was less when the soil was tilled at 1.65 g cm<sup>-3</sup> initial bulk density compared to clods produced at the density of 1.79 and 1.85 g cm<sup>-3</sup> respectively.

It is evident from Fig.4.30 that the mean weight diameter of clods also increased with the increase in bulk density, soil moisture and speed. This indicates that when the soil was compacted to higher bulk density, the occurrence of larger clods dominated the soil surface thereby increasing surface roughness. However, this resultant larger clods induced higher draft as more energy was consumed in the process of lifting furrow slice

Table 4.18 Effect of bulk density, soil moisture and speed on clod size distribution

Treatments	Clod size distribution, per cent									
	>50.00 mm	50.00-25.00 mm	25.00-10.00 mm	10.00-4.76 mm	4.76-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	<0.50 mm		
D <sub>1</sub> M <sub>1</sub> S <sub>1</sub>	N11	8.87	20.26	9.20	12.05	26.63	10.50	12.48		
D <sub>2</sub> M <sub>1</sub> S <sub>1</sub>	N11	10.60	22.21	10.19	10.40	26.61	8.18	11.76		
D <sub>3</sub> M <sub>1</sub> S <sub>1</sub>	N11	21.52	24.20	11.30	8.69	15.82	7.36	10.93		
D <sub>1</sub> M <sub>1</sub> S <sub>2</sub>	N11	17.80	23.58	11.35	10.00	11.78	8.12	11.31		
D <sub>2</sub> M <sub>1</sub> S <sub>2</sub>	N11	33.34	18.89	6.65	9.42	14.70	6.71	10.26		
D <sub>3</sub> M <sub>1</sub> S <sub>2</sub>	5.60	23.28	25.81	6.79	7.27	15.03	5.80	9.82		
D <sub>1</sub> M <sub>2</sub> S <sub>1</sub>	N11	17.40	26.20	10.31	10.59	16.60	7.19	11.38		
D <sub>2</sub> M <sub>2</sub> S <sub>1</sub>	N11	39.50	24.39	7.88	7.62	9.19	5.31	6.05		
D <sub>3</sub> M <sub>2</sub> S <sub>1</sub>	20.00	26.10	20.81	7.69	6.21	8.93	4.48	5.53		
D <sub>1</sub> M <sub>2</sub> S <sub>2</sub>	N11	24.08	21.90	11.40	8.54	16.20	7.08	10.78		
D <sub>2</sub> M <sub>2</sub> S <sub>2</sub>	19.78	24.57	20.00	7.22	6.63	9.87	4.62	7.10		
D <sub>3</sub> M <sub>2</sub> S <sub>2</sub>	25.60	21.28	21.54	8.90	5.45	8.50	4.20	4.52		

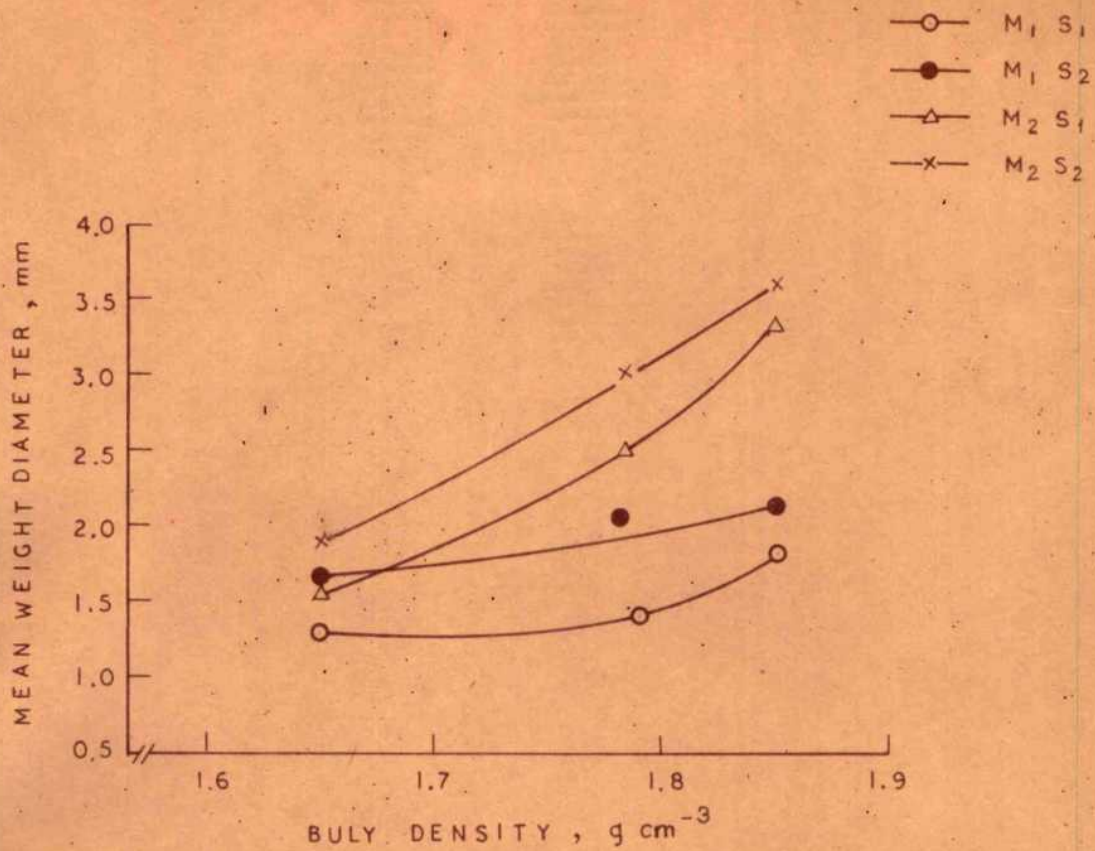


FIG.4.30 EFFECT OF BULK DENSITY, SOIL MOISTURE AND SPEED ON MEAN WEIGHT DIAMETER

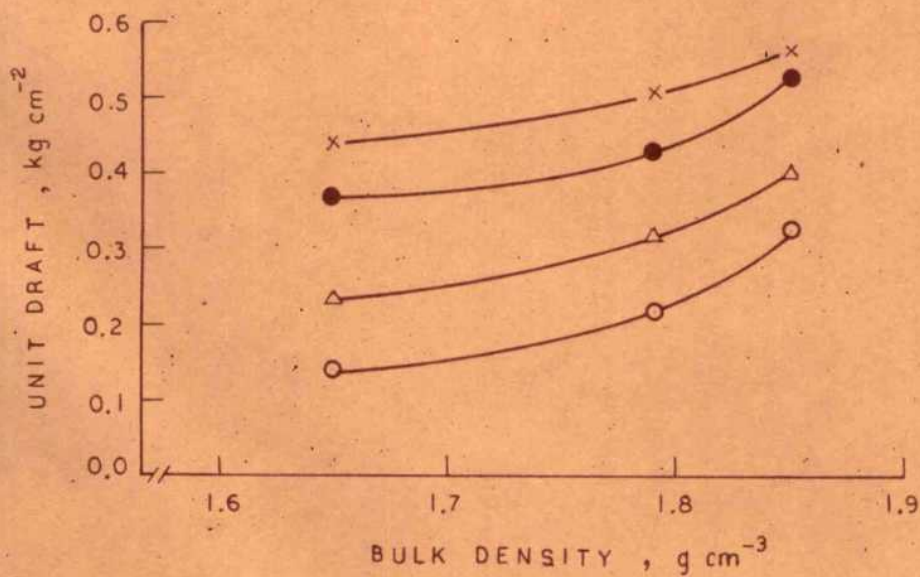


FIG.4.31 EFFECT OF BULK DENSITY, SOIL MOISTURE AND SPEED ON UNIT DRAFT

in such cases (Fig.4.31). The presence of larger clods indicates that the less work was done on the soil whereas more work was done on the tool. The results of Gill and McCreery (1960) also lend a support to this view. The soil fraction at lower values of bulk density, moisture content and speed was dominated with smaller clods. A close observation of Table 4.18 indicates that the clod size distribution of soil varied considerably under different treatments.

Maximum soil fracture was noted (Table 4.19) as the bulk density, moisture content and speed were increased from 1.65 to 1.85 g cm<sup>-3</sup>, 8.66 to 9.84 per cent and 0.25 to 1.25 m/sec respectively. Ideally we are interested in how much energy a tillage tool puts into fracturing the soil. The amount of soil fracture is difficult to estimate in a tillage experiment, but it can reasonably be argued from the data that fracture is proportional to the amount of new soil (clods) surface produced. Furthermore, it is seen from Table 4.19 that the energy or draft required to achieve a certain clod size is directly related to the new soil (clods) surface produced. Our objective, therefore, is to maximise soil fracture for a given input of draft. The maximum soil fracture was 3704 cm<sup>3</sup> which produced clods of 3.60 mm MWD and least soil break-up was noted as 2465 cm<sup>3</sup> which contained clods of 1.28 mm MWD. However, there was no significant difference among the soil fracture produced at higher moisture content and speed, but it was significantly lower compared to highest density (Table 4.20). Similarly the differences in soil density (1.79 g cm<sup>-3</sup>), moisture content (8.66 per cent) and speed (0.25 m/sec) were non-significant.

Table 4.19 Combination effect of bulk density, soil moisture and speed on draft, clod mean weight diameter(MWD) and soil fracture

Treatment combinations	Total draft	Unit draft	Mean weight diameter (MWD)	Soil fracture along 30 cm length of furrow
	kg	kg/cm <sup>2</sup>	mm	cm <sup>3</sup>
D <sub>1</sub> M <sub>1</sub> S <sub>1</sub>	6.00	0.136	1.28	2465
D <sub>2</sub> M <sub>1</sub> S <sub>1</sub>	9.75	0.222	1.39	2727
D <sub>3</sub> M <sub>1</sub> S <sub>1</sub>	14.25	0.325	1.77	3142
D <sub>1</sub> M <sub>1</sub> S <sub>2</sub>	16.25	0.369	1.65	2638
D <sub>2</sub> M <sub>1</sub> S <sub>2</sub>	19.00	0.432	2.06	2815
D <sub>3</sub> M <sub>1</sub> S <sub>2</sub>	23.25	0.528	2.14	2299
D <sub>1</sub> M <sub>2</sub> S <sub>1</sub>	10.00	0.227	1.60	2548
D <sub>2</sub> M <sub>2</sub> S <sub>1</sub>	14.00	0.318	2.52	3075
D <sub>3</sub> M <sub>2</sub> S <sub>1</sub>	17.50	0.398	3.35	3450
D <sub>1</sub> M <sub>2</sub> S <sub>2</sub>	19.25	0.437	1.91	3028
D <sub>2</sub> M <sub>2</sub> S <sub>2</sub>	22.25	0.506	3.03	3175
D <sub>3</sub> M <sub>2</sub> S <sub>2</sub>	25.25	0.561	3.60	3704

Table 4.20 Individual effect of bulk density, soil moisture and speed on draft, clod mean weight diameter (MWD) and soil fracture

Treatments	Total draft kg	Unit draft kg/cm <sup>2</sup>	Mean weight diameter (MWD) mm	Soil fracture along 30 cm length of furrow cm <sup>3</sup>
D <sub>1</sub>	12.87	0.292	1.61	2753.08
D <sub>2</sub>	16.25	0.370	2.25	2948.00
D <sub>3</sub>	19.81	0.453	2.72	3399.00
	**	**	**	**
S. Em ±	0.156	0.0053	0.033	48.984
LSD <sub>0.05</sub>	0.46	0.017	0.11	143.67
LSD <sub>0.01</sub>	0.62	0.023	0.13	195.28
M <sub>1</sub>	14.75	0.335	1.72	2903.22
M <sub>2</sub>	17.88	0.408	2.67	3163.50
	**	**	**	**
S. Em ±	0.127	0.0046	0.027	39.995
LSD <sub>0.05</sub>	0.37	0.014	0.09	117.31
LSD <sub>0.01</sub>	0.51	0.019	0.11	159.45
S <sub>1</sub>	11.92	0.271	1.99	2956.72
S <sub>2</sub>	20.71	0.472	2.40	3110.00
	**	**	**	**
S. Em ±	0.127	0.0046	0.027	39.995
LSD <sub>0.05</sub>	0.37	0.014	0.09	117.31
LSD <sub>0.01</sub>	0.51	0.019	0.11	159.45

\*\* significant at 1% level.

The influence of bulk density, moisture content and speed on clod mean weight diameter (MWD) and unit draft is presented in Table 4.20 and Fig.4.32. It is worth noting that each variable contributed significantly towards the variation in clod MWD. The highest MWD occurred under highest bulk density ( $1.85 \text{ g cm}^{-3}$ ) closely followed by highest moisture content (9.84 per cent) and higher speed (1.25 m/sec). The lower MWD was noted at low soil density ( $1.65 \text{ g cm}^{-3}$ ).

It is evident from Table 4.20 that the variation in draft due to bulk density, soil moisture and speed was highly significant. The relationship of bulk density with respective values of total draft, unit draft, clod MWD and soil fracture under various possible combinations of soil moisture and speed are given in Table 4.21. A positive correlation existed among all of them.

A shatter test was used to establish a relationship between the energy imparted to the soil and the degree of fragmentation. It is evident from Fig. 4.33 that the plotted data tend towards a straight line as the number of drops increases. An energy curve was prepared from the data secured in the drop-shatter tests. The distance of fall was found great enough to cause shatter of the soil and accumulated input energy from a given number of drops was plotted against the resultant clod size as shown in Fig.4.34. The relationship was taken as the characteristics of soil strength. It is observed that clod mean weight diameter (MWD) was inversely proportional to the equivalent energy input by dropping. The observations are in agreement with Gill and McCreery (1960).

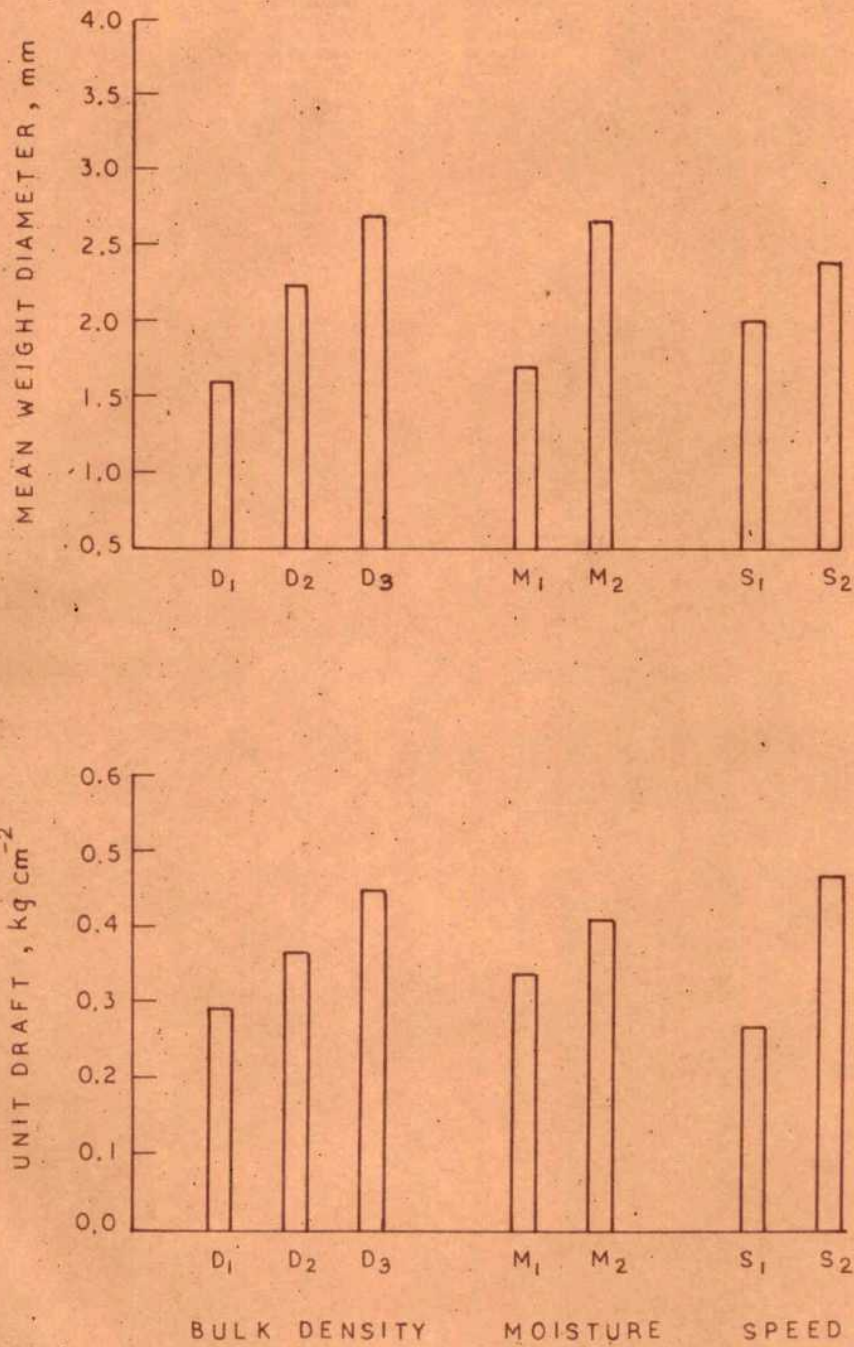


FIG.4.32 RELATIONSHIP BETWEEN MEAN WEIGHT DIAMETER AND UNIT DRAFT AS INFLUENCED BY BULK DENSITY, SOIL MOISTURE AND SPEED

Table 4.21 Relationship of bulk density with respective values of total draft, unit draft, unit draft, mean weight diameter (MWD) and soil fracture

Combination of M and S	Bulk density	Correlation value (r) and regression equation			
		Total draft, kg	Unit draft, kg/cm <sup>2</sup>	MWD, mm	Soil fracture, cm <sup>3</sup>
M <sub>1</sub> S <sub>1</sub>	D <sub>1</sub>	r = 0.96*	r = 0.96*	r = 0.86 NS	r = 0.94 NS
	D <sub>2</sub>	y = 38.69x-58.22	y = 0.88x-1.33	y = 2.16 x-2.32	y = 3117 x - 2718
	D <sub>3</sub>				
M <sub>1</sub> S <sub>2</sub>	D <sub>1</sub>	r = 0.94 NS	r = 0.94 NS	r = 0.99 **	r = 0.88 NS
	D <sub>2</sub>	y = 32.28x-37.42	y = 0.73x-0.85	y = 2.53x-2.52	y = 2943x-2273
	D <sub>3</sub>				
M <sub>2</sub> S <sub>1</sub>	D <sub>1</sub>	r = 0.98**	r = 0.98**	r = 0.98**	r = 0.99**
	D <sub>2</sub>	y = 35.92x-49.5	y = 0.82x-1.13	y = 8.36x-12.25	y = 4378x-4695
	D <sub>3</sub>				
M <sub>2</sub> S <sub>2</sub>	D <sub>1</sub>	r = 0.97**	r = 0.99**	r = 0.99**	r = 0.86 NS
	D <sub>2</sub>	y = 28.48x-27.97	y = 0.59x-0.55	y = 8.37x-11.91	y = 2971x-1937
	D <sub>3</sub>				

\*\* significant at 1% level \* significant at 5% level NS not significant

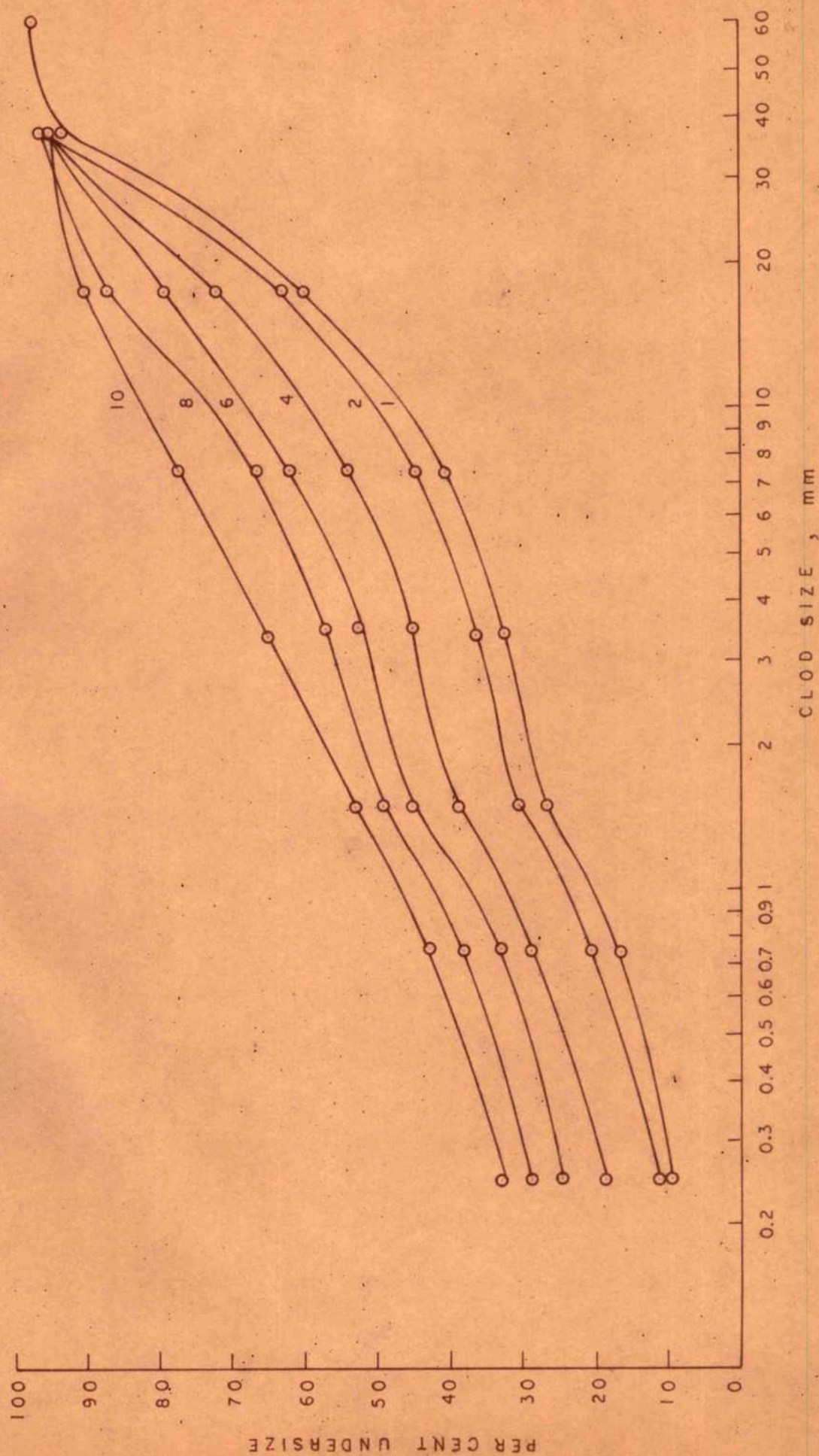


FIG.4.33 RELATION BETWEEN THE NUMBER OF TIMES CLOUDS ARE DROPPED AND THE CLOUD SIZE DISTRIBUTION

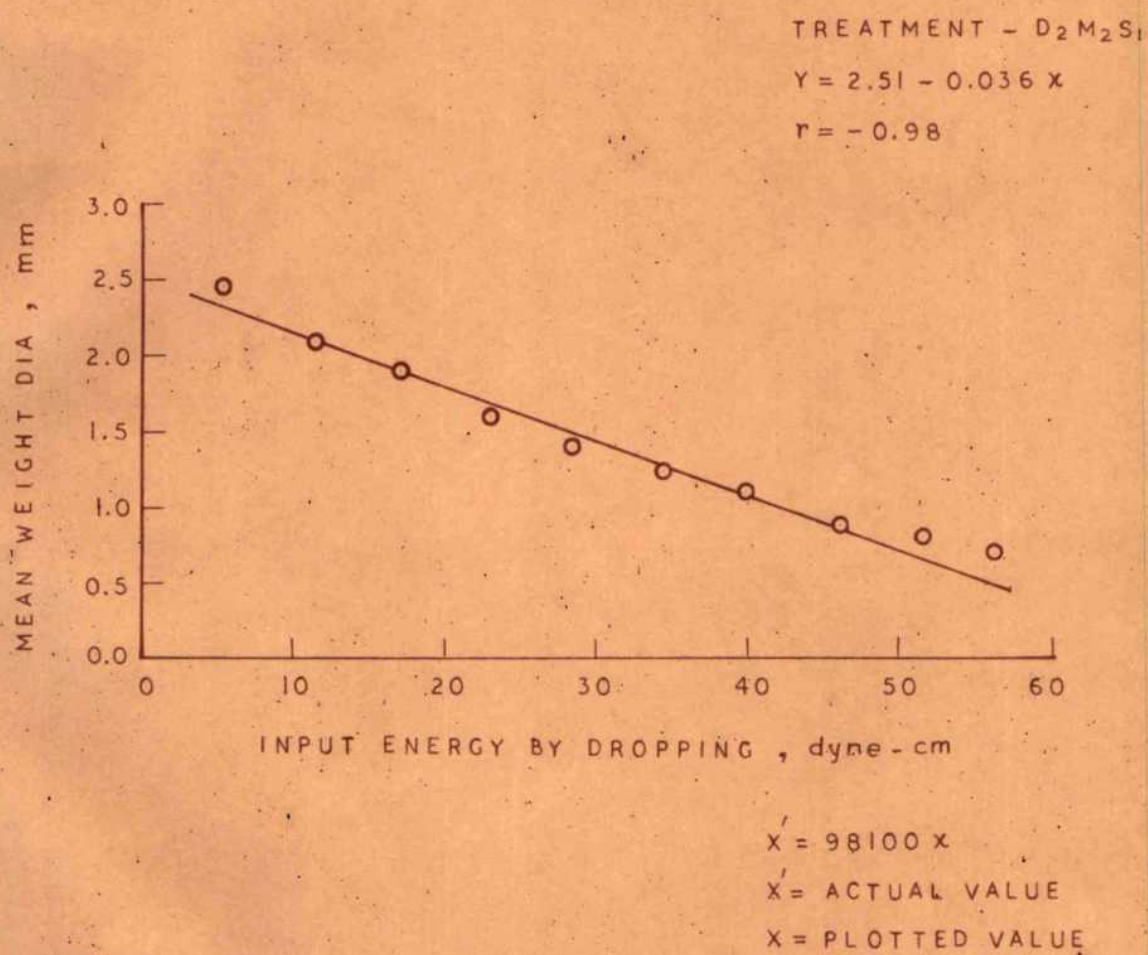


FIG.4.34 RELATIONSHIP BETWEEN THE INPUT ENERGY BY DROPPING AND THE RESULTANT SHATTERED CLOD SIZE

The relationship between cumulative drop height (CDH) and the resultant clod mean weight diameter (MWD) is given in Table 4.22. As expected, clod MWD decreased with repeated droppings in all the treatments. It shows that MWD was inversely proportional to the CDH. It is interesting to note that the clod MWD values at 1000 cm CDH was found to be more at higher bulk density under similar soil moisture and speed conditions. Low values of MWD were noted at lesser bulk density. This low value of clod MWD indicates that more work was done on the soil by repeated droppings. Higher values of MWD even after droppings at higher bulk density indicate that the clods produced in such cases possess greater mechanical stability than those produced at lower density. This increased mechanical stability is attributable to firm packing of the soil particles.

#### 4.10 Effect of Bulk Density on Draft

The packing force of the soil as applied by the weight of the roller during soil bed preparation changed the bulk density. It is evident from Fig.4.31 that every increase in bulk density was accompanied by the increase in unit draft at the same moisture content and speed. This relationship was nearly a straight line in all the cases. This increase in draft may be ascribed to the amount of resistance of soil to the forward movement of the tool. This is because of the firm packing of soil particles which requires more energy to break open the furrow. Under identical conditions of speed, the unit draft was found maximum in the order of 0.528 and 0.561 kg/cm<sup>2</sup> with 1.85 g cm<sup>-3</sup> bulk density at 8.66 and 9.84 per cent moisture content respectively, whereas it was minimum at the density of 1.65 g cm<sup>-3</sup>.

Table 4.22 Effect of cumulative drop height (CDH) on cloud mean weight diameter (MWD)

Cumulative drop height (CDH), cm	Mean weight diameter (MWD), mm											
	D <sub>1M1S1</sub>	D <sub>2M1S1</sub>	D <sub>3M1S1</sub>	D <sub>1M1S2</sub>	D <sub>2M1S2</sub>	D <sub>3M1S2</sub>	D <sub>1M2S1</sub>	D <sub>2M2S1</sub>	D <sub>3M2S1</sub>	D <sub>1M2S2</sub>	D <sub>2M2S2</sub>	D <sub>3M2S2</sub>
100	1.04	1.11	1.34	1.30	1.58	1.78	1.25	1.82	2.43	1.46	2.15	2.92
200	0.92	0.96	1.07	1.12	1.30	1.49	1.10	1.55	2.08	1.15	1.78	2.29
300	0.79	0.82	0.96	0.99	1.09	1.20	0.94	1.29	1.65	0.85	1.41	1.88
400	0.70	0.73	0.85	0.90	0.95	1.12	0.85	1.12	1.38	0.79	1.26	1.65
500	0.63	0.64	0.73	0.77	0.80	1.03	0.72	0.91	1.20	0.74	1.07	1.40
600	0.50	0.59	0.65	0.71	0.68	0.84	0.66	0.75	0.97	0.65	0.89	1.23
700	0.47	0.54	0.52	0.59	0.60	0.64	0.51	0.61	0.85	0.55	0.71	1.08
800	0.39	0.42	0.49	0.45	0.54	0.55	0.43	0.57	0.76	0.52	0.68	0.91
900	0.38	0.40	0.45	0.42	0.50	0.51	0.42	0.53	0.69	0.48	0.63	0.80
1000	0.35	0.36	0.39	0.39	0.43	0.48	0.38	0.51	0.62	0.41	0.58	0.68

#### 4.11 Effect of Moisture Content on Draft.

The data shown in Table 4.19 reveal that the draft increased with the increase in moisture content under identical conditions of bulk density and speed. The gradual increase in unit draft is clearly seen from Fig.4.31. Maximum unit draft was required at 9.84 per cent moisture content when the tool was operated at the speed of 1.25 m/sec and was found minimum at 8.66 per cent moisture content when the speed was 0.25 m/sec under the similar conditions of density of the soil bed. It is surprising to note that even though there was hardly a difference of about 1.18 per cent between two moisture contents, the variation in unit draft was remarkable (Table 4.20) between these two levels of soil moisture contents.

#### 4.12 Effect of Speed on Draft

The moisture content at which speed did not influence appreciably was slightly above the wilting point (Telischi *et. al.*, 1956). It was found that as the moisture content increased from 8.66 to 9.84 per cent, the slope of the line plotted in Fig.4.31 increased progressively under the similar conditions of bulk density. In the present investigations, the high speed selected was 1.25 m/sec which was 5 times higher than the low speed of 0.25 m/sec. It can reasonably be pointed out that though the time required for tillage operation was much less at high speed, the horizontal opposite forces acting on the tool coupled with the resistance of soil against the forward movement of the tool were also obviously higher which resulted in greater draft.

It can be seen from Fig.4.31 that unit draft varied due to two different operational speeds under the same moisture and density conditions. The trend of increase in unit draft was found to be uniform at 8.66 per cent moisture which varied greatly at 9.84 per cent moisture content. This shows that along with speed of operation, soil moisture content and bulk density play a significant role in draft requirement for fracturing the soil during tillage.

## Chapter V

### SUMMARY

Every crop has a range of soil physical environment that provides optimum conditions which may be achieved by various tillage practices. The crop grows simultaneously in two environments i.e. the atmospheric and soil environment. Agriculturist has little or no control over the former whereas it is possible to modify the latter to some extent to meet the requirement of crop. Therefore, agriculturists aim at providing such a soil environment which would provide most favourable condition for seedling emergence, vegetative growth and grain yield. It appears that for every crop, there exists an optimum range of soil edaphic factors for proper plant stand and growth. Once the optimum edaphic factors are known, it would not be very difficult to produce the same conducive condition through various soil management practices.

### Part I

#### Field Experiments

This research project was taken up on the Experimental Farm of Agricultural Engineering Department, Indian Institute of Technology, Kharagpur with the objective to develop suitable soil management practices for successful cultivation of wheat in this region wherein this crop has been recently introduced. Specific information on the basic need of wheat crop for optimum soil physical condition was sought through the present investigations in order to develop a wheat culture schedule.

Different soil conditions were provided in the field with various tillage implements (Table 3.3) which included disk, mould-board, wedge plough and rotary tiller. Soil edaphic factors were correlated with seedling emergence, root growth, various growth parameters and yield attributes in order to find out the most desirable soil physical environment for successful wheat growth. The edaphic factors such as soil aeration, moisture stress and penetration resistance were measured quantitatively at frequent intervals.

#### Seedling emergence

The seedling emergence was higher in untilled plot than in tilled plots. However, the emergence of seedlings was better or almost equal in plot tilled with rotary tiller as compared to untilled plot. Seedling emergence was greatly influenced by moisture stress. The higher percentage of seedling emergence was due to greater moisture availability. A highly significant correlation ( $r = -0.99$ ) was observed between matric suction and seedling emergence. The moisture depletion was very fast under disk and mouldboard due to very rough and broken soil surface. At the same time, due to presence of larger clods, the seed-soil contact was not proper, resulting in poor seedling emergence. The correlation of soil physical properties with clod size brings out the importance of soil structural relation on seedling emergence. The emergence of seedlings was better in the plots dominated with average size clods of 4 to 7 mm mean weight diameter.

### Growth and yield of wheat

The grain yield of crop depends on root and shoot growth. The straight line relationship with root weight indicates that root growth is vital for better harvest. Thus root is the vital part of growing plant which grows entirely in the rhizosphere of the soil. It is evident from highly significant correlation that better root proliferation increased the feeding zone and influenced the aerial parts and hence the yield of wheat. Therefore, root development and proliferation has maximum bearing on crop production. The grain yield of wheat was highly correlated with leaf area index and tillering ability of plants in the early growth phase. It was dependent on the number of fertile tillers, spike length and other yield attributing characters. The significant influence of edaphic factors was through their beneficial effect on root development, growth parameters and yield attributes.

The results clearly indicate that the yield of wheat was significantly higher in tilled plots than in untilled one. Among the soil management practices, disk and mouldboard proved superior to other treatments in their performance. The variation in performance of wheat crop in either seasons is obviously due to the changes brought about in soil environment by tillage. Better performance of wheat crop in tilled plots was attributed to increased root development which was favourably influenced by adequate aeration, lower penetration resistance and lower matric suction.

The bulk density and porosity of soil at various growth phases of wheat plant appear to have governed the edaphic factors. The better crop performance in plots of low bulk density was correlated with higher ODR, lower matric suction and lower penetration resistance. As discussed earlier, the wheat plant is very sensitive to aeration, moisture availability and soil strength. Since the ODR values were always higher than  $30 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ , it may be assumed that ODR was not the limiting factor in tilled plots. But the low ODR value, less than  $30 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$ , in untilled plot seems to have definitely affected the root development and performance of crop adversely.

The matric suction was significantly higher in untilled plot and plot tilled by rotary tiller than other treatments especially at the reproductive phase. The higher moisture stress during this peak moisture requirement phase of wheat appears to have affected the leaf development and production of fertile tiller, head per unit area, grains per head and finally the yield. However, higher porosity under mouldboard and disk, helped in storing water and plant did not suffer from moisture stress and therefore, the resultant grain yield was highest under them.

The curvilinear relationship of grain yield with leaf area index and number of tillers clearly indicates that yield can not go on increasing with increase in the above three factors, rather there lies an optima for an individual factor and combination of all, from the point of view of grain yield. It appears that in the agro-climatic region of West Bengal, wheat yield can be maximised if 19 to 24 tillers/30 cm drill bear heads.

It appears that edaphic factors are closely related to bulk density of soil. From the results, it is evident that bulk density of 1.35 - 1.40 g cm<sup>-3</sup> during vegetative growth phase provides conducive soil environment which produces the desired leaf area and number of tillers. At reproductive phase, the most conducive bulk density, however, would be 1.40 - 1.45 g cm<sup>-3</sup>. During grain formation phase, bulk density in the range of 1.45 - 1.50 g cm<sup>-3</sup> favours the maintenance of the most desired soil environment.

The above soil physical environment should be created by altering the soil structural relationship in such a way that would be conducive to produce the optimum number of tillers and leaf area index. Tillage practices make the soil loose, rough and cloddy. The direct relationship of clod size with bulk density leads to the conclusion that clod size is a single soil parameter to express soil structural changes which are responsible for variation in edaphic factors during the entire period of wheat. In the present investigations, the most conducive soil physical environment found to be created by the disk and mould-board plough in the seed beds of which the initial clod size was 11 to 12.50 mm MWD in lateritic soil of Kharagpur.

## Part II

### Physical Properties of Soil Aggregates

Four pre-plant tillage treatments, namely : disk, mould-board, wedge and rotary tiller were used to obtain different soil conditions. In a seed bed of aggregated soil, the average

aggregate diameter and the proportion having certain diameter limits may be modified somewhat by choice of tillage operation. The desired modification depends on the casual relations between aggregate-diameter distribution ( and geometrical arrangement ) and processes such as movement and retention of water, evaporation losses, seed-soil and root-soil contact. The size and arrangement of aggregates in soils has profound influence on the amount and configuration of the pore space which in turn governs air and water relations.

The significance of the aggregate-diameter distributions for describing packing arrangement was evaluated from the changes in bulk density ( also from the volume loss upon mixing aggregate-diameter separates ) as predicted by the changes in log GMD and  $\sigma \log d$ . The logarithm of geometric mean diameter (log GMD) and the dispersion of aggregate diameter ( $\sigma \log d$ ) changed differently depending on the tillage treatments and year of study. Large differences were noted in these measurements among tillage treatments. It is evident that bulk density increased among tillage treatments with the decrease in log GMD and  $\sigma \log d$ . The larger values of log GMD and  $\sigma \log d$  were noted under disk and mouldboard than under wedge and rotary tiller. The change of bulk density was observed concomitantly with changes in  $\sigma \log d$  and log GMD. The changes in bulk density were brought about mainly by the changes in interaggregate void space. The minimum density was noted under disk and mouldboard as compared to wedge and rotary tiller. The aggregate density increased as the diameter of aggregate decreased. The volume loss measurements also deal

with interaggregate void space, associated with bulk density. Maximum volume loss upon mixing the aggregate mixture was noted under disk and mouldboard whereas minimum under wedge and rotary tiller. In the laboratory, an increase in weight fraction of water was observed from increasing  $\sigma \log d$ . Therefore, it may be suggested that both  $\log GMD$  and  $\sigma \log d$  are measurable parameters of soil conditions in the beds of soil aggregates and may help explain soil water retention and movement, evaporation losses, seed-soil and root-soil contact. Furthermore, the change in bulk density can be predicted from clod size distribution. The values of  $\beta_1$  and  $\beta_2$  computed for this soil were found to be -0.66 and 1.34 respectively. By incorporating these values in the equation suggested by Allmaras *et. al.* (1965), it is interesting to find out the relationship between changes in bulk density from an aggregate size distribution determination.

### Part III

#### Soil Bin Experiments

The relationship between the draft requirement and some variables like bulk density, soil moisture and speed of operation was observed under laboratory conditions in order to study the draft requirements of a rectangular tillage tool and the resultant clod size distribution which serves as a single parameter for evaluation of soil physical conditions immediately after tillage.

Increase in draft was higher with the increase in bulk density, soil moisture and speed. The unit draft increased from

0.292 to 0.453, 0.335 to 0.408, and 0.271 to 0.472 as the bulk density, soil moisture content and speed were increased from 1.65 to 1.85 g cm<sup>-3</sup>, 8.66 to 9.84 per cent and 0.25 to 1.25 m/sec respectively (Table 4.20). Since moisture content and speed of operation can be monitored under field conditions, it may, therefore, be suggested that soil should be tilled at proper moisture content and speed. Maximum soil fracture was noted as the bulk density and moisture content were increased. It is seen that draft required to achieve a certain clod size is directly related to the resultant new soil surface. It is also evident that the clod mean weight diameter increased from 1.61 to 2.72, 1.72 to 2.67 and 1.99 to 2.40 mm as the bulk density, soil moisture content and speed were increased from 1.65 to 1.85 g cm<sup>-3</sup>, 8.66 to 9.84 per cent and 0.25 to 1.25 m/sec respectively (Table 4.20).

A shatter test was also used to establish a relationship between the energy imparted to the soil and the degree of fragmentation. It is observed that clod mean weight diameter (MWD) was inversely proportional to the equivalent energy input by dropping. Low value of clod MWD indicated that more work was done on the soil by repeated droppings.

## Chapter VI

## CONCLUSIONS

The following conclusions may be drawn from the present investigations :

1) the clod MWD may be regarded as a measure of the structural state of seedbed, that governs the soil physical properties at various growth phases;

2) the bulk density and total porosity, which are inter-related, have direct bearing on the edaphic factors, namely : soil water, aeration, and mechanical impedance;

3) the seedling emergence was very adversely affected if the seedbed was dominated by larger clods partly due to faster moisture depletion and partly due to improper seed-soil contact. The most conducive seedbed would be of clod size ranging from 4 to 7 mm MWD. Moisture availability to germinating seeds appears to be the most important limiting factor to seedling emergence under the agro-climatic condition of Kharagpur;

4) the grain yield was higher in disk and mouldboard than in wedge and rotary tiller. The yield was correlated with root growth, vegetative growth and yield attributes;

5) wheat plant was observed to be very susceptible to moisture stress at reproductive phase. Higher moisture stress (greater than 2.0 bar) during this critical phase reduced the number of fertile tiller, ear head per unit area, grains per ear head and finally the grain yield;

- 6) the ODR should always be maintained above  $50 \times 10^{-8} \text{ g cm}^{-2} \text{ min}^{-1}$  for proper root development and yield of grain;
- 7) the lower penetration resistance to 10 cm depth during vegetative phase (less than  $3.0 \text{ joules cm}^{-3}$ ) and reproductive phase (less than  $4.0 \text{ joules cm}^{-3}$ ) helped root proliferation and higher grain yield;
- 8) the significant higher grain yield at lower matric suction, lower penetration resistance and higher ODR, appeared to be due to beneficial effect of above factors on root and shoot growth;
- 9) the number of tillers/30 cm drill, leaf area index, and fertile tillers/30 cm drill should be in the range of 50 to 55, 5 to 6 and 19 to 24 respectively to have best results;
- 10) the most conducive and desirable soil physical environment for wheat under the agro-climatic conditions of Kharagpur could be obtained if the bulk density ranges from 1.35 to 1.40, 1.40 to 1.45 and 1.45 to 1.50  $\text{g cm}^{-3}$  during the vegetative, reproductive and grain formation phase respectively;
- 11) the above soil physical conditions at various growth phases may be obtained by tilling the land with disk and mould-board plough in the seedbeds of which the initial clod size was 11 to 12.50 mm MWD in lateritic soil of Kharagpur;
- 12) the logarithm of geometric mean diameter ( $\log \text{GMD}$ ) and the dispersion of aggregate-diameter separates ( $\sigma \log d$ ) are the

measurable parameters of soil conditions in the beds of aggregated soil and may help explain soil water retention and movement, seed-soil and root-soil contact;

13) the equation established for Kharagpur soil was :

$$\Delta(D_B) = -0.66 [\Delta(\log GMD)] + 1.34 [\Delta(\sigma \log d)]$$

The above equation gave the best results of the changes in bulk density that occurred under different tillage practices. Thus the changes in bulk density can be predicted from clod size distribution immediately after tillage;

14) the larger values of  $\log GMD$  and  $\sigma \log d$  were noted under disk and mouldboard than under wedge and rotary tiller. The bulk density increased with the decrease in  $\log GMD$  and  $\sigma \log d$ . The change of bulk density was observed concomitantly with changes in  $\log GMD$  and  $\sigma \log d$ . Volume loss upon mixing decreased with decreasing  $\sigma \log d$  and was inversely proportional to bulk density of aggregate mixtures. However, water retention at 0.06 bar tension increased with the increase in  $\sigma \log d$  and  $\log GMD$ . The aggregate density increased as the diameter of aggregate decreased;

15) the magnitude of increase in draft was higher with the increase in bulk density, soil moisture and speed. Minimum unit draft occurred at  $1.65 \text{ g cm}^{-3}$  bulk density and 8.66 per cent moisture content when the tool was operated at 0.25 m/sec speed;

16) clod MWD and soil fracture increased linearly with the increase in bulk density, soil moisture and speed. Presence of

larger clods indicated that less work was done on soil whereas more work was done on the tool resulting in greater draft. Fracture was proportional to the amount of new soil (clods) surface produced. Draft required to achieve a certain clod size was directly related to this resultant cloddy surface of soil. Furthermore, the clod MWD was inversely proportional to the equivalent energy input by droppings. Low value of MWD, in such cases indicated that more work was done on the soil by repeated droppings.

From the results of the present investigations, it appears that soil in this agro-climatic region should be tilled at 8 per cent moisture content with the speed of 0.25 m/sec (0.9 km/hr) in order to produce the soil condition desirable for wheat growth and maximization of yield. This results in maximum fracture of the soil with minimum draft and yet help create initial clod size which is conducive for the best performance of wheat.

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## APPENDICES

## APPENDIX A

Summary of analysis of variance of data presented in Table 4.2

Sources of variation	df	Mean sum of squares		
		Clod mean weight diameter (MWD) mm	Bulk density g cm <sup>-3</sup>	Total porosity cm/10 cm
<u>1971-72</u>				
Blocks	4	0.22	0.006	0.32
Tillage	3/4	79.65	0.299	48.34
Error	12/16	3.912	0.0082	0.375
<u>1972-73</u>				
Blocks	4	0.11	0.009	0.78
Tillage	3/4	67.45	5.572	31.86
Error	12/16	0.027	0.0071	1.893

APPENDIX B

Summary of analysis of variance of data presented in Tables 4.3 and 4.4

Sources of variation	df	Mean sum of squares							
		Bulk density, g cm <sup>-3</sup>			Total porosity, cm/10 cm				
		Vegetative phase	Reproductive phase	Post harvest phase	Vegetative phase	Reproductive phase	Post harvest phase		
<b>1971-72</b>									
Blocks	4	0.005	0.006	0.02	0.006	1.87	0.94	0.44	0.79
Tillage	4	0.07	0.05	0.04	0.04	9.68	3.67	2.98	3.32
Error	16	0.002	0.003	0.014	0.005	0.423	0.379	0.125	0.283
<b>1972-73</b>									
Blocks	4	0.0007	0.005	0.0005	0.007	1.74	0.99	0.24	0.44
Tillage	4	0.08	0.06	0.05	0.04	10.99	4.43	5.35	3.78
Error	16	0.0004	0.003	0.0002	0.005	0.088	0.094	0.042	0.068

APPENDIX C

Summary of analysis of variance of data presented in Tables 4.5 and 4.7

Sources of variation	df	Mean sum of squares								
		Matric suction, bar	Vegetative phase	Reproductive phase	Grain formation phase	Seedling emergence stage	Vegetative phase	Reproductive phase	Grain formation phase	
<b>1971-72</b>										
Blocks	4	0.02	0.07	0.13						
Tillage	4	0.36	2.08	0.89						
Error	16	0.004	0.053	0.098						
<b>1972-73</b>										
Blocks	4	0.02	0.05	0.98	0.13	0.24	0.46	0.15		
Tillage	4	0.25	2.95	1.08	3.64	14.66	18.98	18.69		
Error	16	0.007	0.039	0.237	0.081	0.022	0.066	0.059		

## APPENDIX D

Summary of analysis of variance of data presented in Table 4.6

Sources of variation	df	Mean sum of squares							
		Seedling emergence stage		Vegetative phase		Reproductive phase		Grain formation phase	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
Blocks	4	0.46	0.12	0.29	0.09	0.03	0.05	0.87	0.23
Tillage	4	37.96	9.49	37.38	7.48	29.32	7.36	25.48	6.87
Error	16	0.655	0.098	0.059	0.064	0.022	0.047	0.563	0.142

Infiltration rate,  
cm/hr

APPENDIX B

Summary of analysis of variance of data presented in Tables 4.8 and 4.9

Sources of variation	df	Mean sum of squares								
		ODR, $10^{-8}$ g $cm^{-2}$ $min^{-1}$	Vegetative phase	Reproductive phase	Grain formation phase	Seedling emergence stage	Vegetative phase	Reproductive phase	Grain formation phase	Post harvest
<b>1971-72</b>										
Blocks	4	5.04	3.65	4.53	3.75	1.52	1.82	2.27	1.29	1.29
Tillage	4	1892.06	1233.88	1007.87	739.82	315.48	272.63	237.32	101.21	101.21
Error	16	1.250	3.593	1.893	3.031	0.854	1.793	0.947	1.165	1.165
<b>1972-73</b>										
Blocks	4	10.86	7.26	3.98	4.18	2.06	1.63	3.78	1.19	1.19
Tillage	4	1897.56	1285.59	1033.33	798.64	288.89	145.54	187.34	100.74	100.74
Error	16	8.921	6.359	1.396	2.582	1.256	1.596	1.963	0.987	0.987

APPENDIX F

Summary of analysis of variance of data presented in Table 4.10

Sources of variation	df	Mean sum of squares													
		Vegetative phase				Reproductive phase				Grain formation phase				At harvest	
		5 cm	10 cm	15 cm	5 cm	10 cm	15 cm	5 cm	10 cm	15 cm	5 cm	10 cm	15 cm	5 cm	10 cm
<b>1971-72</b>															
Blocks	4	0.18	0.83	1.06	0.02	0.19	0.18	0.02	1.05	1.13	0.04	1.28	2.17		
Tillage	4	1.07	9.71	15.49	0.79	6.39	10.64	0.42	7.63	18.85	0.24	4.38	15.23		
Error	16	0.037	0.216	0.978	0.005	0.046	0.032	0.003	0.483	0.40	0.02	0.485	1.008		
<b>1972-73</b>															
Blocks	4	0.13	0.84	1.04	0.04	0.13	0.13	0.02	0.90	0.99	0.04	1.25	0.99		
Tillage	4	1.06	9.72	15.44	0.82	6.33	10.75	0.41	7.64	19.20	0.20	5.19	14.13		
Error	16	0.022	0.218	0.893	0.017	0.013	0.029	0.004	0.427	0.283	0.019	0.128	0.573		

## APPENDIX G

Summary of analysis of variance of data presented in Table 4.12

Sources of variation	df	Mean sum of squares				
		Maximum plant height cm	Maximum tiller/ 30 cm drill	LAI	Maximum dry matter /30 cm drill g	Straw yield kg/ha
<b>1971-72</b>						
Blocks	4	7.50	12.20	0.13	10.83	10.76
Tillage	4	116.92	297.34	12.53	1316.72	1280.92
Error	16	1.253	9.39	0.047	7.128	8.285
<b>1972-73</b>						
Blocks	4	4.79	10.14	0.17	7.74	13.52
Tillage	4	678.50	677.14	11.47	1304.87	1680.63
Error	16	3.181	6.821	0.078	4.528	4.869

## APPENDIX H

Summary of analysis of variance of data presented in Table 4.13

Sources of variation	df	Mean sum of squares				
		Number of fertile tillers/ 30 cm drill	Spike length  cm	Number of grains per spike	1000 grain weight  g	Grain yield  kg/ha
<u>1971-72</u>						
Blocks	4	5.06	0.19	8.26	1.61	42.75
Tillage	4	81.26	6.53	167.66	32.16	368.74
Error	16	0.485	0.127	1.852	0.987	16.382
<u>1972-73</u>						
Blocks	4	4.98	0.13	7.09	4.49	65.92
Tillage	4	84.16	6.07	177.69	30.38	474.85
Error	16	1.008	0.097	2.518	0.998	38.532

## APPENDIX I

Summary of analysis of variance of data presented in Table 4.14

Sources of variation	df	Mean sum of squares							
		Root length, cm			Root weight, g				
		Seedling stage	Vegetative stage	Reproductive phase	Seedling stage	Vegetative stage	Reproductive phase	Grain formation phase	
<b>1971-72</b>									
Blocks	4	0.48	0.76	1.87	4.69	1.42	1.78	0.98	0.94
Tillage	4	37.98	38.86	128.45	272.63	75.85	148.38	218.27	233.12
Error	16	0.621	0.596	0.548	0.105	0.587	1.689	0.628	0.263
<b>1972-73</b>									
Blocks	4	0.86	0.36	2.47	1.18	0.72	1.57	1.19	0.62
Tillage	4	35.44	37.28	136.16	190.17	76.29	151.11	234.13	264.76
Error	16	0.663	0.589	0.421	0.125	0.561	1.799	0.543	0.685

APPENDIX J

Summary of analysis of variance of data presented in Table 4.16

Sources of variation	df	Mean sum of squares						
		Mean weight diameter (MWD) mm	Geometric mean diameter (GMD) mm	log GMD mm	Standard deviation of log d ( $\sigma$ log d) mm	Weight fraction of water retained at 0.06 bar tension, by volume, cc	Dry density of aggregate (DB) g cm <sup>-3</sup>	Dry density upon mixing (initial volume) cm <sup>3</sup> /100 cm <sup>3</sup>
<b>1971-72</b>								
Blocks	4	0.34	0.16	0.007	0.002	0.0017	0.0002	0.51
Tillage	3	10.48	5.85	0.38	0.22	0.033	0.008	21.57
Error	12	0.112	0.117	0.006	0.0006	0.0003	0.00014	0.427
<b>1972-73</b>								
Blocks	4	0.23	0.07	0.003	0.002	0.003	0.0002	0.14
Tillage	3	19.19	1.21	0.56	0.34	0.018	0.005	58.35
Error	12	0.067	0.04	0.0005	0.0007	0.0002	0.00018	0.083

APPENDIX K

Summary of analysis of variance of data presented in Table 4.20

Sources of variation . df	Mean sum of squares				Soil fracture along 30 cm length of furrow cm <sup>3</sup>
	Total draft kg	Unit draft kg/cm <sup>2</sup>	Mean weight diameter (MWD) mm		
Blocks 2	0.214	0.0000054	0.000025		28792.00
Bulk density 2	144.423	0.078	3.696		211460.00
Soil moisture 1	87.891	0.048	8.208		609710.00
Speed 1	695.641	0.365	1.550		27775.00
<u>Interactions</u>					
Density x Moisture 2	4.594	0.002	2.315		16322.00
Density x Speed 2	2.641	0.001	0.0736		9500.00
Moisture x Speed 1	4.515	0.002	0.027		140720.00
Moisture x Speed x Density 2	0.391	0.00009	0.0016		87050.00
Error 22	0.2908	0.0000039	0.000134		13172.00

## APPENDIX L

Correlation coefficient between grain yield, yield attributes and soil edaphic factors during 1971-72

Characters	Grain yield	Fertile tillers	Dry matter	LAI	Tiller/30 cm drill	Root weight
1000 grain wt.	0.33					
Grain /spike	0.93					
Spike length	0.99					
No.of fertile tillers	0.96					
Dry matter/30 cm drill	0.98					
LAI	0.97	0.98	0.99			
Tiller/30 cm drill	0.99	0.99	0.98	0.99		
Root weight	0.99	0.96	0.99	0.98	0.97	
ODR vegetative		0.89	0.96	0.95	0.96	0.98
ODR reproductive	0.94	0.85	0.95	0.92	0.89	0.96
ODR grain formation	0.92	0.85	0.93			
Matric suction						
vegetative		-0.93	-0.96	-0.98	-0.89	-0.94
reproductive	-0.99	-0.93	-0.98	-0.97	-0.96	-0.94
grain formation	-0.99	-0.98	-0.97			
Penetration resistance						
15 cm vegetative			-0.92	-0.89	-0.84	-0.91
reproductive	-0.97	-0.89	-0.96	-0.94	-0.92	-0.98
grain formation	-0.97	-0.88	-0.95			
10 cm vegetative			-0.92	-0.89	-0.84	-0.90
reproductive	-0.93	-0.85	-0.94	-0.92	-0.86	-0.92
grain formation	-0.93	-0.87	-0.95			
5 cm vegetative			-0.93	-0.91	-0.86	-0.92
reproductive	-0.95	-0.90	-0.96	-0.95	-0.91	-0.96
grain formation	-0.96	-0.92	-0.98			
Bulk density						
vegetative	-0.94	-0.93	-0.97	-0.92	-0.88	-0.92
reproductive	-0.97	-0.95	-0.98	-0.98	-0.97	-0.99
grain formation	-0.94	-0.95	-0.97			
Total porosity						
vegetative	0.99	0.93	0.99	0.98	0.97	0.99
reproductive	0.98	0.94	0.99	0.98	0.96	0.98
grain formation	0.98	0.93	0.98			

## APPENDIX M

Correlation coefficient between grain yield, yield attributes and soil edaphic factors during 1972-73

Characters	Grain yield	Fertile tillers	Dry matter	LAI	Tiller/30 cm drill	Root weight
1000 grain wt.	0.55					
Grain/spike	0.94					
Spike length	0.99					
No.of fertile tillers	0.98					
Dry matter/30 cm drill	0.98					
LAI	0.96	0.97	0.99			
Tiller/30 cm drill	0.99	0.93	0.96	0.95		
Root weight	0.99	0.95	0.98	0.98	0.98	
ODR vegetative		0.89	0.97	0.94	0.91	0.97
ODR reproductive	0.94	0.87	0.95	0.93	0.93	0.96
ODR grain formation	0.92	0.83	0.92			
Matric suction						
vegetative		-0.94	-0.98	-0.96	-0.94	-0.92
reproductive	-0.99	-0.91	-0.96	-0.96	-0.98	-0.99
grain formation	-0.94	-0.94	-0.99			
Penetration resistance						
15 cm vegetative			-0.91	-0.89	-0.88	-0.92
reproductive	-0.96	-0.88	-0.96	-0.95	-0.96	-0.98
grain formation	-0.96	-0.88	-0.95			
10 cm vegetative			-0.92	-0.91	-0.86	-0.91
reproductive	-0.92	-0.85	-0.96	-0.95	-0.86	-0.92
grain formation	-0.93	-0.86	-0.95			
5 cm vegetative			-0.94	-0.92	-0.88	-0.96
reproductive	-0.95	-0.90	-0.97	-0.96	-0.92	-0.93
grain formation	-0.95	-0.90	-0.97			
Bulk density						
vegetative	-0.91	-0.86	-0.94	-0.96	-0.96	-0.95
reproductive	-0.94	-0.90	-0.97	-0.95	-0.93	-0.96
grain formation	-0.95	-0.89	-0.96			
Total porosity						
vegetative	0.70	0.96	0.99	0.98	0.96	0.99
reproductive	0.96	0.94	0.98	0.99	0.92	0.97
grain formation	0.97	0.94	0.99			