EFFECT OF CULTIVATION ON MINERALIZATION OF ORGANIC MATTER IN SOIL

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By
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CERTIFICATE

This is to certify that the thesis entitled "EFFECT OF CULTIVATION ON MINERALIZATION OF ORGANIC MATTER IN SOIL" submitted in the partial fulfilment of the requirements for the degree of Doctor of Philospphy in Soil Science of the College of Post Graduate Studies, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, is a record of bona fide research carried out by Miss. T. Kausalya, I.D.No. 6109, under my supervision and no part of thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

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We, the undersigned members of the Advisory Committee of Miss. T. Kausalya, I.D.No. 6109, a candidate for the degree of Doctor of Philosophy with a major in Soil Science, agree that the thesis entitled "EFFECT OF CULTIVATION ON MINERALIZATION OF ORGANIC MATTER IN SOIL", may be submitted by Miss. T. Kausalya in partial fulfilment of the requirement of the degree.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS AND ABBREVIATIONS

N	Nitrogen
P	Phosphorus
K	Potassium
C	Carbon
S	Sulfur
Al	Aluminium
Cu	Copper
Zn	Zinc
$NaNO_3$	Sodium Nitrate
KNO_3	Potassium nitrate
$CaSO_4$	Calcium sulfate
$CHCl_3$	Chloroform
PVA	Polyvinyl alcohol
MCPA	4-Chloro-2-methyl phenoxy acetic acid
2,4-D	2,4-dichloro-phenoxy acetic acid
Paraquat	1,1'- dimethyl -4,4' bipyridilium
Brom	Bromoxynil 3, 5-dibromo-4-hydroxy benzo-nitrite)
APAU	Andhra Pradesh Agricultural University
IARI	Indian Agricultural Research Institute
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
SAT	Semi-Arid Tropics

GBPUA&T	Govind Ballabh Pant University of Agricult and Technology
TNAU	Tamil Nadu Agricultural University
PME	Permanent Manurial Experiment
CO_2	carbon dioxide
kg/ha	kilograms per hectare
µg/g	micrograms per gram
lb/acre	pounds per acre
W/W	weight by weight
W/V	weight by volume
pH	negative logarithm of hydrogen ion activity
ppm	parts per million
EC	Electrical conductivity
Conc	concentration
NH_4-N	ammonium-nitrogen
NO_3-N	nitrate-nitrogen
max	maximum
min	minimum
°C	degree celsius
ZC	Zero cultivation
SC	Shallow cultivation
DC	Deep cultivation
BF	Broadbed-and-furrow system
FYM	Farm yard manure
S.E	Standard error

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INTRODUCTION

The organic matter contents of tropical soils are low and decline rapidly under continuous cultivation. The implications for the nitrogen nutrition of crops are considerable, because organic matter is the main source of mineral nitrogen for many cereal crops throughout the semi-arid tropics (SAT).

In traditional agricultural systems, the local cereal varieties had a low demand for N because they had a low yield potential. However, introduction of improved cultivars with a much higher yield potential has caused substantial increases in the amount of nitrogen required by a crop. This requirement cannot be met by the amounts of N mineralized from the soil organic matter each year. As a result, improved cultivars will only attain a high yield if additional nitrogen is supplied. The yield increases are large but so are the amounts of nitrogen required; yields may be doubled or tripled with the use of 50-100 kg N/ha on rainfed crops (Venkateswarlu, 1979; ICRISAT, 1979).

The cost of fertilizer is a constraint that severely reduces fertilizer use on the rainfed food crops as the farmers are traditionally very conservative. Several obvious questions arise: What are the rates of organic matter decomposition in Indian soils? Does cultivation substantially affect these? If so, how? Can the decomposition rate be manipulated by cultivation, or other means, to improve the efficiency of use of this resource by the farmer?

Many aspects of the organic matter build-up and mineralization in soil are not well understood, especially for tropical soils. For example, there has been some controversy as to whether tropical soils contain less organic matter than temperate soils (Sanchez, 1982), and if so, what are the causes for the low organic matter in these soils. Causes proposed are the higher rates of decomposition of soil organic matter in the tropics, primarily due to effects of higher soil temperatures on microbial activity (e.g Jenny and Raychaudri,1960) and lower amounts of organic matter added to soil each year by crops in the tropics (Bartholomew, 1972). These factors may not be easily manipulated.

But cultivation is one factor known to promote organic matter decomposition, and it would seem that some cultivation techniques can be manipulated by the farmer. Studies on the effect of cultivation and types of cultivation on organic matter breakdown are needed. There are no data for India in this field. Decomposition rate constants (k) have not been reported for soils of the Indian semi-arid tropics, although there are a number of estimates made for other tropical areas (Jones, 1975). A number of long-term experiments have been conducted in India, and these need to be examined to determine whether sufficient base-data has been collected to permit calculation of 'k' values.

Almost all of the few experiments that have been conducted on the effects of cultivation and minimum cultivation have not reported the effects of cultivation on nitrogen transformations in soil. Therefore, it was necessary to conduct experiments to investigate the effect of cultivation on N mineralization as part of these studies.

The two main areas therefore chosen for study **were** :

i) Examination of data from long-term experiments in India to calculate decomposition rates of the organic matter.

ii) Studies of the effects of cultivation on yields and soil properties (especially decomposition) in a series of experiments:

   a) Effect of cultivation before seeding on nitrogen accessibility to a cereal crop
   b) Effect of cultivation after seeding on nitrogen accessibility to a cereal crop
   c) Effects of cultivation before seeding on response to nitrogen fertilizer
   d) Effect of soil crusting on nitrate movement in soil and
   e) Effect of bed and furrow cultivation on organic matter levels in soil.

II. REVIEW OF LITERATURE

II.1. SOIL ORGANIC MATTER - A DYNAMIC SYSTEM

Organic matter is a heterogenous array of different compounds. It consists of materials ranging from undecomposed plant and microbial residues, and intermediate stages of decomposition of these, to a dark material which has no structural resemblance of the original plant or microbial material. This final dark colored material, which is regarded as the final product of decomposition, is usually termed humus; it represents the bulk of the organic matter in soil (Russell,1973).

Characterization of the chemical components and structure of soil humus has been severely hindered by the difficulties of separating it from the soil mineral fraction without decomposition. Many studies have shown that there is a large range of component molecules of polysaccharides, amino-acids, phenols, hemicelluloses, nucleic acids, phytates etc. (Russell, 1973, Jenkinson, 1971). However, these chemical studies have provided only limited information on how organic matter releases its constituent elements, and, in particular, how it mineralizes nutrients such as N,P and S for plant growth.

Recent studies on the decomposition of organic matter have provided much useful information that is more relevant for understanding the behaviour of organic matter in soils *in situ*. From these studies

(Jenkinson, 1971), it has been shown that the best conceptual approach is to consider organic matter in soil to consist of a number of categories of material with different decomposition rates. Freshly added plant material decomposes most rapidly, at first. The sugars, amino acids, other water soluble materials decompose within a few weeks of the incorporation of plants. Over half of the original material added may be decomposed within 6 weeks. In contrast, the most resistant materials, e.g. lignin, take many years to decompose (Jenkinson, 1971).

According to Jenkinson's model, as the original plant material is being attacked and decomposed, it is incorporated into the microbial cells. These constitute the biomass in soil. Because soil microorganisms generally have a short generation time, the biomass has also only a short life. Thus the decomposition of residues involves not only the breakdown of organic components by microbes, but also the almost simultaneous appearance of debris of microbial cells (protoplasm and cellwall constituents etc.) which is then available for further microbial attack. By use of ^{14}C- labelled plant material, Jenkinson (1971) has shown that 10% of the original plant carbon was in living microbial cells 1 year after addition, and 4% after 4 years.

There is a continual, although slow, addition of organic materials to the soil humus via microbial activity, and there is also slow microbial attack on this material (Jenkinson, 1971). However, the half-life is of the order of hundreds of years. For convenience, Jenkinson (1971) has subdivided this material into chemically resistant and physically inaccessible to attack.

Thus soil organic matter consists of a large bulk of humified organic matter which decomposes slowly. It also increases slowly. The other "pools" of organic matter in the soil - plant residues and microbial biomass - are very much smaller; but, because their decomposition or turnover rate is so much faster, these two pools contribute significantly to the overall decomposition rates of organic matter in soil. More important, they contribute to the soil mineralizable-N pool.

II.2 FACTORS AFFECTING ORGANIC MATTER DECOMPOSITION

II2.1 Temperature

Jenny (1930, 1941) observed an inverse relationship between mean annual temperature and the nitrogen content of Canadian soils. The effect of temperature was consistent with the Vant' Hoff temperature rule; the soil N content increased 2-3 times for each $10^{o}C$ decrease in the mean annual temperature. For reactions in soil, this rule applies fairly generally because the reactions are caused by microbial activity; there are only some limitations, e.g. the activity of the micro-organisms will diminish at excessively high temperatures.

The higher rate of organic matter decomposition in tropical soils is partly the result of the prevailing higher soil temperatures (Jenny, 1941). Bartholomew (1972) emphasised that temperature is the primary factor which influences the mineralization of soil organic nitrogen. Annual rates of mineralization were found to be larger in hotter than cooler climates (Jenny, 1949); the absence of a cold season permitted mineralization to proceed throughout the year whenever moisture is not limiting.

Nitrification ceases at 45°C, but ammonification continues over a considerable range of temperatures above 35°C. (Harmsen and Kolenbrander, 1965). There is however, some uncertainty over the optimum temperature for ammonification. Justice and Smith (1962) and Alexander (1965) state that the optimum temperature for ammonification under steady state temperature conditions is between 25°C and 35°C. Jenny's (1930) findings were substantiated by Stanford _et al_. (1973a) who found in the temperature range 5-35°C, the temperature coefficient for mineralization was $Q_{10} = 2$ for diverse soils of the USA. Stanford _et al_. (1973b) found close correspondence between A-values for soil N and amounts of N mineralized under fluctuating greenhouse tempereautes when the latter were calculated using Q_{10} derived from incubations at constant temperatures.

The present concept of organic matter decomposition (N mineralization) - temperature relations in soils based primarily on laboratory studies conducted at constant temperatures (Campbell, 1976). Under field conditions, marked diurnal fluctuations occur; the results of Stanford _et al_. (1973a, 1975) however, could be extrapolated to quantify the contribution of temperature to N mineralization under field conditions. The fact that fluctuating temperatures tend to retard nitrification (temporarily) should not limit nutrient availability as plants can use NH_4-N as well as NO_3-N (Campbell, 1976).

Moureaux (1967) in Senegal, Africa pointed out that the temperatures of surface soil may exceed 50°C. Soil biological activity was severely limited at this temperature partly because of lack of moisture at this time. The onset of rains improved the soil moisture status at this temperature level and thus causing a **surge** of microbial activity. Moureaux (1967) reported that maximum ammonification occurred at about 50°C in the more northern arid soils of northern Senegal but only at about 35°C in the moister, slightly ferralitic soil in the south. A similar adaptation to the local conditions was also obtained for nitrification but in all soils this activity diminished markedly above 40°C (Moureaux, 1967).

II.2.2 Moisture

The effect of soil moisture on the rate of organic matter decomposition is a function of chemical physical and biological processes (Campbell, 1976). For example, moisture affects ammonification, nitrification, leaching and immobilization of nitrates etc. (Campbell, 1976). The most intensive decomposition occurs under irrigated conditions. For example in the U.S.S.R., irrigated serozems supporting a row crop of cotton lost 53% of their total organic matter in 3 to 5 years; in contrast, losses from the drier chernozems and chestnut soils did not exceed 1% per year (Kononova, 1966). Facek (1965) also reported rapid decomposition of organic matter content in a loamy degraded chernozem of the semi-humid region at a high moisture content.

In laboratory studies, it has been well established that ammonification increases with increase in moisture content, over the range of *ca*

15 bar to ca 0.1 to 0.5 bar (i.e. wilting point to field capacity), and that above and below these limits, the rate of ammonification decreases (Robinson, 1957; Miller and Johnson, 1964; Stanford and Epstein, 1974). Stanford and Epstein (1974) studied nine soils of USA with a wide difference in properties to estimate soil N mineralized under fluctuating moisture conditions. However, while ammonification can continue at suctions well below 15 bar, nitrification ceases at about 15 bar (Robinson, 1957). Nitrate is not formed in air-dried soil. However, the exact point at which nitrification ceases is not clearly known (Vlek et al. 1981).

Most of the findings on the effect of moisture on organic matter decomposition have been based on laboratory observations (Stanford and Epstein, 1974). In the field, the soil moisture content often changes, sometimes rapidly. This effect is a function of temperature, drainage, soil type, wind velocity etc. It is therefore difficult to assess the effect of moisture per se on N mineralization under natural field conditions. More than just the average moisture content of soil, the cycles of wetting and drying, that occur in the field perhaps have the most important effect in causing flushes of decomposition (See Section II.2.2.2).

Studies in the field on West African soils also indicate that nitrification is inhibited more easily than ammonification by high or low moisture content (Robinson, 1967; Moureaux, 1967). In the dry season, in northern Nigeria, Wild (1972) found that ammonification continued slowly at water contents below 15 bars but nitrification was arrested. By the start of the rains, there was a high ratio of NH_4-N:NO_3-N in the soil which was reversed when the soil was sufficiently wet to permit nitrification.

Greenland (1958) suggested that nitrate-N accumulated at the end of the rains when the soil is still moist and there is some evidence for such an accumulation following groundnuts harvested soon after the end of the rains (Wild, 1972a).

II.2.2.1 Effect of mulches on organic matter decomposition

The effect of mulches on organic matter decomposition has been excellently reviewed by Allison (1973). The main effect of organic mulches on soil organic matter contents are primarily to increase water infiltration, reduce water evaporation, modifying soil temperature; which in turn control rate of organic matter decomposition:

i) Mulched soils usually cause more moisture to be available to growing crops than do bare soils, by reducing evaporative losses (Verma and Kohnke, 1951);

ii) Mulches keep the soil cool during summer months (the low temperature retards decomposition); (Allison, 1973),

iii) the activities of micro-organisms are favourably affected largely by mulches of plant materials, due to higher soil moisture contents that prevail during part of the years when mulches are used. (Stevenson and Chase, 1953; Parker and Larson, 1962; Allison, 1973).

II.2.2.2 Drying and wetting of soils

Most laboratory studies have on the decomposition of organic matter been conducted at a constant moisture content. However, the course of decomposition of soil organic matter in the tropics is influenced by marked changes in soil moisture content. These could be in two ways: firstly within a season, the erratic occurrence of rainfall events, causes variation in soil moisture content; secondly, over a year, the pronounced dry season causes extreme dessication. These changes result in two effects on organic matter decomposition: (a) on the water content itself (see previous Section II.2.2) and (b) stumulating effect of extreme dessication on microbial activity in soil in the first few days after rewetting. Dessication of the soil followed by wetting tends to cause a flush of microbiological activity and of nitrogen mineralization (Lebedjantzev, 1924; Hardy, 1946; Birch, 1958; Soils and Fertilizer, 1948; Semb and Robinson, 1969). This flush in mineralization thus increases the amount of available nitrogen in the soil at the onset of the rainy season, over what would normally be expected from the period of time that soil is moist.

The magnitude of the flush depends on both the intensity and duration of heating and drying (Jones, 1975); in general, the longer and hotter the dry season, the greater the proportion of the soil nitrogen mineralized shortly after the onset of the "rains" (Jones, 1975). The most detailed investigation was the series of laboratory studies of Birch (1958; 1959; 1960), who also discussed the possible mechanisms involved. Birch and Friend (1956) calculated that a single cycle of drying and wetting of a forest soil could account for a mineralization of 220 lbs organic matter per acre-6-inch(247 kg organic matterper ha-15-cm.) Birch (1958) showed that repeated cycles of wetting and drying led to repeated flushes of mineralization at each rewetting, the magnitudes of which declined slowly with repetition. He pointed out that where the start of the rains is marked by a number of well-spaced storms interspersed with periods of intense soil drying, repeated flushes of mineralizations might lead to considerable accumulations of nitrate. There are only few reports of this from the field. Greenland (1958) showed that where the annual rainfall distribution was biomodal, a second flush may occur after the mid-season dry period. Field studies by Hagenzieker (1957) and Semb and Robinson (1969) in East Africa, and by Blondel (1967 , 1971a, b, c) in West Africa, also report results confirming what is known as the "Birch effect".

Increasing the temperature during the drying period enhanced the effect of the wetting and drying cycle (Broadbent _et al_., 1964; Agarwal _et al_., 1971). Mineralization of N was highly correlated with that of C (Agarwal _et al_., (1971). Drying stimulated the mineralization of C and N of the humus, but retarded the mineralization of C and N of the recently added organic material (Van Schreven, 1968).

The increase in mineral-N on wetting a dry soil is not universal. Rovira and Greacen (1957) observed that the "Birch" effect does not appear in all soils. They suggested that this effect of drying and rewetting might be related to the nature of the organic matter in a particular soil.

Simpson (1960) in Uganda, and Saunder and Grant (1962) in Rhodesia, found little evidence of any flush. Instead, Simpson (1960) reported an accumulation of nitrate during the dry period. He postulated that the sudden entry of rain into this warm dry topsoil, rich in nitrate, led to conditions, under which nitrate was easily lost by leaching and denitrification. Any flush of mineralization would probably have been masked, by rapid leaching of the nitrate-N formed.

II.2.3 Cultivation

Soils that are ploughed and cultivated frequently over a period of years, invariably contain smaller amounts of organic matter than those that are subject to a minimum disturbance or left permanently under vegetation. (Newton *et al*. 1945; Hobbs and Brown, 1957; Unger, 1968; Boiffin and Fleury, 1974). This difference in organic matter contents is a consequence of many factors associated with cultivation. Some of the consequences are increased mineralization, increased drainage of water (and therefore, leaching of nutrients), lack of addition of organic matter by vegetation, and increased erosion (McCalla *et al*. 1967).

Of particular interest to the present study are the effects of cultivation on microbial activity in soil.

II.2.3.1 Microbial activity

Cultivation increases biological activity in the soil; this is frequently attributed to better aeration (Allison, 1973), because cultivation exposes an inch or so of topsoil to rapid drying, and therefore a flush of biological activity occurs for a two or three day period following the remoistening of soils after each drying (Potter and Snyder, 1916; Rovira, 1955). Birch and Friend (1956) have demonstrated the importance of the increase in soil respiration on wetting air-dry soils, in terms of mineralization of organic compounds. Stevenson (1956) has suggested that amino acids released on drying may be the major organic component providing substrate for the microorganisms.

Rovira and Greacen (1957) demonstrated the importance of increased breakdown of soil humus with tillage; they studied the relationships between aggregate disruption and humus mineralization, and the effect on microbial activity in these soils. In a laboratory study, where tillage conditions were simulated using a ring-shear machine, Rovira and Greacen (1957) found that shearing the soil increased oxygen uptake by the soil microflora. The increased oxygen uptake over 72 hours was closely related to the extent of disruption caused by the tillage treatment, and was attributed largely to exposure of organic matter that was previously inaccessible, due to physical location within aggregates and thus protected from microbial attack. Much of the organic matter released was from the breakdown of soil aggregates that were bound together by humic materials.

In a series of laboratory studies, Craswell and Waring (1972b) found that grinding caused large increases in oxygen uptake in soil - sand mixtures of virgin and cultivated black "cracking clay" soils (probably vertisols) at 10-40% moisture content. Their results showed statistically significant increases, which were much larger in the virgin soils. Working with silt loam soils, Powlson (1980) observed that grinding more than doubled the respiration rate of two silt loam soils, one under arable culture and one under grassland.

Rovira and Greacen (1957) concluded, and Craswell and Waring (1972b) concurred, that the main mechanism responsible for the enhanced oxygen uptake of disrupted soil in their experiments was the exposure of organic matter previously inaccessible to organisms, rather than to improved aeration.

II.2.3.2 Mineralization of N and nutrient availability due to physical distruption of soil

Although it is commonly recognized that cultivation enhances mineralization of nitrogen by soil, there is in fact remarkably little published data (Arnott and Clement, 1966). As a result, the magnitude of the effects, and mechanisms responsible, are poorly understood. Examinations of the effect of cultivation on mineralization usually require weed control by herbicides in the appropriate zero tillage treatment. Invariably, the results of the few studies conducted showed that mineralization of organic matter was enhanced by cultivation (Brown and Ferguson, 1956; McCalla *et al.*, 1962a; Dev *et al.*, 1970; Anderson, 1971). In the studies by Anderson (1971) there was evidence that the herbicides (2,4-D ester, Bromoxynil, MCPA) depressed mineralization and nitrification; this was also shown by Campbell *et al.* (1976) and Chandra (1964).

Burford *et al*. (1977) observed that soil under a winter cereal crop (sown the previous autumn) contained 30 kg ha^{-1} more mineral-N in spring where conventional cultivation rather than zero tillage (direct drilling) was used for establishing the crop. Dowdell and Cannell (1975) found that mineralization of N was 2.5 times greater in a clay soil in which crops had been established by (deep cultivation) ploughing as compared to zero-tillage. However, this difference lasted for only a few months. Similar results had been obtained earlier by Bakermans and de Wit (1970) and Free (1970). These differences between cultivated and uncultivated soil can perhaps explain why crops established by a zero-tillage system sometimes need more N fertilizer to reach maximum yields than crops sown into well cultivated soil (Cannell and Ellis, 1979). Davies and Cannell (1975) and Tomlinson (1973) as quoted by Cannell and Finney (1973) however, found no difference in N requirement due to disturbance of the soil to provide a seed bed.

Gainey (1916) in a study of ammonification and nitrification of plots in Kansas, USA, found that moisture was probably of paramount importance in increasing the nitrate content of the ploughed plots in comparison with disked plots. Similar results were reported by Gamble *et al*. (1952) and McCalla *et al*. (1962a). For these reasons, McCalla (1967) emphasised the importance of assessing the effects of specific microbial activities, such as nitrification, denitrification, disease etc., as a tool to evaluating a tillage practice.

In his review, Powlson (1980) concluded that most measurements of enhanced nitrogen mineralization following cultivation have been reported in soils of fairly high organic matter content such as those that had been previously under pasture for long periods. He measured the effects of cultivation on the mineralization of soil nitrogen in old arable soils of low organic matter content (ca 2.4% organic matter) at Rothamsted. Field data indicated that mineralization was slightly faster in an "old-cultivated" soil but the difference was only significant at the site previously under grass (ca 2.0% organic matter). At this site, cultivated soil contained 7 kg ha^{-1} more mineral N than uncultivated soil two weeks after treatment, and 9 kg ha^{-1} more after another four weeks. The corresponding figures for the site with a long history of continuous cultivation were 4 and 6 kg ha^{-1}. The differences between the cultivated and uncultivated soils from the sites previously under grass were statistically significant. Even though the soil at the site under grass contained slightly less total organic matter than that at the site which had been cropped to wheat, it would have contained more recently added material derived from plant roots (Powlson, 1980).

The greater effect of cultivation in the "pasture" than in the "wheat" soil, indicates that cultivation accelerates the decomposition of fresh organic matter rather than that of the older, more stable parts of the soil organic matter. These effects obtained by Powlson (1980) are consistent with the results of laboratory experiments of Craswell and Waring (1972a) on the effects of grinding on soil N mineralization rates. Powlson's results clearly pointed out that the effect of cultivation on the mineralization of N varies considerably between soils, probably depending on the organic matter content of the soil, particularly the fresh organic matter. The slower mineralization of nitrogen in undisturbed soils may not be the sole reason for the higher fertilizer N requirements in direct-drilled crops. Powlson (1980) further reports that there are indications that at certain growth stages, direct-drilled crops may absorb nitrate from the soil more slowly than crops drilled into cultivated soil, hence root exploration was impeded in the uncultivated soil.

Some workers have found increases in the rate of decomposition of soil organic matter when soil aggregates are physically disrupted (Rovira and Greacen, 1957; Harada et al., 1964; Waring and Bremner, 1964; Edwards and Bremner, 1967), while others have not found this effect (Fitts, 1953; Hagin and Halevy, 1961; Robinson, 1967; Rixon and Melville, 1969). This may possibly due to differences between the effect of different soil types, methods of aggregate disruption, conditions of incubation and the indices of organic matter decomposition used (Craswell and Waring, 1972a). An exhaustive comparison of results therefore becomes difficult.

Craswell and Waring (1972a) examined various soil types in a detailed laboratory study; they found that grinding caused large increases in aerobic nitrogen mineralization in virgin and cultivated soils. The virgin soils in their study showed a larger proportional increase in organic matter decomposition due to grinding than did the cultivated soils. This, they attributed to the presence in virgin soils of relatively large amounts of readily decomposed light fraction organic material (Greenland and Ford, 1964). Craswell and Waring (1972a)presume that grinding the light fraction would cause a flush in decomposition similar to that shown when plant material is ground (Van Schreven, 1964). Despite a large decrease in organic matter content due to 50 years of exploitive cultivation, the soils they used ("Cracking-clays", probably vertisols from the Darling Downs, Queensland, Australia) showed a still substantial increase in decomposition rates due to grinding. Because these large increases were obtained in the laboratory only after severe grinding, it would appear that field tillage only slowly exposes organic matter for decomposition. Rovira and Greacen (1957) suggested large effects (though short lived) of field tillage treatments on organic matter breakdown. However, the view suggested by Craswell and Waring (1972a) is supported by their observation that very disruptive grinding treatments are needed to cause large increases in decomposition rates.

II.2.4 Addition of crop residue/manure

The rate of decomposition of plant residues in soil and their incorporation into soil organic matter reserves, depends to a very large extent on the method of their addition (Swaby, 1966). For example, when left on the surface as a mulch, residues often become dessicated and decompose more slowly than if incorporated (Parker, 1962; Brown and Dickey, 1970; Shields and Paul, 1973). Depth of placement below the soil surface also determines the rate of decomposition. This is the result of factors associated with depth - for example, temperature, aeration and moisture (Swaby, 1966). Generally organic residues mineralize more rapidly and leave less humus when buried at shallow depths, rather than at greater depths. However, organic residues decompose only slowly when buried under wet, cold conditions (Kononova, 1966) or very dry conditions (Shields and Paul, 1973), because these environmental factors retard decomposition.

Ferguson and Gorby (1964) reported that release of nitrate from soil organic matter was reduced markedly when straw was applied to fallow fields; the same was true when soil samples with straw were incubated in the laboratory. This was due to immobilization caused by the wide C/N ratio of the straw. In a long-term experiment of four years, Jones (1971) suggested that to maintain soil organic matter status, all the crop residues, should be returned to soil; in a 3-year bare fallow plot, the increase in soil N buildup exceeded 50 kg/ha/year.

Studies on the continuous application of organic manures and fertilizers on the carbon and nitrogen levels in soil have attracted the attention of many workers. Unlike green manures, farmyard manure and composts decompose slowly, because they are already partially decomposed. Newton et al. (1945) work in western Canada over a period of 25-30 years indicated that farmyard manure reduced the rate of loss of soil C and N compared to losses resulting from grain summer-fallow rotations. The work of Ridley and Hedlin (1968) and Dubetz et al.(1975) showed that the benefits of manure increased with time. Warren's (1956) results from the continuous barley experiments at Rothamsted in Britain showed that an annual dressing of 34 metric tons of FYM almost trebled the total N content in 94 years. Evidence that manure breaks down only slowly can be seen from the fact that one-third of the N added in manure between 1851-1871 still remained in the soil in 1946 (Jenkinson, 1966a). In the USSR, systematic application of FYM increased soil organic matter primarily in the top 20 cm with smaller increases in the 20-40 cm depth (Kononova, 1966).

However, the role of organic manures in the build up of organic matter in the soil, particularly in tropical countries, has been a subject of controversy. Contradictory results have been obtained. In India, Jenny and Raychaudri (1960), Nijhawan (1961), and Singh (1972) emphasised that hot climates do not allow the build up of organic matter in tropical soils, because of rapid decomposition due to higher soil temperatures. On the other hand, Acharya and Rajagopalan (1956) and Mariakulandai (1961) reported that addition of organic residues significantly increased the level of organic matter.

The analytical data collected by Acharya and Rajagopalan (1956) indicate that in the continuous application of FYM (4000 to 8000 kg/ha/year) increased the carbon content of the treated plots by 20 to 40% over that of the check plots. The nitrogen content did not increase. These data were obtained for the long-term manurial experiments in progress at Pusa and in Coimbatore. At Coimbatore, the soil nitrogen content of the 15-30 cm layer was much higher than the 0-15 cm layer in all the treatments viz., no manure, N, NK, NP, NPK, PK, K, P and cattle manure. This was interpreted as indicating a downward movement of nitrogen, and that the N content of the surface layer is conditioned by climatic factors and not much by manurial practices.

In carrying out similar investigations a number of workers have observed that the application of farmyard manure was beneficial to the soil; the content of nitrogen increased significantly at Ambala and Hansi (Kanwar and Prihar, 1962); at Berhampore (Mandal and Pain, 1965); at Kotah (Dayal et al. 1965); at IARI (Havanagi and Mann, 1970; Maurya and Ghosh,1975) and at Hissar (Mishra et al. 1974). Despite these numerous studies of the longterm effects of additions of organic residues on soil organic matter and nitrogen levels, there is no consensus on the effect of organic matter additions on soil organic matter content. Further, there are no widely-quoted values for the decomposition rates of organic matter in Indian soils. There is no reason to suggest that this value should be different to else-where in the tropics, but it is particularly surprising that no one has attempted to quantify the decomposition rates, especially as there have been a number of long-term experiments conducted in the past.

II.3 USE OF LONG-TERM EXPERIMENTAL DATA TO EVALUATE DECOMPOSITION CONSTANTS

Organic matter levels in soil reflect the dynamic equilibrium system, which is determined by the overall agronomic environment. The amount of N in a soil is determined by the rate of addition of organic material to the soil, and the rate of decomposition of the soil organic matter which as indicated earlier must be considered as a number of components ranging from freshly added plant residues to humified material. Many attempts have been made to express the general equilibrium by mathematical models. For example, the rate of change of soil N (under the influence of man's activities; climate, vegetation etc) has been described in the equation proposed by Salter and Green (1933).

$$N = N_o^{kt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (i)$$

where

N is the weight of organic matter per unit mass of the soil after 't' years.

N_o is the weight of N in the soil - plant system initially

k is the fraction of N decomposed annually per unit mass of soil (decomposition constant).

This equation only describes the decomposition of N; it does not allow for the annual additions of humus, which Jenny (1941) therefore included this annual addition term:

$$\frac{dN}{dt} = A - kN \text{ .... (ii)}$$

where

A is the yearly addition of N or new biomass per unit mass of soil.

On integrating and transposing terms the equation becomes

$$N = \frac{A}{k} + (N_o - \frac{A}{k}) e^{-kt} \text{ ....(iii)}$$

When the system is in a steady state condition, then

$$\frac{dN}{dt} = 0; \qquad \frac{A}{k} = N_E \text{ .... (iv)}$$

where N_E is the steady state N content of the soil plant system (more commonly named the equilibrium value).

One form or another of this equation has been used by various workers (Greenland and Nye, 1959; Woodruff, 1949; Russell, 1962; Campbell, 1976) to describe past changes in soil organic matter or to predict future changes - Equation (iii) is commonly used to describe the total soil N changes in a system; the model is particularly useful for calculating the, decomposition constants 'k', and the annual addition 'A' (Russell, 1962, 1973; Campbell et al., 1976b; Jenkinson, 1966a; Woodruff, 1949). Jenkinson, (1966a) points out that although this model is very useful it greatly oversimplifies the situation. The most serious objections to the equation (iii) are that it assumes that:-

i) the annual addition of biomass to the soil, A, is constant;

ii) the rate of decay of organic matter is independent of the amount added;

iii) all components of the organic matter decompose at the same rate;

Bartholomew and Kirkham (1960) used the integrated from (iii above) of Jenny's equation to obtain the constants 'A' and 'k' used to calculate the probable equilibrium level (N_E, which is equal to A/k) for long-term rotation plots in the USA. Woodruff (1949) used data from the Sanborn plots in Columbia, Missouri (USA) and found that the average rate of decomposition of organic matter under cultivated crops, small grain crops and grass ley to be 2%, 1% and 0.75% respectively.

Jenkinson (1966a) has used this equation for predicting the amount of N entering soil organic matter each year in a Rothamsted experiment on continuous barley. The constants in the equations (A and k) were calculated from percentage of N in the soil at 0, 30 and 61 years after the experiment had started. A curve was fitted using these constants (k was found to be 0.0251) co-responding to a half-life ($t_{1/2}$) of 40 years,

Where,

$$t_{1/2} = \frac{0.693}{k} \; ; \quad \ldots\ldots\ldots\ldots \quad (v)$$

k = decomposition constant

$t_{1/2}$ = half-life;

and A was 0.0078% N per year. He observed that the actual annual addition of FYM-N (224 kg N/ha) was found to correspond closely with the amount of N entering the soil organic matter per year (A), as calculated value of annual addition or accretion was 226 kg N/ha.

Greenland (1971) assigned values to the decomposition and accretion constants; with these values, equation (iii) described changes in his soils. Greenland, then used the values to predict the length of cropping and pasture phases under continous fallow - wheat and pasture - wheat rotations needed to maintain a mean N value.

The equation $\frac{dN}{dt} = A - kN$, has been used to deduce the half-life ($t_{½}$) for organic matter by Russell (1962) for soils under pasture in temperate regions. Campbell *et al*., (1976) presented similar data ($t_{½}$) for Canadian prairie soils and discussed these in terms of the effects of length of cultivation, rotation, texture and crop residues. The rate of N depletion was found to be rapid during the first 5-10 years of cultivating land and then gradually declines.

In India, despite the numerous long-term experiments on the effects of additions of organic residues on soil organic matter and nitrogen levels in soil, (Acharya and Rajagopalan, 1956; Mariakulandai, 1961; Mariakulandai and Thiagarajan, 1959; Maurya and Ghosh, 1972; Mandal and Pain, 1965; Mishra *et al*., 1974; Kanwar and Prihar, 1962) there has been no previous attempt to determine the values for decomposition constants of organic matter in Indian soils. Additionally, the dynamic nature of organic matter in Indian soils has received little attention; although emphasis is given to the low organic matter contents and the possible effects of temperature on these (Jenny and Raychaudri, 1960), there has been no recognition of the fact that the fast rate of turnover (attributed to high soil temperature) may partially compensate for the high decomposition rates.

III MATERIALS AND METHODS

III.1 DECOMPOSITION OF SOIL ORGANIC MATTER

III.1.1 Determination of the decomposition rate of soil organic matter from long-term experiments

Determination of constants in the dynamic equation describing the organic matter should be attempted only if a number of criteria are met. These basically arise because the changes in soil nitrogen over one season are very small in relation to the sampling error. Therefore, the measurement period needs to extend over a long period of time preferably several decades. The criteria for suitable experiments have been clearly defined by Greenland (1971) and Jenkinson (1966a):

i) Continuation of the same agronomic practice over many seasons;

ii) Thorough sampling of the soil to obtain a representative sample of the soils on the experimental areas;

iii) Sampling on at least three occasions so that the shape of the soil nitrogen vs time curve can be determined;

iv) Correct determination of the mean bulk density of the soil to the depth sampled on all occasions, so that the nitrogen content can be converted to a weight per acre for the same depth of soil (that is, with allowance made for any changes in bulk density);

v) An analytical method which will accurately determine the nitrogen content of the sample.

Experimental data from several long-term manurial trials in India were examined. Only one of these experiments, located at Tamil Nadu Agricultural University at Coimbatore,(TNAU) was found to satisfy the above criteria sufficiently to warrant further investigation of the data.

III.1.1.2 Permanent manurial experiments at Tamil Nadu Agricultural University (TNAU), Coimbatore

Continued application of organic manures and inorganic fertilizer have been made to the same plots year after year in experiments conducted on calcareous red sandy loam soils at TNAU, Coimbatore. The effect of the repeated treatments on crop yield and physical and chemical properties of the soil have been studied under rainfed conditions in two separate experiments; the 'Old' Permanent Manurial Experiment (Old PME) and under irrigated conditions in the New Permanent Manurial Experiment (New PME). The only available descriptions of these experiments were reported in a Bulletin, "Permanent Manurial Trials conducted at Coimbatore", authored by Krishnamurthy and Ravikumar (1973), which followed a much earlier report of the preliminary research results by Mariakulandai and Thyagarajan (1959).

The Old-PME was started in the year 1909, and the New PME in 1925. There were ten unreplicated main treatments in both experiments, and eight of these comprised fertilization with inorganic fertilizers to give a full N x P x K factorial; the remaining two treatments involved additions of cattle manure. In each year, nitrogen was supplied as ammonium sulphate to supply 22.5 kg of N/ha/yr, phosphorus as superphosphate to supply 26.4 kg P/ha/yr and potash as potassium sulphate to supply 37.5 kg K/ha/yr. The New

PME additionally contained a duplicated series of 10 plots termed the Western series which received 2000 lbs/acre of cattle manure; this manure added 12 kg/N/ha and 3.5 kg P/ha per year. The data from the New PME has not been examined in this study, because this experiment was irrigated; only the Old PME was maintained under dryland conditions.

III.1.3 Collection of additional data

III.1.3.1 Records

The yield of crops and chemical analysis of products (grain and straw), and the result of sampling and analysis of soils, have been reported by Krishnamurthy and Ravikumar (1973). The soil nitrogen contents of the 0-15 cm depth were reported only for the years 1916, 1952 and 1958; it was therefore necessary to assess the total soil N status in 1980.

The TNAU staff had collected soil samples in June 1980; sub-samples were kindly given to me for analysis for total N. These samples were analysed at ICRISAT using the methods described in Section III.3.2. The soil samples had been obtained with a 4.5 cm diameter Veihmeyer tube from the surface soil (0-15 cm). These nitrogen contents, together with those reported for the previous years by Krishnamurthy and Ravikumar (1973), thus provided values for the years 1916, 1952, 1958 and 1980. These were fitted to the equation to evaluate decomposition rate constants, as described in the next section.

III.1.4 Calculation of decomposition rates

Several authors have given the standard equation for describing the change in organic carbon or nitrogen contents with time (e.g. see Section II.3). Jenny's (1941) modification of Salter and Green's (1933) equation was used,because this includes the term for the amount of organic materials added each year as plant debris and roots:

$$\frac{dN}{dt} = A - kN$$

where

N is the weight of organic N per unit mass of the soil

A is the amount of N added annually per unit mass of soil

k is the decomposition constant, that is the fraction of N decomposed annually per unit mass of the soil.

On integrating and transposing the terms in this equation, it becomes

$$N = \frac{A}{k} + (No - \frac{A}{k})\ e^{-kt}$$

where

No is the initial weight of soil N in the soil system

The amount of organic N at equilibrium (when $t = \infty$) is N_E which is, of course, numerically equal to $\frac{A}{k}$ since at equilibrium,

$$\frac{dN}{dt} = 0 = A - kN$$

N is the weight of organic N per unit mass of the soil;

K is the decomposition constant or the fraction of N decomposed annually per unit mass of the soil.

When the amount of organic materials added each year (e.g. as plant debris and roots) is included, the equation (1) takes the form

$$\frac{dN}{dt} = A - kN$$

where

A is the amount of N added annually per unit mass of soil (Jenny, 1911). On integrating and transposing there terms in equation (2), the equation becomes

$$N = \frac{A}{k} + (N_o - \frac{A}{k}) e^{-kt} \qquad (2)$$

where

N_o is the initial weight of soil N in the soil system.

The amount of organic N at equilibrium (when t $= \infty$) $\frac{A}{k}$ is of course, numerically equal to N_E since $\frac{dN}{dt} = 0 = A - kN$).

Data from the Old PME were used to calculate the decomposition rate constants for organic nitrogen in this soil using standard statistical programs (see Section III.3.3).

III.2 FIELD EXPERIMENTS

Short-term experiments, were conducted(over 1-2 seasons) to obtain experimental data on the effect of different cultivation systems, on crop yields and the uptake of soil nitrogen by crop. Particular emphasis was given to the effects of pre-seeding cultivation.

Table 1. Characteristics of soils (0-15 cm depth) from experimental sites, ICRISAT Center, Patancheru.

Property	Vertisol (BW6B)	Alfisol (RP19B)
Particle size distribution (%)		
Sand (2-0.02 mm)	24	63
Silt (0.02-0.002 mm)	25	10
Clay (<0.002 mm)	51	27
Organic matter (%)		
Organic carbon	0.	0.35
Total nitrogen	0.04	0.06
pH in 1.2 soil water	8.05	7.30
Electrical conductivity (millimhos/cm)	0.26	0.15
DTPA extractable micronutrients (ppm)		
Fe	2.5	4.5
Zn	2.3	3.0

Table 2: Rainfall and temperature data at ICRISAT Center, Patancheru,1980-81.

Month	Rainfall (mm)			Temperature (°C)[*]			
	1980[+]	1981[+]	Long-term mean [¢]	1980		1981	
				Max	Min	Max	Min
Jan	0.0	15.6	6	29.0	15.5	27.0	14.1
Feb	4.0	0.0	11	32.1	18.2	32.5	15.8
Mar	9.0	76.8	13	35.5	20.2	33.6	19.8
Apr	7.0	3.4	24	38.3	24.5	38.1	23.3
May	18.0	1.6	27	40.4	26.0	38.5	25.6
Jun	145.2	202.6	115	33.2	23.7	34.9	23.6
Jul	82.5	209.2	171	30.4	23.0	31.3	23.0
Aug	357.3	218.3	156	28.3	22.0	28.3	21.8
Sep	118.9	86.6	181	29.8	2.8	29.0	22.2
Oct	1.3	154.5	67	32.0	18.6	29.6	19.8
Nov	0.3	1.8	23	30.5	16.7	28.3	15.0
Dec	0.0	0.0	6	28.9	15.2	26.9	13.0
Total	743.2	1170.4	800				

* Based on 1931-60 temperature data at Hyderabad

\+ Recorded at ICRISAT, Patancheru, A.P. India.

¢ Based on 1901-70 rainfall data at Hyderabad.

The experiments were conducted at ICRISAT Center, Patancheru in the two consecutive rainy (Kharif) seasons (1980-81) on an alfisol (Field RP 19B) and a vertisol (Field BW6B). Characteristics of the two soils are given in Table 1. Rainfall data are given in Table 2.

III.2.1 Effect of pre-seeding cultivation on N uptake from soil

The major objective was to assess the effect of cultivation on the availability of soil nitrogen to the cereal crop. This was achieved by comparing the effect of four treatments, representing different intensities of cultivation, on yield and nitrogen uptake. Agronomic details of these experiments are given in Table 3.

The three depths of cultivation were nil or zero cultivation (ZC), shallow, to a depth of 5cm(SC)and deep to a depth of 10-12 cm (DC). The raised broadbed-and-furrow system (BF) indicates the creation of a bed which is about 110 cm - 120 cm wide and raised about 10 cm above the furrows; these are about 30 cm wide. This was developed at ICRISAT to provide improved drainage on vertisols.

All major cultivations for these different treatments were done before the kharif season in each year. On the vertisol, sorghum seed was sown into the dry seed bed (at a depth of 5 cm and with an interrow distance of 50 cm), just before the first rains of the southwest monsoon. On the alfisol, cultivations were completed and the crop sown only after the soil had been wet to a depth (20-30 cm) which is that considered sufficient to provide a good probability of successful establishment.

Table 3. Experimental details - pre-seeding cultivation experiments

Details	Alfisol		Vertisol	
	1980	1981	1980	1981
Treatments:	ZC : Zero cultivation SC : Shallow cultivation DC : Deep cultivation BF : Broadbed-and-furrow			
Design	Randomized block design with four replications			
Plot size	15 x 4.5m		18 x 4.5m	
Basal fertilizer				
Super phosphate, kg P/ha	20	20	20	20
Urea, N kg/ha	20	-	20	-
Crop				
Sorghum, CSH-6	+ (F)[*]	+	+	+
Millet BJ-104	+	-	-	-
Date of planting	14 Jul(S)[π] 5 Aug(M)	23 Jun	20 Jun	13 Jun
Date of thinning	20 Aug	2 Jul	10 Jul	5 Jul
Date of harvesting	11 Nov	15 Oct	12 Oct	2 Oct

[*] Failed, due to shootfly attack; resown with millet on 5 August, 1980.

[π] S = Sorghum; M = Millet

The soils were not cultivated after sowing. Weeds were removed by hand pulling in 1980, and in 1981, by the same method on the vertisol. On the alfisol in 1981 weeds were controlled, by carefully spraying between the rows of sorghum, with the herbicide, paraquat (Gramaxone).

III.2.1.1 Measurements and observations

i) Plant measurements

a) Crop yields and N uptake

At harvest time, border strips were removed from each plot; these consisted of 2 rows from each side and 0.5 m from each end. All the produce on the remaining area of each plot (14 x 2.5 m on alfisol and 17 x 2.5 m on vertisol) was removed and weighed. It was then threshed. The grain was collected, winnowed free from chaff and weighed. A subsample of 500 g from each,of the grain and straw was dried at 60°C to provide an estimate of the moisture content as well as a sample for chemical analysis. The yield per unit area were adjusted to a moisture content of 14 percent (W/W). The nutrient uptake was assessed by the product of total weight and N content.

ii) Soil measurements

a) Mineral-N contents of soil

Soil samples were taken on both soils (alfisol and vertisol) during crop growth to monitor mineral-N in soil. The samples were taken with a 4.5 cm (i.d.) tube sampler. The soil profile was sampled (when soil was sufficiently moist for sampling) at 0-15, 15-30, 30-60 and 60-90 cm depth increments to 90 cm, and to shallower depths at the beginning of each rainy season. Six replicate cores were taken from each plot, bulked, then quickly airdried and lightly ground to pass a 2 mm sieve.

b) Biomass in soil

The microbial biomass in soil under contrasting cultivation treatments was estimated, by measuring the flush of decomposition caused by fumigation with chloroform (Jenkinson and Powlson, 1976a and b). Biomass was also compared in intact soil cores and sieved soil, because Lynch and Panting (1980a) have criticised the technique used by Jenkinson and Powlson (1976b).

Between 23 July 1981 and 28 August 1981, four replicate soil samples were taken from with stainless steel open-ended tubes (7.2 cm dia x 10 cm) deep) from the surface soil (0-10 cm) of each of the two cultivation treatments (zero and deep cultivated) on the alfisol.

To test Lynch and Panting's (1980a) claim that sieving caused a decrease in soil biomass (by killing a part of the biomass) the effect of sieving was investigated. Four replicate samples were taken from the soil surface of the two cultivation treatments (zero and deep cultivated) with open ended tubes (as described in the previous paragraph), the soil removed and sieved to pass through a < 6.25 mm sieve. The intact cores and sieved soil were fumigated and incubated separately. Biomass was measured by the method described by Jenkinson and Powlson (1976b).

The same two cultivation treatments, zero (ZC) and deep cultivated (DC) were sampled on the vertisol, but measurements were made only on sieved soil (< 6.25 mm mesh). Where the effect of sieving was investigated, the soil treatment was done by the method described by Jenkinson and Powlson (1980). The intact cores could not be studied in the vertisol, for two reasons: *firstly*, the high moisture content and stickiness of the clay would have prevented uniform fumigation; *secondly*, studies of these factors would have created the need for equipment and resources which were not available.

III.2.2 The effect of pre-seeding cultivation on response to nitrogen fertilizer

This experiment was conducted to test whether the effect of the contrasting cultivation treatments would persist or disappear as the input of nitrogen fertilizer to sorghum was increased.

Location : BW6B
Plot size : 4.5 m x 4 m
Crop : Sorghum, CSH-6
Replications : Four
Basal fertilizer : 20 kg P/ha as single superphosphate

Treatments

There were two main plots and five sub-plots:

1) Main treatments
    a) No cultivation
    b) Deep cultivation

2) Sub-treatments

a) Fertilizer levels 0, 40, 80, 120, 160 kg N/ha

Plant measurements

At harvest two rows (1.0 m) were removed from each side of plot, and 0.5 m was removed from each end. The fresh weight of the produce on the remaining area (2.5 x 3 m) was recorded. The procedures for measuring yield and nutrient uptake were similar to those described earlier (III.2.1.1)

III.2.3 Effect of post-seeding cultivation of an alfisol on crop yields and N uptake of millet

This experiment was undertaken to investigate whether post-seeding cultivation would increase yields and N uptake by the crop. Disturbance of the soil surface (as opposed to deep interrow cultivation) was included as a control treatment to assist in separating between effects due to mineralization, and those due to the physical breaking of the surface crust.

Location of the trial : RP 19B

Treatments

Treatment number	Cultivation* post seeding	Distrubance of soil** surface
A	Nil	---
B	Nil	+++
C	One (+)	+++
D	Several (+++)	---

Cultivation(+++) indicates shallow cultivation (0.5 cm) of the soil surface between the crop rows three times after seeding.
Surface disturbance (0-2 cm) at the same time as the deep cultivations.

Experimental details

Plot size : 4.5 x 3 m

Design : RBD

Replications : Seven

Crop : Millet, BJ-104

Sowing details : Sown on 14 August 1981, at 50 cm interrow distance.

Basal fertilizer : 20 kg P/ha as single superphosphate.

III.2.4 Effect of surface crusting on nitrate movement in soil

As a surface crust limits the entry of water into soil, the effect of cultivation on yield can be due to a combination of chemical and physical factors: Apart from effects of cultivation on mineralization of N, disturbance of the soil can break the surface crust, and therefore allow more water to enter the soil. To provide information on this, an experiment was therefore conducted in which surface crust formation was prevented by use of the synthetic soil conditioner polyvinyl alcohol (PVA). The effect of preventing crust formation on water relations was examined by measuring runoff of water; and additionally, measuring the leaching of nitrate of provide an index of the infiltration of water into the soil (under 'flat' cultivation).

The soil conditions used PVA, is composed of linear molecules with ıe structure:

$$A - (CH_2 - CHOH)_P - B$$

where

P represents the degree of polymerization, and the end groups A and B are chemically inert. The commercial product used in our experiment was "Mowiol" obtained from Hoechst, W. Germany; it had a molecular weight of about 70,000.

Preparation of PVA

The PVA was dissolved by dispersing 16 kg in about 120 litres of tap water, with stirring but without aeration (Oades and Grierson, 1978). To do this, it was necessary to steam heat the water to about 90°C while gently stirring with a propeller type stirrer. The volume was made up to 200 l. The eight percent (W/V) solution was transported to the field, and diluted to a 1% solution before spraying.

Treatments

Four "runoff" plots (10 m x 4 m) on an alfisol in RCE7 were cultivated with a rotovator to provide a fine seed bed. To follow the nitrate-N movement, nitrate was applied at the rate of 80 kg N/ha. The soil was sampled to estimate the initial nitrate-N content in the soil profile. Both sodium nitrate ($NaNO_3$) and potassium nitrate (KNO_3) were used due to limited supplies of nitrate salts in our laboratory at this time. PVA was uniformly sprayed on two of the plots, while the other two were left untreated. The rate of application of PVA was 10 g per sq meter; the date of application was 17 August, 1980.

The amount of run-off was measured for each plot after each rainfall event. On 31 August 1981, nine replicate soil cores were taken to 80 cm depth from each plot. The cores were sectioned into 10 cm depth increments. The samples were quickly air-dried, then ground to pass a 2 mm sieve. These were analysed for nitrate-N in the profile (Section III.3.2).

III.2.5 The effect of broad bed and furrow cultivation on organic matter levels

The broadbed-and-furrow system was introduced into ICRISAT's Farming System Program in 1975, yet there has been relatively little characterization of its effects on soil properties. The accumulated effects on soil organic carbon contents across a bed were therefore examined since these could give information on the decomposition of organic matter.

Treatments

Soil samples were obtained along transects across beds were made on the three replicates of three agronomic treatments in the existing experiment (long-term phosphate experiment). These treatments were:

P_0 - No superphosphate for 4 years.
P_{20} - 20 kg superphosphate P/ha/year for 4 years.
FYM - 30 tons of FYM/ha as one application, four years previously.

The soil samples were collected 10 cm intervals across the bed; since ıe mid-furrow to mid-furrow distance is 150 cm, there were 16 positions to sample on each transect. The sampling depths were: 0-15 cm and 15-30 cm. The soil samples were air-dried and ground to pass a 2 mm sieve, prior to analysis for organic carbon (Allison, 1965).

III.3 ANALYTICAL PROCEDURES

III.3.1 Plant analyses

Grain and straw samples were oven-dried at 60°C for 24 hours and ground to pass a 40 mesh sieve; a sample of 5 gram was drawn from the ground material for subsequent analyses. Nitrogen in a sub-sample was determined by digestion with 4 ml of concentrated sulphuric acid containing 0.5% selenium for one and half hours and NH_4-N in the digest was determined colorimetrically. The quantification of ammonia is achieved by utilizing the Berthelot reaction in which the formation of a blue indophenol complex occurs when ammonia is reacted with sodium phenate followed by the addition of hypochlorite (Technicon Instruments Corporation, 1974). The results were calculated on drymatter basis. Nitrogen content of grain and straw were multiplied by the respective grain and straw weights per plot to obtain nitrogen yield (uptake) per hectare for each plot at harvest.

III.3.2 Soil analysis

i) Determination of ammonium and nitrate N

A sub-sample of 10 g of soil was shaken with 100 ml of 2 M potassium chloride for 60 minutes in a reciprocating shaker. The equilibrium suspenson was filtered using Whatman No.1 paper (12.5 cm diameter). A 20 ml aliquot of clear filtrate was distilled first with 0.2 g Devardas alloy an alloy of Al, Cu, Zn in the ratio 45:50:5; 25 ml of distillate was collected for each distillation in 5 ml of 4% boric acid and titrated against 0.005 N sulphuric acid using methyl red and bromcresol green as the indicator (Bremner, 1965b). In the titration, 1 ml of 0.005 N H_2SO_4 was equivalent to 70 µg of ammonium N or nitrate-N.

In the experiment, where leaching (movement) of nitrate as affected by PVA application was studied, nitrate-N was estimated by the phenoldisulfonic acid method (Bremner 1965). Nitrate was extracted by shaking the soil sample with a saturated solution of $CaSO_4$ (5 ml per g of soil) for 10 minutes the extract obtained by filtration of the soil suspension was analysed for nitrate by the phenol-disulfonic acid method.

Total N in soils was estimated by the macroKjeldahl method described by Bremner (1965a). To a subsample of 10 g soil (< 2 mm mesh), 1 g reduced iron and 10 ml water were added and left to stand for 45 minutes. Then 35 ml of conc. H_2SO_4 were added and digested at low heat for one hour until the water had evaporated. To this digest, 2 Kjel-tabs (each tab weighed 5 g and contained 100 parts K_2SO_4, 6 parts $CuSO_4$ and 1 part Se) were added and digestion was continued until one and a half hours after clearing. The digest was cooled, and distilled in 40 ml of 4% foric acid using 150 ml of 40% NaOH; 150 ml of distillate was collected and titrated against 0.01 N H_2SO_4. In this titration, 1 ml of 0.01 N H_2SO_4 was equivalent to 140 g of ammonium-N or nitrate-N.

ii) Measurement of microbial biomass

Soil samples were fumigated with purified chloroform and incubated. The increase in CO_2 evolution in the fumigated soil over that of an unfumigated soil(flush in decomposition) was used as an index to measure microbial biomass. Each group of soil cores (7.6 cm x 10 cm diam), were placed in a large confectionary glass jar (3 kg capacity) together with a beaker containing 100 ml of 1 M NaOH to absorb CO_2 and two test-tubes with water (to maintain humidity). Two jars without soils served as controls for carbon dioxide absorption by the NaOH. This conditioning incubation was imposed to allow the effects of sampling, and imposition of the new environment, to subside.

The incubation procedure and analytical methods for estimating biomass were those described by Jenkinson and Powlson (1976b). In brief, the duplicate samples of soil were incubated for a 10-day period, and the evolution of carbon dioxide was measured by trapping it in NaOH and subsequent titration with HCl; one sample was incubated after chloroform treatment (to kill the microbial population) and the other without chloroform treatment which served as the control.

The soil samples collected on 23 July 1981 were not given a conditioning incubation; instead unfumigated controls were incubated for a further 10-20 day period, after beakers of fresh NaOH had been introduced in these jars. The soils which were sampled on 28 August 81, were given a conditioning incubation for 4 days; therefore the incubation for the 10-20 day period for the unfumigated controls was omitted as followed by (Jenkinson and Powlson, 1980).

ii. a. Calculation of microbial biomass in soil

Biomass was calculated from the expression:

$$\text{Biomass C} = (X - x)\ k_c$$

where

k_c is taken to be 0.45, the fraction of the killed biomass C mineralized to CO_2 in 10 days at 25°C.

X is the CO_2-C evolved from fumigated soil in 10 days;

x is the CO_2-C from the unfumigated control over the same period if conditioning incubation was given; if a conditioning incubation was not given, it is the CO_2-C evolved over the 10-20 day period (Jenkinson and Powlson, 1976b).

III.3.3 Statistical analyses for all experiments

The grain yield and straw yield as well as N-uptake were analysed statistically for each experiments by the standard analysis of variance. For all experiments the analysis of variance was carried out and the significance in all cases was tested by 'F' test (Cochran and Cox, 1965). The data were analysed with the help of VAX computer at ICRISAT, Patancheru. To fit the data from the old PME (Coimbatore), the GENSTAT program handled the curve fitting, on the ICRISAT computer, using an iterative process.

IV RESULTS AND DISCUSSION

IV.1. DECOMPOSITION RATE CONSTANTS FROM LONGTERM EXPERIMENTS, TNAU, COIMBATORE

IV.1.1 Results

The examination of all long-term experiments on dryland in India yielded only one site where there were sufficient experimental data available to warrant further investigation. This experiment was the "Old" Permanent Manurial Experiment at Tamil Nadu Agricultural University, Coimbatore.

The sites rejected (Table 4) were not suitable mainly because soil sampling and analysis had not been conducted at several times during the experiment. At least 3, preferably more, good samplings were required and it is essential that these be as widely distributed in time as position - e.g. at initial time (T_o) and the end of the experiment (T end) and at intermediate times so that the shape of the N vs time curve can be precisely determined. All the sites rejected had at least one common feature there was no published report of samplings at the beginning or end of experiments.

The TNAU Old Permanent Manurial experiment appeared suitable because it has been conducted for a very long time - it was now in its 65th year - and regular soil sampling had been made. However, the data (Table 4) was very variable; attempts to fit the soil data from the individual treatments data to the relationship - did not succeed. The GENSTAT program for this

$$N = N_E + (N_o - N_E)e^{-kt}$$

on the ICRISAT computer handled the curve fitting by an iterative process,

Table 4. Details of manurial experiments in India

Location/site	Duration	Soil sampled	Reason for rejection	Acceptable but with listed disadvantages
Berhampore	1946 -	1960	Insufficient soil sampling	-
Pusa, Bihar	1908 - (Old) 1932 - (New)	1968	Insufficient soil sampling	-
TNAU, Coimbatore OPMT (Old)	1906 -	1916,1953, 1959,1980	-	1) Consistency of agronomic handling ? 2) No bulk density data
NPMT (New)	1925 -	1926,1952 1958,1980	Irrigated	
Gurdaspur	1956 -	1972	Insufficient soil sampling	-
Ambala	1946 -	1959	- do -	-
Hansi	1952 -	1959	- do -	-
Jullundur	1947 -	1959	- do -	-
Kanpur	1967 -	1972	Insufficient duration as well as sampling	-
Hissar	1967 -	1972		

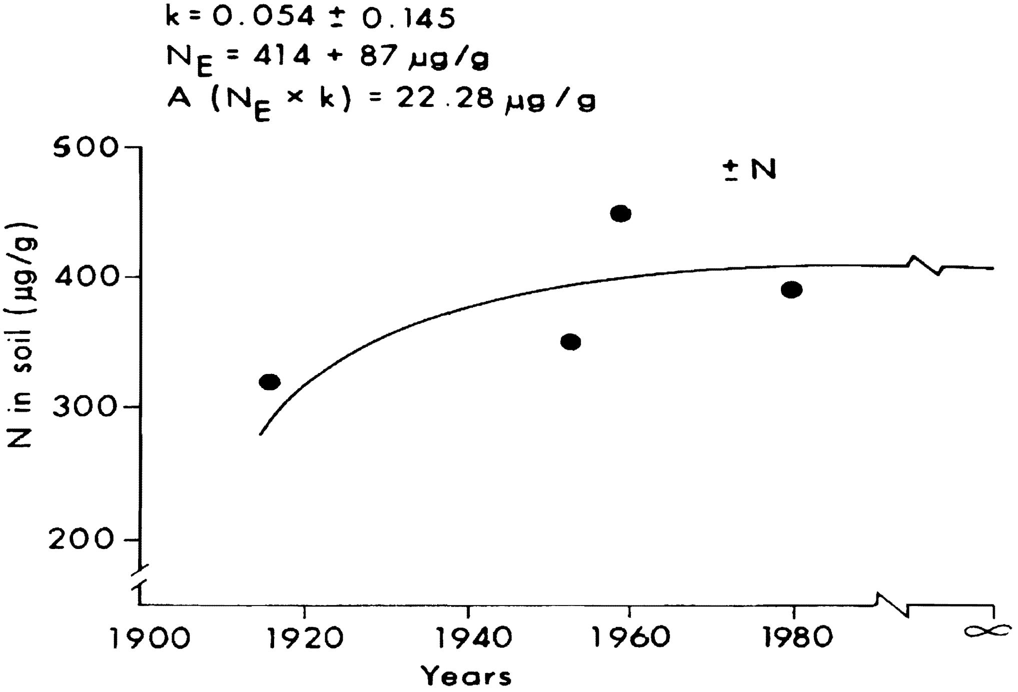


Fig. 1 N content of soil (0-15 cm) in the Old Permanent Manurial Trial, (unirrigated) at TNAU, Coimbatore.

but for the individual treatments, the iterative process did not terminate (that is, successive iterations did not approach a common curve).

However, by taking the average nitrogen concentration of the eight (8) treatments involving inorganic fertilizers (an N X P X K factorial) a curve was fitted (after 14 iterations), which yielded the values for the constants of :

k, decomposition rate = 0.054 ± 0.145

N_E, equilibrium N content = 414 ± 87 µg/g

A, annual addition (N_E x k) = 22.3 µg/g soil

However, there was very poor fit of the data to a smooth curve asymptoting towards an equilibrium value;the standard error of 'k'was very large. However, other authors, have not given standard errors of their data (Krishnamurthy and Ravikumar, 1973).

IV.1.2 Discussion

Prior to examination of the soil data, the long-term experiments at TNAU at Coimbatore appeared to hold considerable promise; even on a world scale, there were very few experiments that had been conducted for such a long time as that at TNAU. Usually, the longer that such an experiment has been conducted, the smaller are effects of errors in soil sampling and analysis. It had therefore, been hoped that an accurate value for 'k' could be obtained from historical Indian data.

Table 5. Old permanent manurial trial at TNAU, Coimbatore

Treatment	N in soil (µg/g)			
	1916	1953	1959	1980
1. Control	290	410	540	310
2. N	280	320	360	430
3. NK	300	410	450	300
4. NP	370	310	500	360
5. NPK	300	400	750	530
6. KP	300	330	450	380
7. K	310	270	470	350
8. P	310	320	370	490
Mean (T1-T8)	315	346	480	390
9. CM	420	430	450	600
10. CMR*	360	300	320	430
Mean (T9 and T10)	390	365	385	515

*CMR = Cattle manure residue i.e. cattle manure at 5 tons/acre/yea
applied for initial 6 years only.

The variability of the data, such that there was only a poor fit to the expected relationships, was disappointing. Some of the possible causes were :

i) There had been changes in crops and techniques of cultivation during the experiments.
ii) Errors in soil sampling and analysis.

The latter would appear to be at least a contributing factor since the averaging of the individual plot data for inorganic fertilizer improved the fit of data to the equation describing organic matter changes in soil. Further, the large apparent change of 134 ppm (480-346) in only 6 years (1953-59) is too large to be due solely to natural N increases, sampling error is the only plausible explanation.

The difficulties encountered highlight again the extreme importance of attention to detail in experiments of this type. It should perhaps be mentioned that nowhere in the 2 published accounts of this experiment (Mariakulandai and Thiagarajan, 1959; Krishnamurthy and Ravikumar, 1973) was there a complete description of the full details of crops or of the sampling and analysis techniques for collecting the soils.

IV.2. EFFECT OF PRE-SEEDING CULTIVATION ON YIELDS, N CONTENT AND N UPTAKE

IV.2.1. Results

IV.2.1.1. Vertisol : In both years the yields of sorghum grain, straw and grain-plus-straw (stalk) consistently increased with increasing depth of cultivation (Table 6), the raised bed and furrow treatment gave comparable yields to those on the deep cultivation treatment; both were cultivated to about the same depth.

For both 1980 and 1981, the yields may therefore be ranked :

$$ZC < SC < DT \approx BF$$

In 1980 the yields on all the three treatments SC, DC and BF were significantly greater than the ZC at the 5% level of significance. In 1981, only the yields of the DC and BF treatments were significantly greater than the ZC treatment, at the 5% level of significance.

The concentration of N in the grain and straw (Table 7) also increased in both years with increasing depth of cultivation. As both the yield and the N content of grain, straw, and grain-plus-straw increased with increasing depth of cultivation, the uptake of N increased considerably as a result of the combination of the parallel increases of the two components (Table 8). The ranking of the N uptake was consistent in both years :

$$ZC < SC < DC < BF$$

In both years, the shallow cultivation gave significantly greater N uptake than the zero cultivation and significantly lesser N uptake than the deep cultivation (at the 5% level of significance). However, the broadbed and furrow treatment gave a significantly higher uptake in 1981 but not in 1980.

Table 6. Effect of different cultivation systems on grain and straw yield (kg/ha) on Vertisol and Alfisol (1980-81)

Plant component	1980 Tillage system**					1981 Tillage system**				
	ZC	SC	DC	BF	SE ±	ZC	SC	DC	BF	SE ±
VERTISOL										
	Sorghum					Sorghum				
Grain	1820	2000	2090	2060	38	730	760	920	940	88
Straw	5880	6580	6910	6870	119	4050	4180	4540	4650	72
(Grain + Straw)	7700	8580	9000	8930	122	4780	4940	5460	5590	87
ALFISOL										
	Millet*					Sorghum				
Grain	790	970	1070	1040	41	2820	1830	2500	2690	405
Straw	2680	2910	2970	3290	166	9800	6860	9100	10540	532
(Grain + Straw)	3470	3880	4040	4330	172	12620	8490	11600	13230	486

* Initial crop of sorghum failed due to heavy shootfly attack; millet sown 20 days after originally sowing sorghum.

** ZC = Zero cultivation
SC = Shallow cultivation
DC = Deep cultivation
BF = Broadbed-and-furrow system

Table 7. Effect of different cultivation systems on the concentrations of nitrogen in grain and straw

Plant component	1980 Tillage system** ZC	SC	DC	BF	SE ±	1981 Tillage system** ZC	SC	DC	BF	SE ±
	Nitrogen concentrations (percent w/w)*									
	VERTISOL									
	Sorghum					Sorghum				
Grain	1.01	1.07	1.12	1.07	0.03	0.95	1.02	1.06	1.10	0.04
Straw	0.69	0.71	0.77	0.78	0.04	0.26	0.28	0.37	0.41	0.05
	ALFISOL									
	Millet					Sorghum				
Grain	2.10	2.00	1.95	2.02	0.08	1.15	1.08	1.05	1.11	0.03
Straw	0.65	0.54	0.58	0.74	0.09	0.26	0.28	0.29	0.27	0.02

Oven-dry basis (105°C)

ZC = Zero cultivation
SC = Shallow cultivation
DC = Deep cultivation
BF = Broadbed-and-furrow system

IV.2.1.2 Alfisol

The alfisol site was subject to many difficulties. In 1980, millet was used as a test crop because the original sowing of sorghum failed, due to a shootfly attack. In 1981, the data from this site was unreliable due to heterogenity caused by two unexpected calamities; firstly, it was accidentally cultivated to a shallow depth (2 cm) by farm staff in the month before the arrival of the monsoon, and later (just after arrival of the monsoon) an adjacent drain overflowed, resulting in flooding of about one-half of the plots.

IV.2.2 Discussion

Grain and straw yields and N uptake increased with the increasing disturbance of the soil, as created by the different depths of cultivation. The maximum increases caused by cultivation were not dramatic, being about 15-20% for yield and about 20-30% for N uptake. However, the increases were very consistent. Even in 1981, when the yields were very low on the vertisol, deep cultivation increased uptake by 50% over the control.

It is well known that cultivation may increase yields, for example, Sykes (1961), Jhamkandikar (1949), and Talati and Mehta (1963) reported increases in yield of both cereal grain and straw due to deep ploughing. However, only Talati and Mehta (1963) measured soil nitrogen; they observed a positive correlation between nitrate content of the soil and yield of millet. These authors suggested that the main effect of increased cultivation to the yield was due to the increased availability of N and/or moisture; however, they did not measure uptake of nitrogen by the crop.

Table 8. Effect of different cultivation systems on nitrogen uptake (kg/ha) in grain and straw

Plant component	1980					1981				
	Tillage system**					Tillage system**				
	ZC	SC	DC	BF	SE ±	ZC	SC	DC	BF	SE ±
					VERTISOL					
			Sorghum					Sorghum		
Grain	18.5	21.2	23.4	22.5	0.72	7.0	7.6	10.0	10.3	0.40
Straw	40.5	46.7	54.2	54.1	2.19	10.6	11.8	16.8	18.9	0.72
(Grain + Straw	59.0	67.9	77.6	76.6	2.41	17.6	19.4	26.8	29.2	0.62
					ALFISOL					
			Millet*					Sorghum		
Grain	15.5	18.7	23.5	22.2	1.09	38.8	23.7	29.1	32.2	53.2
Straw	44.7	47.5	51.5	55.8	2.34	29.1	19.8	28.2	31.3	5.59
(Grain + Straw)	60.2	66.2	75.0	78.0	2.69	67.9	43.5	57.3	63.5	6.72

*Initial crop of sorghum failed due to heavy shootfly attack; millet sown 20 days after originally sowing sorghum.

**ZC = Zero cultivation
SC = Shallow cultivation
DC = Deep cultivation
BF = Broadbed-and-furrow system

Considerable investigations have been made on the effect of ploughing on cereal yields in West Africa. Charreau and Nicou (1971a) and Haddad and Seguy (1972), reported a 21 to 29% increase in yield of millet and sorghum with ploughing over the control. Similar results have been reported for maize at Ivory Coast (Le Buance, 1972); and for groundnuts, cotton, sorghum at Upper Volta (IRAT/Haute Volta, 1972).

Increased severity of cultivation caused increased crop productivity and nitrogen uptake; this indicate that cultivation increased the accessibility of soil N to the crop. However, there are two possible interpretations for the mechanisms responsible :

i) increased mineralization due to increased physical accessibility of substrate to microbial attack (because of increased breakdown of aggregates)

ii) increased root exploration by the crop, and therefore more efficient uptake of nitrogen in the soil, due to the better soil physical conditions created by the deeper cultivation.

IV.2.3 Soil Mineral N

IV.2.3.1 Results

IV.2.3.1.1 Vertisol : The nitrate-N contents of the 0-15 cm and 15-30 cm, and the 30-60 and 60-90 cm depths of the vertisol are shown in Figures 2 and 3 respectively. Detailed data and statistical treatments are given in Appendices I-XVI.

The results were variable, in common with many other results of measurements of nitrate-N in soil profiles (Haynes and Goh, 1980, but some

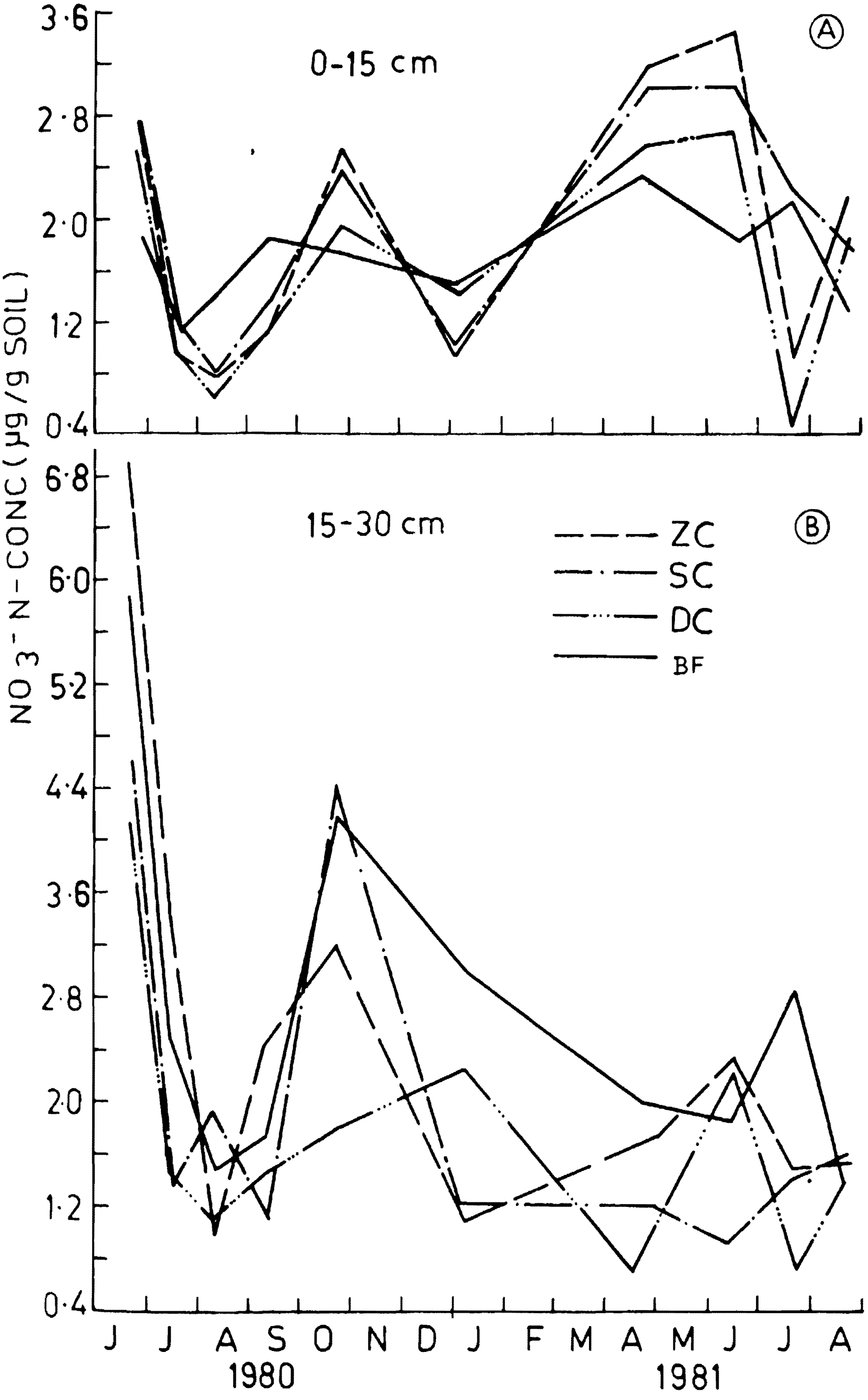


Fig. 2 Seasonal fluctuations in NO_3- N (μg/g) under different systems of cultivation in Vertisol (A = 0 - 15cm, B = 15 - 30cm) ; 1980 - 81

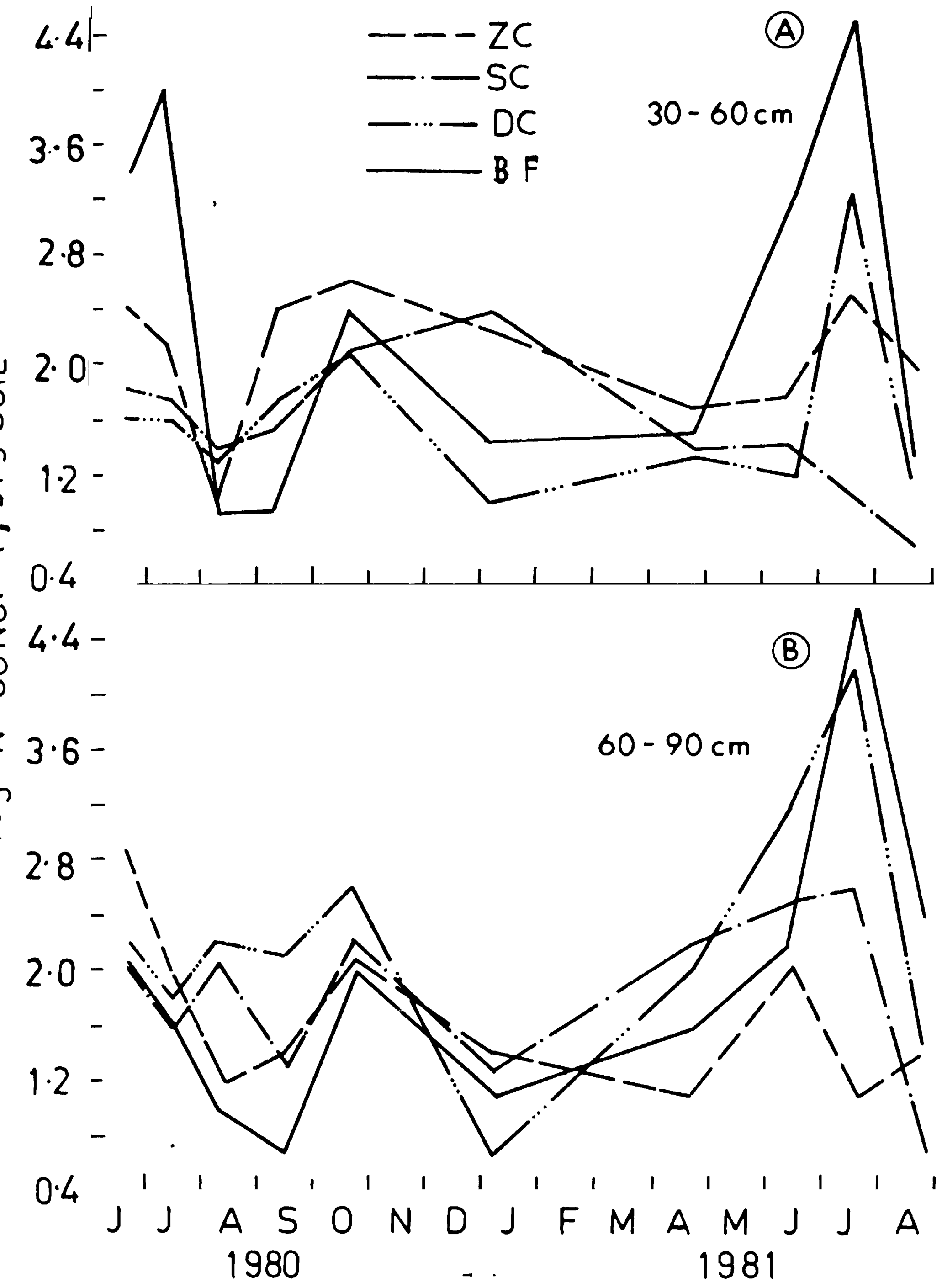


Fig. 3 Seasonal fluctuation in NO_3- N (μg/g) under different systems of cultivation in Vertisol (A= 60 cm, B=60-90 cm), 1980-81

In the lower depths (30-60 and 60-90 cm) changes in nitrate-N during the season tended to follow those in surface soil but changes with time were less, and data were more variable. There was a greater accumulation of nitrate-N under the deep cultivation treatments in June'81. This was presumably due to leaching of nitrate-N to the downward layers.

In general, the concentration and amounts of ammonium-N in the soils changed much less than those of nitrate-N. Seasonal changes were again much larger than effects due to depth of cultivation (Appendix IX-XII and XVI-XX). These were no consistent effects due to cultivation treatments. However, ammonium-N concentrations were quite high; they were quite commonly about the same magnitude as the nitrate concentration. Similar high values of ammonium-N have also been obtained in other soils at ICRISAT (Moraghan, 1981) but the reasons are not known.

IV. 2.3.1.2 Alfisol : The seasonal fluctuations in the mineral-N content of the alfisols (Fig 4) exhibited a somewhat similar pattern to those in the vertisol, except that the increase in the nitrate-N in the surface soil over the 1980-81 post rainy (rabi) season and the first few weeks after the kharif were much greater in magnitude (four to five fold) than that in the vertisol. Also, nitrate-N increased in the 15-30 cm depth during the post-rainy season of 1980-81, as well as in the 0-15 cm depth whereas it only increased in the 0-15 cm depth in the vertisol. The magnitude of this flush after a shower of rain of 124 mm before planting (23 June '81) in the surface soil (0-15 cm) ranged from 18 to 23 kg

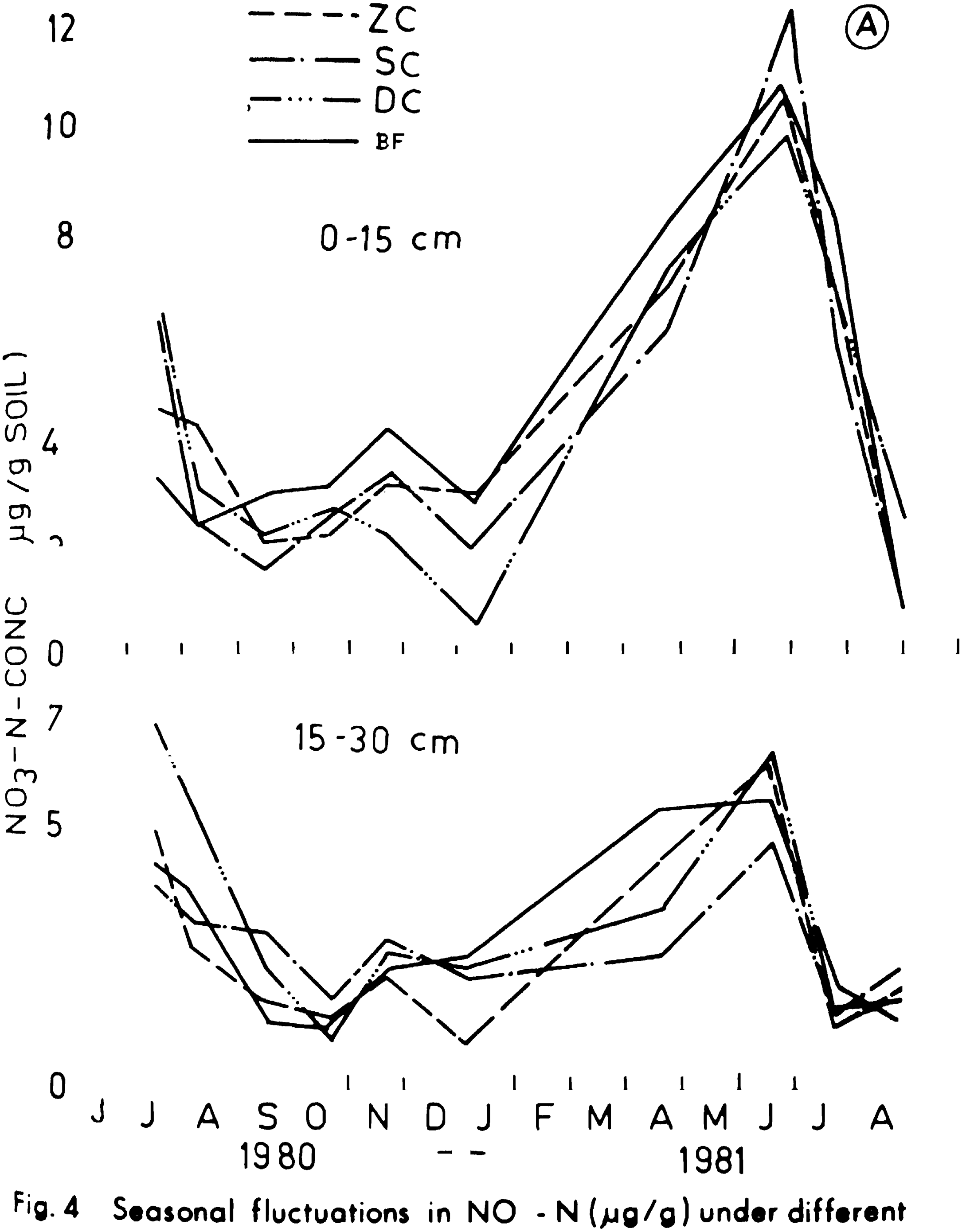


Fig. 4 Seasonal fluctuations in NO - N (µg/g) under different cultivation treatments , Alfisol (A = 0-15 cm , B = 15-30 cm); 1980-81

NO_3-N/ha under the four cultivation systems. During the crop growth phase, the mineral-N in soil decreased rapidly because of crop utilization (uptake) from the soil.

IV 2.3.2 Discussion : The main feature of the results was that seasonal fluctuations caused much greater changes than the cultivation treatments. The results indicate an accumulation of mineral-N during the "dry" season (November-May) and during the first few weeks of the wet period, a subsequent loss of N by leaching and crop uptake during the growing seasons and then accumulation over the following dry season. The values of mineral-N in the growing season of 1981 were not so variable, possibly because the cultivation treatments had by now been imposed for a full year.

There was no consistent trend for one cultivation treatment to be superior. The only clear example of an increase due to treatment was the accumulation of nitrate in subsoil of vertisol before and after the commencement of the rainy season 1981(Figure 3); the peaks for deeper cultivation (BF and DC) were very much more pronounced than shallower cultivation (SC or ZC). This effect of deep cultivation is of interest, although the reason is not clear. The most logical explanation assumes greater movement of water down the soil profile due to deep cultivation; the higher concentrations of nitrate in the subsoil could have arisen from greater mineralization of soil N in deeper layers, or, more probably, from leaching of nitrate from the surface soil.

Other reported work on cultivation and mineralization has also given variable results. Some workers have found an increase in N mineralization on cultivation (Arnott and Clement, 1966; McCalla _et_ _al_., 1962a; Bakermans and deWit, 1970; Free, 1970), this effect was transitory and only lasted a few months (Dowdell and Cannell, 1975). However, Tomlinson (1973), as quoted by Cannell and Finney (1973) did not find significant differences in soil nitrate content between direct-drilled and ploughed treatments.

IV.2.4 Effects of cultivation on biomass in soil

IV. 2.4.1 Results

a) Sample treatment : The effect of sieving the soil on measurements of microbial biomass was examined because of previous controversy. Measurements made on intact soil cores gave smaller value for microbial biomass in soil (Lynch and Panting 1980a). Jenkinson and Powlson (1980) reported that sieving did not affect the determination. This point was of some significance for our studies, because the between-core error was so large that many replicate cores need to be analysed to establish differences between treatments, and the number of treatment comparisons will be markedly reduced if intact cores must be examined. Because of the need to study a large number of cores only two treatments 9ZC and DC) could be examined.

The results of comparisons of microbial biomass measurements on sieved soil and intact cores show that sieving did not markedly affect the biomass measurements under either systems of cultivation or at the two different sampling times (Table 9). In one comparison biomass values under the deep cultivation treatment was slightly higher in the undisturbed soil compared to sieved soil.

Sieving also did not have any consistent effects on soil respiration, which was measured by the amount of CO_2-C evolved (μg/g) from the control (unfumigated soil) during the 0-10 day period. This was sometimes higher after sieving than in intact cores (unfumigated), whereas for other samples, the reverse was true.

b) <u>Effect of cultivation</u> :

Cultivation caused variable effects on biomass. On the vertisol, only one sampling was made (Table 9) because of the extremely wet season, the intractable nature of clay, when very wet, restricted access in the field during the exceptionally wet 1981 kharif season. Biomass-C in sieved samples of soil, was similar under the two cultivation treatments studied (zero cultivation and deep cultivation). Cultivation also did not affect respiration (Table 9).

For the alfisol (Table 10), the microbial biomass in the surface soil was higher under deep cultivation than under no cultivation for a short period after the cultivation treatment had been imposed. But within two months of pre-seeding cultivations, the higher activity under the deep cultivation treatment had diminished and biomass values were similar for both deep and zero cultivation.

Table 9. Comparison of microbial biomass in a sieved soil over two treatments in vertisol. (Sampled on 25 August, 1981).

Tillage treatment	Replicate	CO_2-C evolved		Decomposition flush	[§]Biomass
		[*]Fumigated (F)	[ʃ]Unfumigated (f)	(F-f)	(B)
		µg C/g oven dry soil			
Zero cultivation	I	3.5	1.9	1.6	3.5
	II	3.8	1.6	2.2	4.9
	III	4.1	2.6	1.5	3.3
	IV	2.6	1.6	1.0	2.2
	Mean	3.5	1.9	1.6	3.5
	SE	0.3	0.2	0.2	0.5
Deep cultivation	I	2.7	1.2	1.5	3.3
	II	3.4	1.6	1.8	4.0
	III	2.9	1.5	1.4	3.1
	IV	4.4	3.3	1.1	2.4
	Mean	3.3	1.9	1.6	3.3
	SE ±	0.3	0.2	0.2	0.2

[*] F, 0-10 days

[ʃ] f, 10-20 days

[§] $B - (F-f)/k_c$ where $k_c = 0.45$

Table 10: Comparison of microbial biomass in sieved and disturbed soil cores at two sampling dates in Alfisol, 1981

Treatment	Sample* treatment	Sampling date 23 July	28 August
Zero cultivation	UD	8.8 ± 0.6	9.8 ± 2.6
	S	9.2 ± 0.7	12.1 ± 1.0
Deep cultivation	UD	15.7 ± 0.5	11.3 ± 1.5
	S	14.0 ± 0.5	10.4 ± 0.4-

UD = Undisturbed; S = Sieved

IV. 2.4.2 Discussion

The results are in good agreement with those of Lynch and Panting (1980b). Who found that microbial biomass values were similar in direct-drilled plots and deep cultivated plots, except immediately after ploughing. The increase in biomass value shortly after the disturbance of soil by cultivation, was attributed to the exposure of surfaces of previously inaccessible organic substrates which this promote microbial activity.

The measured microbial biomass in the vertisol were of comparable size to those reported by Lynch and Panting (1980b) for clay soils (3.0-7.5 µg C/g soil). These results were in conformity with those reported by Jenkinson and Powlson (1976b) but are not strictly comparable because they were sampled to a depth of 23 cm, as opposed to 10 cm in this study.

The biomass values for the alfisol were generally much higher (two to three fold) than on vertisols. This may be attributed to more substrate being available for attack by microbes in the alfisol than in vertisol; the clay content in the vertisol (ca 55%) was much higher than that in the alfisol (ca 15%) and thus the organic matter in the vertisol was probably protected from microbial attack to a much greater extent by inclusion within aggregates.

The differences between sieved soil and intact cores on Alfisol were not large nor were they significant at the 5% level of probability for three out of the four comparisons made. This finding is in good agreement with that obtained by Jenkinson and Powlson (1980), who point out that it would be surprising if the passing of structure surface soil through a large mesh sieve (6.25 mm) would cause much change in microbial biomass. A much more vigorous grinding treatment only killed a quarter of the biomass (Powlson, 1980b).

Sieving also did not cause consistent change in the respiration rates of unfumigated soil. In these experiments, the incubation period was long (10 days). Mechanical disturbance has been known to stimulate respiration (Rovira and Greacen, 1957; Powlson, 1980b); but Rovira and Greacen (1957) could detect the effects of disturbance only for a few hours.

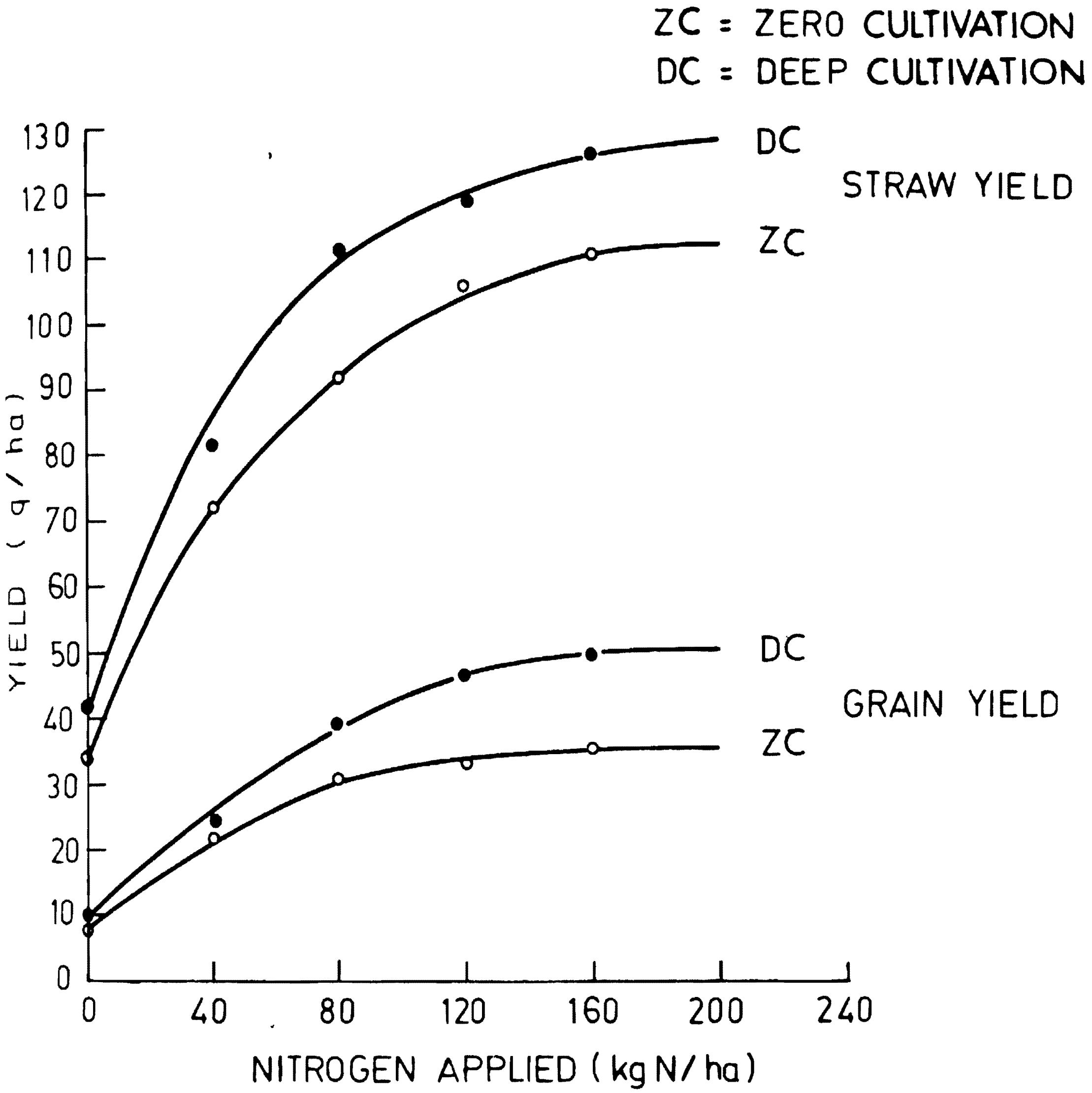
The effects of sieving on microbial biomass in soil in this study and that of Jenkinson and Powlson (1980a) are in disagreement with that reported by Lynch and Panting (1980a). However, the experiments of Lynch and Panting (1980a) were conducted on a very wet soil (64% moisture); compression during sieving may have rendered some regions of their soil inaccessible to chloroform vapour. Incomplete penetration of the soil by $CHCl_3$ vapour would decrease the proportion of the microbial population killed and thus, the size of the flush of activity and thus the estimated biomass. Jenkinson and Powlson (1980) have outlined the advantages of sieving and further point out, that biomass is best and most conveniently measured in coarsely sieved soil which represents a composite sample from as large a number of cores as is practicable to collect.

IV. 2.5 Effect of pre-seeding cultivation on response to N fertilizer

IV. 2.5.1 Results

Yields of grain, straw, and grain-plus-straw were higher on the deep cultivated plots than on the zero-cultivated plots (Table 11). Deep ploughing increased grain and straw yields; the increases were more marked with increasing N fertilizer (Fig. 5) and were significant ($P < 0.05$,see Table 11) only at higher rates of fertilizer-N (N_{80}, N_{120}, and N_{160}).

The concentration of N in the grain and straw decreased with N applied upto 80 kg N/ha, then increased with increasing fertilizer levels. However, deep cultivation caused significant increases (at the 5% level of probability) in the nitrogen content of the grain at almost all levels of nitrogen applied (except 40 kg N/ha); the effect on the concentration of N in the straw was less marked, and non-significant (table 11).



5 Effect of cultivation on nitrogen response to unirrigated Sorghum on a Vertisol.

The uptake of N by the grain and straw and grain-plus-straw was consistently greater under the deep cultivation treatment than under the no cultivation treatment (Table 11). However, the effects increased with the amount of fertilizer N applied such that the increase in total uptake of N was only 2.9 kg/ha on the N_o treatment, but it was 17.0 kg N/ha on the N_{160} treatment. The increase in N uptake was significant (at the 5% level) only for the higher rates of N applied.

IV. 2.5.2 Discussion

Fertilizer N increased concentration of N in the grain only at the two higher N rates (N_{120} and N_{160}). At the two lower rates, the N content of grain w-s reduced, no doubt due to growth dilution - that is, the application of nitrogen stimulated growth to such an extent that the concentration of N in the tissues actually decreased (Table 11). In the earlier experiment (Section IV.2.1), deep cultivation (DC) increased grain yields and total N uptake on the vertisol over the control (ZC) by about 15-20% and 20-30% respectively, in the two years 1980-81. In Table 11, cultivation increased grain yields by 140 kg N/ha and total uptake by 2.7 kg N/ha on the N_o treatment; these represent increased grain yield and N uptakes of 19% and 16%, these values compare well with results in Section IV.2.1 and with those reported by Poulain and Tourte (1970). However, the important finding is that the effect of cultivation did not diminish with increase in added N but, in fact, it increased. This indicated that the effect of cultivation on yield in these experiments was

Table 11 . Effect of cultivation on response of sorghum to N fertilizer.

Plant component	Fertilizer levels (kg/ha)										
	N_0		N_{40}		N_{80}		N_{120}		N_{160}		
	*ZC	**DC	ZC	DC	ZC	DC	ZC	DC	ZC	DC	SE ±
Yield (kg/ha)											
Grain	750	980	2030	2360	3030	3890	3100	4670	4550	4870	346
Straw	3330	4170	7200	8130	9240	11110	10930	11870	11040	12660	678
Grain + Straw	4080	5060	9230	10790	1270	15000	14030	16550	14490	17530	910
N content (%)											
Grain	1.07	1.00	0.95	0.90	1.00	0.92	1.19	1.04	1.19	1.12	0.03
Straw	0.30	0.29	0.34	0.32	0.32	0.29	0.27	0.28	0.36	0.35	0.04
N uptake (kg/ha)											
Grain	8.0	8.9	19.2	20.4	30.5	35.8	36.8	48.5	42.0	55.0	3.91
Straw	10.1	12.1	24.9	26.3	29.4	32.8	28.9	34.4	40.3	44.3	1.40
Total N uptake (Grain + Straw)	18.1	20.0	43.9	46.7	59.9	68.6	65.7	82.9	82.3	99.3	5.50

* ZC = Zero cultivation

** DC = Deep cultivation

at least partly due to soil physical factors associated with cultivation. Cultivation effects on yield could be attributed solely to increased mineralization of N only if the yield increases diminished with increasing N level.

From these results, therefore, it can be concluded that the effect of cultivation of increasing yield and N uptake by cereals was due to increased accessibility of N in the soil to the crop, but that this increased accessibility was due at least partly to improved soil physical conditions that allowed better collection of N in the soil by plant roots.

IV. 2.6 Effect of post-seeding cultivation on mineralization of N in soil

IV. 2.6.1. Results

Yields of grain, straw, and grain plus straw on the alfisol were greater where the soil had been disturbed after seeding, either by deep cultivation or by surface disturbance. The yields of millet on treatment which received one deep inter-row cultivation initially with subsequent shallow hoeings after seeding and treatment B which received no initial ploughing but three shallow cultivations after the crop was planted, were significantly greater than yields on no-cultivation treatment at the 5% level of significance (Table 12).

Soil disturbance or cultivation did not cause significant increases in the N concentration in grain and straw but all three cultivation/disturbance treatments caused significant increases in the N uptake of grain,

Table 12. Effect of post-seeding cultivation on grain and straw yield (kg/ha), N content (%) and N uptake (kg/ha) of millet in Alfisol, 1981.

Cultivation treatment	Cultivation depth				
	A	B	C	D	SE ±
Initial	Nil	Nil	10 cm (1)[a]	10 cm (3)[a]	
Subsequent	Nil	2 cm (3)[a]	2 cm (2)[a]	Nil	
(Surface disturbance)					
Yield (kg/ha)					
Grain	250	370	390	320	28.8
Straw	2720	3880	4070	3490	246.2
N-content (%)					
Grain	1.24	1.3	1.28	1.25	0.03
Straw	0.80	0.86	0.90	0.81	0.04
N-uptake (kg/ha)					
Grain	3.1	4.8	4.0	5.0	0.33
Straw	21.9	33.6	36.6	28.3	1.75
(Grain + Straw)	25.0	38.4	40.6	33.3	1.42

a, numbers in parentheses indicate the number of cultivations straw and grain-plus-straw (at the 5% level of significance) over that on the no cultivation treatment. However, the differences between the total N uptakes on the 3 cultivation treatments were not statistically significant, at the 5% level of probability (Table 12).

IV. 2.6.2 Discussion

The results show that disturbance of the soil surface - by either shallow or deep inter-row cultivations made after crop emergence - increased yields and N uptake of grain and straw when compared to the control treatment in which there was no cultivation after sowing. Dev et al. (1970) obtained similar results that is an increase in yield, where cultivations consisted of one deep ploughing and several subsequent cultivations. However, in the present work, there was no appreciable difference between the shallow cultivation and the deeper more thorough disturbance of the soil. This indicated that the breaking of the surface crust, which forms on alfisols after each rain, was just as important as the disturbance of a much greater depth of soil. Shallow cultivation would affect mainly the surface of the soil; it is only deeper cultivation that would be expected to directly influence mineralization rates.

Surface crusting is a problem on alfisols, and it causes considerable loss of effective rainfall due to shedding of rain by surface runoff eg. see Oades, 1976). The result obtained here was interpreted as indicating that the minimizing of surface runoff and maximizing of infiltration of water into soil by frequent disturbance of soil surface, was in fact the major factor resulting in the improved yields and N uptake. The next experiment was therefore, conducted specially to examine this point.

IV 2.7 Effect of surface crusting on nitrate movement in alfisol

IV 2.7.1 Results

The proportions of rainfall that were lost as surface runoff from the untreated plots were much greater than those from the plots in which the structure of the surface soil was stabilized with PVA. The substantial runoff from untreated plots amounted to on an average of 46% of the rainfall; the PVA-treated plots lost 7% of rainfall as runoff.

On the PVA-treated plots, the nitrate-N concentration in the soil increased with increasing depth in the profile to a peak in the 30-40 cm depth; with further increases in depth, the concentration of nitrate-N decreased (Fig. 6 , Table 14). The untreated plots, the peak concentration remained at a much shallower depth (0-10 cm).

Table 13. Influence of PVA* on infiltration of rainfall on alfisols

		RUNOFF							
	Rain-fall (mm)	Amount (mm)				As percent of rainfall			
Date		PVA treated		Untreated		PVA treated		Untreated	
		Plot 1	Plot 2	Plot 3	Plot 4	plot 5	Plot 6	Plot 7	Plot 8
Aug 18	13.6	0	0	3.8	2.8	0	0	28	21
Aug 30	44.5	3.1	2.5	19.0	16.3	7	6	43	37
Sept 2	11.4	0.5	0	4.6	3.9	4	0	40	34
Sept 3	22.0	4.0	2.2	16.4	17.0	18	10	45	77
Total	91.5	7.6	4.7	43.8	40.0	-	-	-	-
Mean	-	-	-	-	-	7.9	4.4	47.9	43.8
Treatment means		6.2		41.9		6.2		46.0	

* PVA, Polyvinyl alcohol

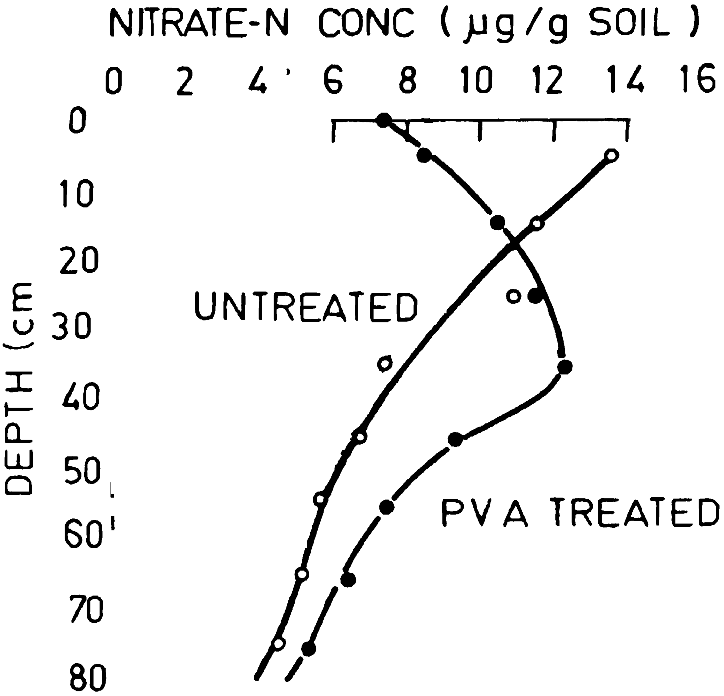


Fig. 6 Movement of Nitrate-N in PVA treated and untreated Alfisol, under natural rainfall conditions.

Table 14. Mineral-N concentration (µg/g) in an alfisol profile as affected by PVA treatment

Depth (cm)	PVA treated		Average	SE ±	Untreated		Average	SE ±
	$NaNO_3$	KNO_3			$NaNO_3$	KNO_3		
0-10	5.2	11.6	8.4	2.26	13.0	14.2	13.6	0.430
10-20	8.2	11.3	10.1	1.28	10.2	13.6	11.3	0.910
20-30	8.9	14.2	11.3	1.70	10.6	12.1	11.3	0.530
30-40	9.2	15.1	12.2	1.93	7.1	7.2	7.1	0.005
40-50	8.0	10.3	9.2	0.95	7.0	6.8	6.9	0.070
50-60	7.8	8.4	7.6	0.51	6.0	5.9	5.9	0.005
60-70	7.1	6.5	6.7	0.57	5.2	5.3	5.2	0.005
70-80	6.1	5.6	5.8	0.18	4.8	5.0	4.9	0.070

PVA = Polyvinyl alcohol

IV. 2.7.2 Discussion

It is well known that PVA applications can prevent crust formation by stabilizing the structure of aggregates. An outstanding example of stabilization of structure in the field, on a Australian Rhodustalf (Oades, 1976) led us to try the same procedure on our alfisol. The dramatic reduction (85%) in runoff volume due to the PVA treatment (Table 13) was much larger than the 50% reduction observed by Oades (1976). Oades observed that the volume of runoff at any one time over a 20 min-period was approximately twice as much from the untreated areas. This two-fold increase in runoff due to the deterioration of structure after rainfall in the S.Australian alfisol contrasts with the average 5 fold increase in our alfisol. Oades and Grierson (1978) in a later publication, report that PVA increased the proportion of water-stable aggregates and that this treatment also significantly increased the infiltration rate of water.

For the present study the important consequence of the decreased runoff was the fact that there was improved infiltration of water. Addition on nitrate to the soil surface provided a means of independently assessing the extent of increased infiltration of water into the soil where the surface soil was better structured. The approach was particularly successful (Fig. 6); the peak nitrate concentration had passed the 30 cm depth on the PVA treated plot, but did not pass below 10 cm on the untreated plots.

These results therefore provide good evidence to support the conclusion reached from the results of the post-seeding cultivation studies (Section 2.6). It was suggested from results of this experiment (Table 14)

(Section 2.6) that the primary effect of the several post-seeding cultivations on the alfisol was due to improved infiltration of water into the soil rather than to increased mineralization of nitrogen. Each repeated cultivation broke the soil crust and would have allowed more rain to enter the soil than if the crust had remained intact. The data in Table 13 therefore show that preservation of an open structure of the surface soil can increase yields by reducing runoff by as much as 85% (45% to 6% rainfall) and therefore increase infiltration by as much as 40% (55% to 94%).

Therefore, while increased cultivation may increase yield and N uptake, reflecting increased accessibility of soil N to the plant root, this increased accessibility may not be due only to a direct mechanism of increased mineralization but as well as to improved moisture relation which would promote both mineralization of N and uptake soil N by plant.

IV. 2.8 Effect of broad-bed and furrow

IV. 2.8.1 Results

The micro-topographic study of changes in soil organic carbon contents across the beds of a broadbed-and-furrow system showed that carbon contents of the soil exhibited a systematic variation across the bed. The treatments receiving only inorganic fertilizers (nitrogen, or nitrogen plus phosphorus) had a lower organic carbon content in the bed that that in the furrow (Fig.7). The reverse was true on plots which received only FYM application; the organic carbon content of the soil was higher ($\sim$0.35) than in the bed than in the furrow ($\sim$ 0.25).

IV 2.8.2 Discussion

Repeated applications of FYM increased the organic carbon content of the beds relative to that of the furrows. This result is in good agreement with the results obtained by many other workers (Kanwar and Prihar, 1962; Mandal and Pain, 1965; Maurya and Ghosh, 1972 and Acharya and Rajagopalan,1956) who reported that continuous application of FYM increased the carbon or organic matter content of the soil. Acharya and Rajagopalan (1956) reported a 20 to 40% increase in carbon content of the soil over the control plots when FYM was applied at the rate of 4000 to 8000 kg/ha.

The higher organic carbon contents in the center of the bed obviously originated from the original placement of the FYM; the FYM was placed on the bed during each annual application. None was placed in the furrow. As the furrow was used as a permanent traffic zone for bullocks, wheel implements, and laborers, compaction is restricted to the furrows, there was no traffic on the beds, the FYM application was usefully placed only on the section that was optimum for plant growth; nevertheless, the amounts of organic carbon mineralized annually were obviously less than that added as FYM.

Inorganic fertilizers were applied only to the beds. This practice has obviously encouraged root exploitation in the beds. The cultivation of the bed, but not the furrow, would promote greater mineralization of organic N in the bed and uptake of the mineral N by plants. Further, the continued use of the furrow as a traffic zone has resulted in considerable

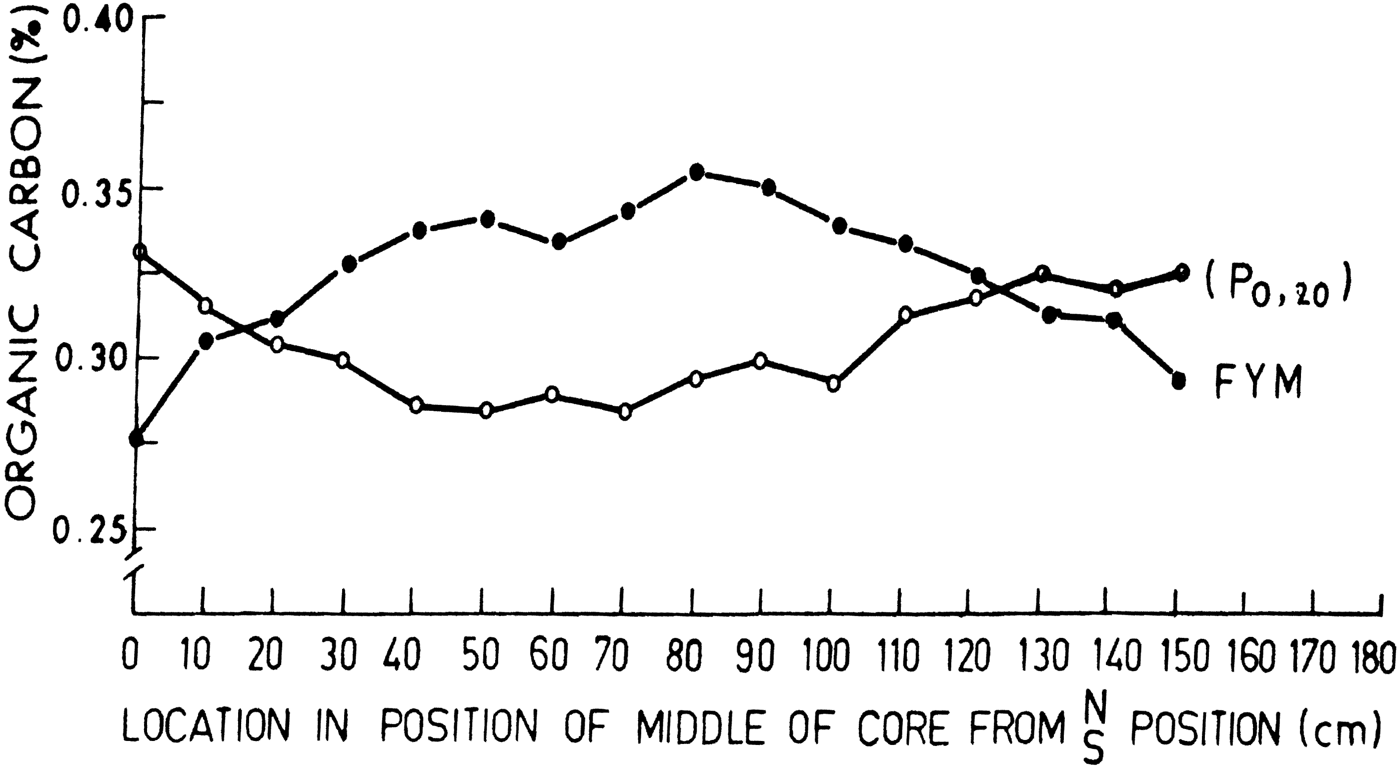


Fig. 7 Effect of fertilizer and manure application on organic carbon content in (0-30 cm) soil across a bed and furrow in an Alfisol

accumulated compaction and consolidation (ICRISAT, 1979), thus creating a zone under the furrow that would be less penetrable to roots than the soil under the bed. Additionally, the lack of cultivation in the furrow would result in less mineralization of N than in the bed. Thus the trend to higher C contents in the furrow than in the bed can be interpreted as a result of lower mineralization due to lack of cultivation, and also of lack of leaching and uptake of N due to the presumed poorer ability of water and roots to move through the more compact soil.

These results provide a useful guide for future fertility studies at ICRISAT. To date, there has been little characterization of changes in chemical characteristics of the soil due to the microtopographic changes caused by introduction of the broadbed-and-furrow system of cultivation. The fact that definite changes can be detected, indicates the need for caution in where a high degree of accuracy is required; one obvious example is,studies of the changes in total soil nitrogen or carbon contents.

V GENERAL DISCUSSION

This study commenced because of lack of data on the decomposition and turnover of organic matter in the soils of the Indian semi-arid tropics. Although there are many examples in the literature which show that the organic matter contents of soils in India are low, there have been very few attempts to quantify the changes in the organic matter contents.

It is widely considered partly as a result of work in India, (Jenny and Raychaudri, 1960) that organic matter contents of tropical soils are low primarily because of the prevailing high temperatures which result in high decomposition rates of the soil organic matter. But so far, there are no published values for the decomposition constant (k) of organic matter for soils under dryland agriculture in SAT India. The value for 'k' of 0.054 (page 50) for the very long-term experiment at TNAU, Coimbatore, is therefore the first reported such value in India. This value, which is synoyomous with an annual decomposition of rates 5.4%, is well within the range one would expect for tropical soils. Researchers in other countries in the tropics have reported rates 'k' of 4 to 7% in uncultivated soils (Gunesekara, 1980) and up to 10-12% under cultivated crops (Wetselaar and Norman, 1960). In contrast, the decomposition rate for soil organic matter in cool temperate or mediterranean climates have commonly been as low as 1% under a no-cultivation system (e.g. grassland) and up to 2-4% under continuous cultivation (Greenland, 1971; Russell, 1962).

The implications of high decomposition rates are commonly not fully recognized. The major concern has been that these result in low organic matter levels in the soil. This is correct, but too much emphasis has been given to the fact that the organic matter contents are low. One important fact, has been ignored; a low organic matter content and a high decomposition rate can produce a moderate amount of mineralized N. In the tropics, a greater amount of nitrogen will be mineralized than in a soil of identical organic N content in a temperate zone.

Although it is commonly recognized that organic matter levels are lower in the tropical soils, it must be mentioned that all workers are not in agreement. For example, Sanchez et al ., (1982) suggested that the organic matter levels of comparable temperate and tropical soils are similar. However, in presentation of their data at the Interantional Soils Conference, 1982 (Sanchez, 1982; personal communication), no mention was made of the previous history of the soils used so far in their comparative study.

Although the study of soils at Coimbatore has given a realistic decomposition rate (k=0.054), this estimate had an unsatisfactorily high error (± 0.145). The high variability in the base data, i.e. the soil nitrogen values, would seem to arise at least partly from sampling error, because averaging across treatments gave input data that were sufficiently consistent to be acceptable for statistical treatment. This again highlights the need for very careful attention to methodology in studies of this nature. The maintenance of long-term experiments and the measurements made in these, require continued attention to detail. One of the difficulties, of course, is that methodologies for sampling may differ between workers; several different scientists would have conducted the agronomic work in this experiment over its life of 65 years. Thus systematic errors between successive operators of the experiment may have contributed as much to error as the errors within an individual sampling. However, despite these difficulties, this permanent experiment at TNAU, Coimbatore was the only one of a number of long-term experiments that approached suitability for this initial study. Because of its long duration which is exceeded by only very few other long-term experiments in the world, efforts to improve the output of data from this experiment should be given very full encouragement.

Long-term experiments provide data which are an average over a number of seasons, and the fluctuations of results between and within seasona are smoothened out. However, only a small number of treatments can be examined; further, once commenced, most long-term experiments have little, if any flexibility for changes in design. The old PME at TNAU, Coimbatore was useful in providing data on the changes in organic matter over many years, for a cultivated soil. However, there were no treatments providing effects on different intensities of cultivation. To study this, the annual field experiments described in sections III.2.1, III.2.2 and III.2.3 were conducted at the ICRISAT Center.

The field experiments undertaken in this study showed clearly that increasing the disturbance of soil before seeding, increased grain yields (Table 6), and total N uptake (Table 8) by the crop. Although the yield increases were not large (15-20%), both yield and the increased N uptake (20-30%) showed that cultivation improved the accessibility of the soil-N to plants. It was not possible in these preliminary experiments to separate clearly between the two contributing factors of improved mineralization and soil physical factors (e.g. improved root penetration into soil and improved infiltration rate).

However, the conduct of these initial experiments over 2 rainy season provided useful information on the mineralization of organic nitrogen in the soil. The measurements of mineral-N showed that seasonal fluctuations in nitrate-N contents, which were presumably caused by the marked changes in rainfall and soil water status throughout the year, were much larger than any changes in nitrate-N due to cultivation. A pronounced accumulation of mineral nitrogen developed over the dry season, and the first few weeks of the 1981 rainy season. This is due to the so-called 'Birch effect' which describes the flush of microbial activity during the first few days after rewetting of an air-dry soil. The increase in nitrate-N in the soil profile was of a much greater magnitude (four to five fold) in the alfisol than in the vertisol.

However, the nitrate-N which accumulates over the dry season and the first few weeks of the rainy season is susceptible to leaching. The present results (see section IV.2.1) indicate that pre-monsoon sowing would give maximum benefit to crops in vertisols by promoting the most efficient use of the mineralized soil N. But the flush of decomposition in the vertisol is much smaller than that in the alfisol. However, dry sowing is not practised on alfisols; crops are not usually sown until after the rains have wet the soil to a depth of 10 or 20 cm (ICRISAT,1979). The tendency of these soils to form surface crusts, and their low water holding capacities are major factors preventing early sowing. The possible benefits of planting as early as possible on alfisols, so that crops can utilize this flush on N mineralized before it is leached, are obvious; not only is the flush of N mineralization greater on alfisols, but leaching losses will also be greater.

The limited measurements of biomass also indicated that the microbial activity changed during the growing season, and that the activity in alfisols was greater than in vertisols (Tables 9 & 10). Tillage increased biomass but only for a short period after the ploughing and the pre-seeding cultivation. Although only a few measurements were made in this work, the results agreed with those from temperate areas. Lynch and Panting (1980b) also observed that biomass was significantly greater in ploughed soils than in zero-tilled soils, but only early in the season; later in the season the zero-tilled soil had a higher activity than the ploughed soil. Jenkinson and Powlson (1980) also came to similar conclusions. However, Lynch and Panting (1980b) indicate that differences in severity of cultivation cause changes only in the pattern of activity during a season; they considered that the total amount of N mineralized on an annual basis was not changed by cultivation. If this is correct for our soils at ICRISAT, then the increased N uptake due to cultivation represents an improved efficiency in the utilization of mineralized N. There is need for further studies to investigate this point and also to compare the role of such biomass studies in the tropics with that in temperate zones. Such effects of cultivation were expected, but until recently there has been little evidence from which to predict the time scale over which the changes would occur.

The biomass measurements clearly showed that microbial activity was much greater in the alfisol than in the vertisol (Tables 9 & 10). There are also similar marked differences between the yields on the control plots of these two soils in 1981 (see Table 6), when soil had been under a low-N-input system for the previous season. These results are also in agreement with the size of the flush of mineralization (see figures 2 and 4) that occurred shortly after the onset of the rains.

The higher biomass in the alfisol than in the vertisol probably developed because more substrate was available for microbial attack in the alfisol. The clay contents of the alfisol and vertisol were ca 25% and 55%; the organic matter was presumably protected from microbial attack by its inclusion within aggregates to a much greater extent in the vertisol than the lower clay content in alfisol. In Table 15, the results show that not only was the biomass higher in alfisol but the proportion of soil carbon as biomass-C was over 5-fold higher for the alfisol than that for the vertisol.

Table 15: Biomass-C (as percent of total carbon) in alfisol and vertisol,1981

Measurement	Alfisol	Vertisol
Biomass (g C/g soil)	11.4	3.4
* Total C (%)	0.35	0.60
Biomass-C as percent of total carbon	0.326	0.056

Source: Mean value of those reported in Tables 9 (alfisol) and 10 (vertisol).

Source: Table 1.

Although the above results show the importance of studies on the mineralization of nitrogen, the results in other experiments increasingly indicated the importance of soil physical conditions and the effects of cultivation on these. On the vertisol, yield differences between cultivated and uncultivated treatments increased with increasing inputs of fertilizer nitrogen (Table 11). This showed quite clearly that cultivation affected crop yields on the vertisol, primarily by its effects on the soil physical conditions, rather than by mineralization of N. This result was not expected, because the vertisols are self-mulching, and maintain a good structure in the surface soil.

In contrast, alfisols at ICRISAT possess a poor water stable structure in the surface soil. Preserving a good structure of the soil surface of an alfisol by stabilization with PVA (Polyvinyl Alcohol), was clearly shown to markedly improve the entry of water into an alfisol; the PVA treatment reduced runoff from 45% to 6% (Table 13) of the rainfall, and thus presumably increased infiltration from 55% to 94% of rainfall (Section IV.2.7). The improved moisture relations per se would have promoted mineralization as well as plant growth. Further. the improved structure of the surface soil would have improved aeration, thus creating a better exchange of oxygen and carbon dioxide; however, there is little information on the importance of aeration on alfisols at ICRISAT, except that poor aeration has been implicated as a contributory cause of an occurrence of iron chlorosis in groundnuts (J. Koteshwar Rao, 1982*). However, the relative importance of these various contributions to increased yield could not be assessed in these experiments. Nevertheless, it can be inferred that the frequent mechanical disturbance of the soil surface increased yields (Table 12) due to similar causes. Surface crusting is known to be a problem on alfisols. Maintenance of a stable friable soil structure will obviously optimize water entry into soil. The two simple experiments in sections IV.2.6 and IV.2.7 indicated the importance of surface structure of the soil. The Indian farmer is also aware of this factor. On alfisols, he commonly tills the soil to a very shallow depth with a 'bakra' (blade harrow) almost as frequently as after each rain. While this shallow soil disturbance obviously kills weeds, and so reduces

J. Koteshwar Rao, 1982. Investigations into nutritional disorders causing chlorosis of groundnut at ICRISAT Center. M.Sc. thesis submitted to APAU, Rajendranagar, Hyderabad.

water loss by this route, it also obviously decreases surface runoff and promotes infiltration. His many post-seeding shallow cultivations would also improve moisture relations in the soil. While the improved moisture content of the soil would also increase mineralization, further work is needed to determine the relative contribution of water and mineralization as individual factors.

The microtopographic study of changes in soil organic carbon contents across the beds and furrow system, indicated a lower value in the bed than that in the furrow. The higher content of carbon in the furrow is interpreted as a result of lack of cultivation and a lack of root activity. Since definite changes in the soil carbon status could be detected these results could provide a useful guide for future fertility studies at ICRISAT.

These studies on the effects of cultivation have shown that organic matter and mineralization cannot be considered in isolation from other consequences of cultivation especially soil physical properties and soil aeration as a consequence of moisture relations in soil. This in turn reflects the fact that moisture as well as nitrogen is a limiting factor in the SAT environment. Studies in the future will need to consider both physical and biological factors.

VI SUMMARY AND CONCLUSIONS

The studies in this thesis initially involved examinations of historical data from long-term experiments conducted elsewhere in India, and subsequently annual experiments were conducted to determine the effect of cultivation on organic matter decomposition, crop yields and N uptake. The results are summarized:-

1. Of the 9 long-term Indian experiments examined, only one (the Old Permanent Manurial Trial at Tamil Nadu Agricultural University, Coimbatore) was reported sufficiently fully to allow calculations of decomposition rates of organic matter in soil to be attempted. The results were:

(i) The data from this experiment was fitted to the standard equation

$$N = N_E + (N_O - N_E)\, e^{-kt}$$

and, the values determined for the constants were

$k = 0.054 \pm 0.145$

$N_E = 414 \pm 87 \mu$ g/g soil

$A = 22.3$ μg/g soil $(= k.N_E)$

$N_O = 310$ μ g/g soil

(ii) However, the high error (± 0.145) of the calculated decomposition constant indicates the difficulties of conducting long-term experiments, and the need to reduce the effects of both random and systematic error by more attention to methodology of sampling.

2. Annual experiments conducted at ICRISAT showed that increasing the depth of the preseeding cultivation increased the cereal crop yield and N uptake on both vertisol and alfisol. These effects were attributed as much more to the effect of improvement in the soil physical characteristics of the seedbed than to effects of cultivation on mineralization *per se*, because:

(i) Concentrations of mineral-N were not consistently affected by cultivation; seasonal fluctuations in the soil moisture regime caused a much greater effect on mineral-N than the cultivation treatments.

(ii) Disturbance of the soil surface after crop emergence increased grain yield and N uptake by grain and straw. The disturbance was equally effective for very shallow (1 cm) or deep (10 cm) cultivation, it was concluded that the major effect of disturbance was improved water entry into the soil resulting from the repeated breaking of the surface crust.

(iii) A subsequent experiment confirmed that the prevention of formation of the surface crust (by application of the stricture-stabilizing agent, PVA), reduced the amount of rainfall lost as surface runoff from 45% to 7%; by inference, the infiltration was increased from 55% to 93%, or by over 70% by the improved surface structure.

3. Studies on the mineralization of N in soil showed that.

(i) The seasonal drying and wetting cycle caused a pronounced accumulation of nitrate-N between December and June. The accumulation was much higher (3-4 fold) in the alfisol than in the vertisol.

(ii) Biomass was higher in the cultivated than in the direct-drilled soil in the month after cultivation and seeding, but this order was reversed later in the season.

(iii) Biomass differed considerably between vertisol and alfisol. This difference was in agreement with the amount of N released on wetting and drying of soil, and with the amounts of N taken up by unfertilized cereal crops.

4. It is concluded that cultivation increased accessibility of N in the soil to the cereal crops because N uptake was increased, but that the mechanisms involved were possibly increased mineralization but physical factors such as improved entry of water into soil and an improved medium for root exploration were important. Further research in these areas is needed.

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*Original not seen.

Appendix I: Effect of cultivation treatments on nitrate-N concentration (ug/g) in the surface soil (0-15 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jan	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	2.8	3.1	0.5	1.2	1.5	2.3	2.5	3.1	0.6	0.8
	3.1	0.5	1.2	1.4	0.4	0.0	1.8	1.8	0.5	1.4
	1.8	0.6	0.0	0.5	3.9	1.5	3.1	3.5	-	4.5
	2.6	0.2	0.8	1.9	2.3	0.8	2.9	2.5	-	1.0
Mean	2.6	1.1	0.6	1.3	2.0	1.2	2.6	2.7	0.6	1.9
SE ±	0.3	0.65	0.25	0.3	0.75	0.5	0.3	0.35	0.1	0.85
SC	3.3	1.5	1.0	1.2	2.4	0.2	1.4	2.7	1.4	2.4
	4.0	0.9	1.3	1.6	3.2	3.1	3.7	2.2	3.2	3.0
	2.0	2.2	2.1	1.8	0.9	0.2	4.1	3.8	-	0.7
	2.1	0.6	0.3	1.0	2.1	0.7	3.0	3.8	-	112
Mean	2.9	1.3	1.2	1.4	2.4	1.1	3.1	3.1	2.3	1.8
SE ±	0.5	0.35	0.3	0.2	0.3	0.7	0.6	0.6	0.9	0.55
DC	5.6	2.1	0.2	0.5	4.6	1.5	3.6	5.1	0.5	1.2
	1.0	0.5	1.8	0.5	1.8	1.7	2.2	4.3	1.5	0.7
	1.4	0.3	1.0	2.8	3.6	1.3	2.7	1.8	-	2.4
	3.4	1.1	0.2	1.8	0.3	0.1	4.0	2.8	-	3.0
Mean	2.9	1.0	0.8	1.4	2.6	1.2	3.1	3.5	1.0	1.8
SE ±	1.2	0.4	0.4	0.55	0.95	0.35	0.4	0.75	0.5	0.55
BF	3.5	1.9	1.9	1.7	2.6	2.2	1.5	0.5	4.1	1.5
	0.5	0.7	2.6	1.6	2.3	2.7	1.9	1.8	0.3	1.0
	1.7	0.8	1.2	1.9	1.8	0.7	3.9	3.1	-	2.0
	1.9	1.8	2.0	2.5	0.5	0.5	2.2	0.8	-	0.7
Mean	1.9	1.3	1.9	1.9	1.8	1.5	2.4	1.6	2.2	1.3
SE ±	0.6	0.3	0.3	0.2	0.45	0.55	0.55	0.6	1.8	0.3

* Incomplete sampling due to onset of continuous wet weather.

Appendix II: Effect of cultivation treatments on nitrate-N concentration (μg/g) in the sub-surface soil (15-30 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jan	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	4.5	2.0	0.7	0.9	1.3	3.0	0.3	2.9	1.2	1.0
	4.2	0.7	1.4	1.8	0.1	0.5	0.5	2.4	0.2	2.7
	4.5	1.5	1.2	2.6	5.0	0.3	0.8	2.0	-	1.3
	3.1	1.8	1.1	0.8	0.8	5.6	1.2	1.6	-	0.5
Mean	4.1	1.5	1.1	1.5	1.8	2.4	0.1	2.2	0.7	1.4
S.E.±	0.4	0.3	0.2	0.4	1.1	1.2	0.2	0.3	0.4	0.4
SC	6.7	1.8	1.8	1.0	3.5	1.7	0.5	0.5	0.5	1.3
	3.9	1.0	0.4	0.5	7.1	1.2	1.5	0.9	2.3	2.2
	4.7	1.1	4.9	0.2	4.1	1.1	2.9	0.4	-	0.8
	3.1	1.7	0.6	2.7	2.8	0.9	0.2	1.9	-	2.0
Mean	4.6	1.4	1.9	1.1	4.4	1.2	1.3	0.9	1.4	1.6
S.E.±	0.8	0.2	1.1	0.6	0.9	0.2	0.6	0.4	0.9	0.3
DC	7.7	3.5	1.7	0.8	3.8	0.3	3.1	5.7	2.5	0.4
	5.6	4.4	0.2	6.6	3.7	2.7	0.2	1.4	1.1	0.3
	6.8	2.2	0.2	2.1	3.8	1.2	2.2	0.4	-	2.5
	7.3	3.5	1.7	0.2	1.7	0.2	1.2	1.8	-	1.7
Mean	6.9	3.4	1.0	2.4	3.3	1.1	1.7	2.3	1.8	1.7
S.E.±	0.5	0.5	0.5	1.4	0.5	0.6	0.7	1.2	0.5	0.5
BF	6.8	3.0	2.0	2.8	4.1	2.1	3.2	3.3	5.2	1.2
	5.6	1.8	1.6	1.3	2.3	1.6	1.1	1.6	0.4	0.0
	5.4	2.7	1.4	1.4	8.2	4.1	1.5	2.0	-	0.1
	5.7	2.5	1.0	1.5	2.6	4.3	1.9	0.4	-	2.2
Mean	5.9	2.5	1.5	1.7	4.3	3.0	2.0	1.8	2.8	1.0
S.E.±	0.3	0.3	0.2	0.4	1.4	0.7	0.5	0.6	1.7	0.6

* Incomplete sampling due to onset of continuous wet weather.

Appendix III: Effect of cultivation treatments on nitrate-N concentration (μg/g) in the sub-surface soil (30-60 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	2.2	2.5	2.3	1.7	3.1	1.7	2.5	1.6	4.5	0.8
	1.0	2.3	1.2	1.0	1.6	1.1	0.8	2.2	2.0	1.8
	0.9	1.0	0.5	2.3	2.3	1.0	1.0	0.0	-	0.5
	2.3	0.8	1.1	1.7	1.6	0.5	0.9	1.0	-	1.5
Mean	1.6	1.6	1.5	1.7	2.2	1.1	1.3	1.2	3.3	1.2
S.E.±	0.4	0.5	0.4	0.3	0.4	0.3	0.4	0.5	1.3	0.3
SC	3.2	0.5	1.7	1.7	4.8	2.7	0.0	2.0	1.7	0.3
	0.8	1.3	1.2	0.7	2.5	3.1	1.6	1.5	0.5	1.0
	1.0	1.9	1.0	2.2	0.4	1.4	1.9	1.2	-	0.3
	2.2	3.2	1.5	1.5	0.7	2.4	1.2	1.0	-	1.3
Mean	1.8	1.7	1.4	1.5	2.1	2.4	1.2	1.4	1.1	0.7
S.E.±	0.6	0.6	0.2	0.3	1.0	1.4	0.4	0.2	0.6	0.3
DC	2.6	3.0	0.5	1.6	2.6	3.8	0.1	0.5	2.3	1.7
	2.2	2.8	0.5	3.4	2.4	2.5	2.7	3.6	2.7	3.2
	1.3	1.7	0.3	2.5	2.1	2.4	0.9	1.4	-	0.7
	3.6	1.0	2.1	2.4	3.6	0.7	3.8	1.5	-	2.5
Mean	2.4	2.1	0.9	2.5	2.7	2.4	1.9	1.8	2.5	2.0
S.E.±	0.5	0.5	0.5	0.4	0.4	0.7	0.9	0.7	0.2	0.6
BF	3.3	6.0	0.3	0.8	2.4	2.2	0.8	3.5	7.4	1.0
	4.1	3.2	1.0	0.1	2.2	0.7	0.7	1.8	1.7	1.5
	2.9	1.7	1.1	1.3	1.0	1.5	2.7	4.7	-	0.7
	3.3	2.5	1.4	1.8	4.0	1.2	1.7	1.8	-	2.3
Mean	3.4	3.3	1.0	1.0	2.4	1.4	1.5	3.0	4.6	1.4
S.E.±	0.3	1.0	0.3	0.4	0.6	0.3	0.5	0.7	2.8	0.4

* Incomplete sampling due to onset of continuous wet weather.

Appendix IV: Effect of cultivation treatments on nitrate-N concentration (μg/g) in the sub-surface soil (60-90 cm); Vertisol, 1980-81.

Treatment	1980				1981				
	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	2.0	1.6	1.2	3.1	0.7	0.2	1.6	5.7	0.8
	3.2	2.2	2.2	3.6	0.4	0.9	4.4	2.7	1.4
	1.1	2.5	2.8	0.8	0.8	3.1	3.4	-	1.2
	0.9	2.6	2.1	2.8	0.8	3.8	3.4	-	2.5
Mean	1.8	2.2	2.1	2.6	0.7	2.0	3.2	4.2	1.5
S.E.±	0.5	0.3	0.1	0.6	0.1	0.9	0.6	1.5	0.4
SC	3.0	3.1	1.2	3.4	2.1	1.8	2.2	1.7	0.3
	1.3	2.2	3.1	3.0	1.3	2.5	2.5	3.5	1.8
	2.2	2.0	1.2	1.3	2.0	3.0	1.8	-	0.3
	0.2	1.0	0.6	1.3	1.0	1.5	3.4	-	0.5
Mean	1.7	2.1	1.5	2.2	1.4	2.2	2.5	2.6	0.7
S.E±	0.6	0.5	0.6	0.6	0.4	0.4	0.4	0.9	0.4
DC	2.0	0.5	2.3	4.4	0.2	0.9	2.1	1.0	0.7
	1.1	1.8	1.1	1.0	1.5	0.2	1.1	1.2	1.2
	0.8	1.2	1.8	2.1	3.0	1.7	3.2	-	1.0
	4.1	1.5	2.2	1.1	1.0	1.7	1.5	-	2.7
Mean	2.0	1.3	1.9	2.2	1.4	1.1	2.0	1.1	1.4
S.E.±	0.8	0.3	0.3	0.8	0.6	0.4	0.5	0.0	0.5
BF	1.5	1.4	0.3	3.5	1.2	0.2	3.2	5.4	0.8
	2.0	1.0	0.7	1.8	0.3	1.3	1.0	3.8	1.7
	0.7	0.4	0.9	1.0	1.7	3.9	2.6	-	4.9
	2.2	1.2	1.0	1.8	1.2	1.1	1.7	-	2.2
Mean	1.6	1.0	0.7	2.0	0.1	1.6	2.1	4.6	2.4
S.E.±	0.4	0.2	0.2	0.6	0.3	0.8	0.5	0.8	0.9

Incomplete sampling due to onset of continuous wet weather.

Appendix V: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the surface soil (0-15 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	5.3	5.8	0.9	2.3	2.8	4.4	4.7	5.8	1.9	1.5
	5.8	0.9	2.3	2.6	0.8	0.0	3.5	3.4	0.9	2.6
	3.4	1.1	0.0	0.9	7.4	2.8	5.9	6.6	-	8.5
	4.9	0.4	1.5	3.6	4.4	1.5	5.5	4.7	-	1.9
Mean	4.9	2.1	1.2	2.3	3.8	2.2	4.9	5.1	1.4	3.6
S.E.±	0.5	1.3	0.5	0.6	1.4	1.0	0.6	0.7	0.5	1.7
SC	6.3	2.8	1.9	2.3	4.5	0.4	4.6	5.1	2.6	4.5
	7.6	1.7	2.5	3.0	6.1	3.8	7.0	2.1	6.0	5.7
	3.8	4.1	4.0	3.4	3.6	0.4	7.7	7.2	-	1.2
	3.9	1.1	0.7	1.9	0.6	1.6	5.7	7.2	-	2.3
Mean	5.4	2.4	2.3	2.7	3.7	1.6	6.2	5.4	4.3	3.4
S.E.±	1.0	0.7	0.7	0.4	1.2	0.8	0.7	1.2	1.7	1.0
DC	10.6	3.9	3.4	0.9	8.7	0.8	6.8	9.7	0.9	2.3
	1.9	0.9	0.4	0.9	3.4	2.2	4.2	8.1	2.8	1.3
	2.6	0.6	1.9	5.3	6.8	2.5	5.1	3.4	-	4.9
	6.4	0.1	0.4	3.4	0.7	0.2	7.6	5.3	-	5.7
Mean	5.4	1.4	1.5	2.6	4.9	1.4	6.0	6.6	1.9	3.6
S.E.±	2.0	0.9	0.7	1.1	1.8	0.6	0.8	1.4	0.9	1.1
BF	6.6	3.6	3.6	3.2	4.9	4.2	2.8	0.9	7.7	2.8
	0.9	1.3	4.9	3.0	4.4	5.1	3.6	3.4	0.7	1.9
	3.2	1.5	2.3	3.6	3.4	1.3	7.4	5.8	-	2.8
	3.6	2.4	3.8	4.7	0.9	0.9	4.2	1.5	-	1.3
Mean	3.6	2.2	3.6	3.6	3.4	2.9	4.5	2.9	4.2	2.2
S.E.±	1.2	0.5	0.6	0.4	0.9	1.1	1.0	1.1	3.5	0.4

Incomplete sampling due to onset of continuous wet weather.

Appendix VI: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the sub-surface soil (15-30 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	8.6	3.8	1.3	1.7	2.5	5.7	0.6	5.5	2.3	1.9
	8.0	1.3	2.7	3.4	0.2	0.9	1.0	4.6	0.4	5.1
	8.6	2.9	2.3	4.9	9.5	0.6	1.5	3.8	-	2.5
	5.9	3.2	2.1	1.5	1.5	10.6	2.3	3.0	-	1.0
Mean	7.8	2.8	2.1	2.9	3.4	4.5	1.4	4.2	1.4	2.6
S.E.±	0.6	0.6	0.3	0.8	2.1	2.4	0.4	0.6	0.9	0.9
SC	12.7	3.4	3.4	1.9	6.7	8.2	1.0	1.0	1.0	2.5
	7.4	1.9	0.8	1.0	13.5	2.3	2.9	1.7	2.4	2.2
	8.9	2.1	9.3	0.4	7.8	2.1	5.5	0.8	-	1.5
	5.9	3.2	1.1	5.1	5.3	1.7	0.2	3.6	-	3.8
Mean	8.7	2.7	3.7	2.1	8.3	3.6	2.4	1.8	1.7	2.5
S.E.±	1.5	0.4	1.9	1.1	1.8	1.6	1.2	0.7	0.7	0.5
	14.6	6.7	3.2	1.5	7.1	0.6	5.9	10.8	2.8	2.3
	10.6	8.4	0.4	12.5	7.0	5.1	0.4	2.7	2.1	0.6
	12.9	2.2	0.4	4.0	7.2	2.3	2.2	0.8	-	2.8
	13.9	6.7	3.2	0.4	3.2	2.4	2.3	3.4	-	3.2
Mean	13.0	6.0	1.8	4.6	6.2	2.6	2.7	4.4	2.5	2.3
S.E.±	0.9	1.2	0.8	2.7	1.0	1.0	1.2	2.2	0.4	0.6
BF	12.9	5.7	3.8	5.3	7.8	4.0	6.1	6.3	9.0	0.3
	10.6	3.4	3.0	2.5	4.4	3.0	2.1	3.0	0.8	0.0
	10.3	5.1	2.7	2.7	15.6	7.8	2.9	3.8	-	0.0
	10.8	4.8	1.9	2.9	4.9	8.2	3.6	0.8	-	4.2
Mean	11.2	4.8	2.9	3.4	8.2	5.8	3.7	3.5	5.4	1.1
S.E.±	0.6	0.5	0.4	0.7	2.6	1.3	0.9	1.2	4.5	1.0

Incomplete sampling due to onset of continuous wet weather.

Appendix VII: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the sub-surface soil (30-60 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	8.5	9.7	8.9	6.6	12.0	6.6	9.7	6.2	17.5	8.1
	3.9	8.9	4.7	3.9	6.2	4.3	3.1	8.5	7.8	7.0
	3.5	3.0	1.9	8.9	8.9	3.9	3.9	0.0	-	1.9
	8.9	3.1	0.3	6.6	6.2	1.9	3.5	3.9	-	5.8
Mean	6.2	6.2	4.0	6.5	8.3	4.2	5.1	4.7	12.7	5.7
S.E.±	1.5	1.8	1.9	1.0	1.4	1.0	1.6	1.8	4.9	1.4
SC	12.4	1.9	7.4	6.6	6.2	10.5	0.0	7.8	6.6	1.2
	3.1	5.0	4.7	2.7	9.7	12.0	6.2	5.8	1.9	3.9
	3.9	7.4	3.9	8.5	1.6	5.4	7.4	4.7	-	1.2
	8.5	12.4	5.8	5.8	2.7	9.3	4.7	3.9	-	5.0
Mean	7.0	6.7	5.5	5.9	5.1	9.3	4.6	5.6	4.3	2.8
S.E.±	2.2	2.2	0.8	1.2	1.9	1.4	1.6	0.9	2.3	1.0
DC	10.1	7.6	1.9	6.2	10.1	14.7	0.0	1.9	8.9	6.6
	8.5	10.9	1.9	13.2	9.3	9.7	10.5	14.0	10.5	12.4
	5.0	6.6	0.8	9.7	8.1	9.3	3.5	5.4	-	2.7
	14.0	3.9	8.5	9.3	14.0	2.7	15.1	5.8	-	9.7
Mean	9.4	7.2	3.3	9.6	10.4	9.1	7.3	6.8	9.7	7.9
S.E.±	1.9	1.5	1.8	1.5	1.3	2.5	3.7	2.6	0.9	2.1
BF	12.8	23.3	1.2	3.1	9.3	8.5	3.1	13.6	28.7	3.9
	15.9	12.4	3.9	0.4	8.5	2.7	2.7	7.0	6.6	5.8
	11.3	6.6	2.3	5.0	3.9	5.8	10.5	13.2	-	4.7
	12.8	9.7	5.4	7.0	15.5	4.7	6.6	7.0	-	8.9
Mean	13.2	13.0	3.2	3.9	9.3	5.4	5.7	10.2	17.7	5.8
S.E.±	0.9	3.2	0.9	1.4	2.4	1.2	1.8	1.9	11.0	1.1

Incomplete sampling due to onset of continuous wet weather.

Appendix VIII: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the sub-furcace soil (60-90 cm); Vertisol, 1980-81.

Treatment	1980				1981				
	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24Aug
ZC	7.7	6.1	4.6	11.9	2.7	0.8	6.1	21.9	3.1
	12.3	8.4	8.4	13.8	1.5	3.5	16.9	10.4	5.4
	4.2	9.6	10.8	13.1	3.1	11.9	13.1	-	4.6
	3.5	10.0	8.1	10.8	3.1	14.6	13.1	-	9.6
Mean	6.9	8.5	8.0	9.9	2.6	7.7	12.3	16.2	5.7
S.E.±	2.0	0.9	1.3	2.4	0.4	3.3	2.2	5.7	1.4
SC	11.5	11.9	4.6	13.1	8.1	6.9	8.4	6.5	1.2
	5.0	8.4	11.9	11.5	1.2	9.6	9.6	13.4	6.9
	8.4	7.7	4.6	5.0	7.7	11.5	6.9	-	1.1
	0.8	3.8	2.3	5.0	3.8	5.8	13.1	-	1.9
Mean	6.4	8.0	5.8	8.7	5.2	8.4	9.5	10.0	2.8
S.E.±	2.3	1.6	2.1	2.2	1.6	1.3	1.3	3.5	1.4
DC	7.7	1.9	8.8	16.9	0.8	15.5	8.1	3.8	2.7
	4.2	6.9	4.2	8.8	5.8	0.8	4.2	4.6	4.6
	3.1	4.6	6.9	8.1	11.5	6.5	12.3	-	3.8
	15.7	5.8	8.4	4.2	3.8	6.5	5.8	-	10.4
Mean	7.7	4.8	7.0	8.3	5.5	7.3	7.6	4.2	5.4
S.E.±	2.9	1.1	1.1	3.1	2.3	3.0	1.8	0.4	1.7
BF	5.8	5.4	1.2	13.4	4.6	0.8	12.3	23.7	3.1
	7.7	3.8	2.7	6.9	1.1	5.0	3.8	13.6	6.5
	2.7	1.5	3.5	3.8	6.5	15.0	10.0	-	18.8
	8.4	4.6	3.8	6.9	4.6	4.2	6.5	-	8.4
Mean	6.1	3.8	2.8	7.8	4.2	6.2	8.2	18.6	9.2
S.E.±	1.3	0.9	0.6	2.4	1.1	3.1	1.8	5.0	3.4

Incomplete sampling to onset of continuous wet weather.

Appendix IX: Effect of cultivation treatments on ammonium-N concentration (μg/g) in the surface soil (0-15 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jan	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	3.7	3.8	7.7	2.6	6.6	2.5	3.9	2.9	1.1	2.7
	2.8	3.5	4.5	2.1	2.6	5.6	5.6	4.4	1.8	2.5
	4.4	4.9	5.1	5.2	3.2	4.4	2.7	2.5	-	4.2
	4.3	5.8	7.0	2.1	3.0	4.8	4.1	2.8	-	0.1
Mean	3.8	4.5	6.1	3.0	3.9	4.3	4.1	3.2	7.5	2.4
S.E.±	0.4	0.6	0.8	0.7	1.0	0.7	0.6	0.5	0.4	0.9
SC	3.3	3.9	5.4	4.5	3.0	4.2	5.4	2.3	0.4	3.2
	3.8	5.3	4.7	3.3	2.5	5.1	3.4	3.0	3.0	3.5
	3.5	3.0	5.9	3.5	4.3	4.1	4.1	1.3	-	2.4
	3.7	3.8	7.4	3.0	2.0	6.1	4.3	2.9	-	1.5
Mean	3.6	4.0	5.8	3.1	2.9	4.9	4.3	1.9	1.7	2.7
S.E.±	0.1	0.5	0.6	0.3	0.5	0.4	0.4	0.5	1.3	0.5
DC	4.4	5.4	4.9	2.1	2.0	5.3	4.9	3.8	3.0	2.2
	2.1	7.4	5.0	6.1	3.1	5.1	3.2	2.0	2.0	6.0
	5.2	2.0	4.8	4.5	3.3	4.3	3.4	3.2	-	4.0
	2.8	3.4	4.5	4.7	3.0	4.3	3.7	2.5	-	3.0
Mean	3.6	4.4	4.8	3.4	2.8	4.7	3.8	2.4	2.5	3.8
S.E.±	0.7	1.2	0.1	0.9	0.3	0.2	0.4	0.5	0.5	0.8
BF	2.6	3.2	5.1	4.9	2.5	3.9	5.3	2.0	1.5	2.4
	4.9	4.9	3.1	2.1	2.6	5.6	4.2	3.9	2.7	3.0
	3.2	4.5	5.5	3.1	3.0	3.4	2.4	4.0	-	2.9
	2.8	2.2	3.3	3.6	3.1	4.4	3.4	2.5	-	1.0
Mean	2.7	3.7	4.2	3.4	2.8	4.3	3.9	3.1	2.1	2.3
S.E.±	0.5	0.6	0.6	0.6	0.4	0.9	1.2	1.0	0.6	0.9

Incomplete sampling due to onset of continuous wet weather.

Appendix X: Effect of cultivation treatments on ammonium-N concentration(µg/g) in the sub-surface soil (15-30 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	3.1	3.3	7.9	3.0	4.4	4.3	7.8	3.2	3.0	2.2
	6.3	2.1	5.6	4.7	6.6	3.9	3.6	3.3	1.7	2.7
	2.4	2.0	3.6	3.2	3.4	3.1	4.3	2.7	-	4.2
	2.2	3.0	6.1	3.8	4.4	3.9	3.7	3.6	-	1.0
Mean	3.5	2.6	5.8	3.7	4.7	3.8	4.6	3.2	2.4	2.5
S.E.±	0.9	0.3	0.8	0.4	0.7	0.3	1.0	0.2	0.6	0.7
SC	3.0	4.0	5.1	3.0	3.1	3.4	4.6	3.8	1.5	2.5
	4.0	3.2	5.2	2.8	2.3	3.6	3.9	3.5	1.5	3.9
	3.0	3.5	7.0	2.4	3.6	4.9	3.4	3.8	-	4.0
	3.2	3.3	7.0	3.0	2.3	4.4	5.6	2.2	-	1.2
Mean	3.3	3.5	6.1	2.8	2.8	3.8	4.5	3.3	1.5	2.9
S.E.±	0.2	0.5	0.6	0.2	0.3	0.4	0.5	0.4	0.0	0.6
DC	2.8	3.9	4.4	2.2	4.4	3.6	6.6	3.3	2.0	3.5
	1.9	4.5	5.0	3.1	2.5	4.1	5.2	2.2	1.2	6.6
	3.1	2.1	4.0	4.0	3.3	5.1	6.3	3.8	-	2.4
	2.6	2.3	5.4	4.5	3.4	3.9	3.9	2.7	-	3.4
Mean	2.6	3.2	4.7	3.4	3.4	4.2	5.5	3.0	1.6	4.0
S.E.±	0.3	0.6	0.3	0.5	0.4	0.3	0.6	0.4	0.4	0.9
BF	3.3	3.1	4.9	4.6	2.8	3.2	3.6	2.5	1.3	2.2
	3.2	4.4	4.5	4.2	3.1	2.2	6.0	4.8	2.3	6.9
	3.1	2.6	3.8	3.0	2.0	1.7	2.6	1.8	-	3.9
	3.0	5.1	4.6	4.4	2.5	2.0	5.4	3.6	-	3.7
Mean	3.1	3.8	4.4	4.0	2.6	2.2	4.4	2.7	1.8	4.2
S.E.±	0.1	0.6	0.4	0.4	0.3	0.4	0.8	0.7	0.5	1.0

Incomplete sampling due to onset of continuous wet weather.

Appendix **XI**: Effect of cultivation treatments on ammonium-N concentration (μg/g) in the sub-surface soil (30-60 cm); Vertisol, 1980-81.

Treatment	1980			1981				
	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	5.8	2.5	2.6	1.7	4.7	3.8	1.5	3.2
	3.8	1.9	3.8	2.5	5.1	3.7	2.0	2.7
	4.0	3.0	3.1	2.7	3.9	2.4	-	2.5
	5.2	3.0	3.3	4.3	4.4	2.1	-	1.8
Mean	4.7	2.6	3.2	2.0	4.5	3.0	1.7	2.6
S.E.±	0.5	0.3	0.3	0.6	0.3	0.5	0.2	0.3
SC	2.8	2.4	3.3	1.9	4.3	2.9	2.8	3.5
	3.8	2.7	1.6	2.9	4.6	2.8	3.5	4.2
	5.4	3.3	4.9	3.7	4.8	3.8	-	2.9
	5.9	2.0	3.4	5.1	5.1	4.3	-	1.5
Mean	4.5	2.6	3.3	3.5	4.7	3.4	3.1	3.0
S.E.±	0.7	0.3	0.7	0.7	0.2	0.4	0.4	0.6
DC	4.9	2.4	5.3	3.2	5.2	2.0	1.4	3.5
	3.9	2.0	2.5	5.6	4.1	2.0	2.0	4.7
	5.5	2.8	2.1	3.6	4.9	3.3	-	2.5
	3.3	3.2	3.1	3.2	3.6	3.4	-	0.8
Mean	4.1	2.6	3.8	3.9	4.4	2.7	1.7	2.9
S.E.±	0.5	0.3	0.8	0.6	0.4	0.4	0.3	0.8
BF	4.7	3.8	2.5	2.4	5.1	2.5	2.3	3.4
	2.2	3.4	3.9	3.6	3.6	5.9	5.0	4.0
	3.9	4.0	3.4	2.2	3.6	2.5	-	4.7
	3.2	2.6	3.8	2.4	3.9	2.4	-	3.2
Mean	3.5	3.4	3.4	2.7	4.0	3.3	3.6	3.8
S.E.±	0.6	0.3	0.3	0.3	0.3	0.8	1.3	0.4

* Incomplete sampling due to onset of continuous wet weather.

Appendix XII: Effect of cultivation treatmenents on ammonium-N concentration (µg/g) in the sub-surface soil (60-90 cm); Vertisol, 1980-81.

Treatment	1980			1981				
	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	3.8	3.5	5.3	2.5	5.2	2.7	1.3	3.0
	2.8	3.7	2.6	3.2	5.2	3.9	3.2	3.5
	5.2	2.7	4.3	4.3	2.7	2.7	-	7.2
	5.6	3.2	3.3	4.6	3.7	2.9	-	2.7
Mean	4.3	3.2	3.9	3.7	4.2	3.1	2.0	4.1
S.E.±	0.6	0.1	0.6	0.5	0.6	0.3	0.9	1.0
SC	2.6	3.5	4.8	2.5	5.1	3.6	2.8	3.4
	2.8	3.3	2.3	3.6	5.8	2.8	3.0	3.7
	4.2	2.0	4.4	3.1	6.6	3.3	-	1.7
	4.6	3.1	2.4	5.1	4.1	3.3	-	0.7
Mean	3.6	3.0	3.7	3.6	5.4	3.3	2.9	2.2
S.E.±	0.5	0.4	0.7	0.6	0.6	0.2	0.7	0.7
DC	2.6	2.7	3.3	5.1	4.7	4.0	2.5	3.0
	4.3	3.8	5.6	4.3	5.4	1.8	1.5	7.7
	4.3	3.5	3.6	1.4	4.9	3.3	-	1.0
	4.4	3.4	3.3	5.1	5.3	3.6	-	1.3
Mean	3.9	3.3	4.0	4.0	5.1	3.2	2.0	3.3
S.E.±	0.5	0.3	0.6	0.9	0.6	0.5	0.5	1.5
BF	3.0	3.3	3.9	2.7	2.9	2.3	2.2	3.0
	3.3	2.1	4.8	3.1	3.4	4.6	4.4	7.2
	4.0	3.9	1.5	2.9	5.8	3.4	-	7.6
	5.2	3.6	3.8	3.6	5.3	5.4	-	1.8
Mean	3.9	3.2	3.5	3.1	4.3	3.9	3.3	4.2
S.E.±	0.5	0.4	0.6	0.2	0.6	0.6	1.1	1.5

* Incomplete sampling due to onset of continuous wet weather.

Appendix XIII: Effect of cultivation treatments on amount of ammonium-N (kg/ha) in the surface soil (0-15 cm) Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	7.0	7.2	14.6	4.9	12.5	4.7	7.4	5.5	2.1	5.1
	5.3	6.6	8.5	4.0	4.9	10.6	10.6	8.3	3.4	4.7
	8.3	9.3	9.6	9.8	6.0	8.3	5.1	5.3	-	7.9
	8.1	11.0	13.2	4.0	5.7	9.1	7.7	4.7	-	0.2
Mean	7.2	8.5	11.5	6.8	7.2	8.1	7.6	5.9	2.6	4.5
S.E.±	0.7	1.0	1.5	1.4	1.8	1.3	1.1	0.8	0.6	1.6
SC	6.2	7.4	10.2	8.5	5.7	7.9	10.2	4.3	0.8	6.0
	7.2	10.0	8.9	6.2	4.7	9.6	6.4	5.7	5.7	6.6
	6.6	5.7	11.2	6.6	8.1	7.7	7.7	2.5	-	4.5
	7.0	7.2	14.0	5.7	3.8	11.5	8.1	5.5	-	2.8
Mean	6.8	7.6	11.0	5.9	5.5	9.3	8.1	4.5	3.2	5.1
S.E.±	0.5	1.4	1.1	0.6	0.9	0.9	0.8	0.8	2.4	1.9
DC	8.3	10.2	9.3	4.0	3.8	10.0	9.3	7.2	5.7	4.2
	4.0	14.0	9.5	11.5	5.9	9.6	6.0	3.8	3.8	11.3
	9.8	3.8	9.1	8.5	6.2	8.1	6.4	6.0	-	7.6
	5.3	6.4	8.5	8.9	5.7	8.1	7.0	4.7	-	5.7
Mean	6.8	8.3	9.1	6.4	5.3	8.9	7.2	5.4	4.7	7.2
S.E.±	1.4	2.2	0.2	1.4	0.6	0.5	0.7	0.8	0.9	1.6
BF	4.9	6.0	9.6	9.3	4.7	7.4	10.0	3.8	2.8	4.5
	9.3	9.3	5.9	4.0	4.9	10.6	7.9	7.4	5.1	5.7
	6.0	8.5	10.4	5.9	5.7	6.4	4.5	7.6	-	5.5
	5.3	4.2	6.2	6.8	5.9	8.3	6.4	4.7	-	1.9
Mean	5.1	7.0	7.9	6.4	5.3	8.1	7.4	5.9	4.0	4.4
S.E.±	1.0	1.2	1.1	0.6	0.3	0.9	1.2	1.0	0.9	0.9

* Incomplete sampling due to onset of continuous wet weather.

Appendix XIV: Effect of cultivation treatments on amount of ammonium-N (kg/ha) in the sub-surface soil (15-30 cm); Vertisol, 1980-81.

Treatment	1980					1981				
	20 Jun	15 Jul	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	5.9	6.3	15.0	5.7	8.4	8.2	14.8	6.1	5.7	4.2
	12.0	4.0	10.6	8.9	12.5	7.4	6.8	6.3	3.2	5.1
	4.6	3.8	6.8	6.1	6.5	5.9	8.2	5.2	-	8.0
	4.2	5.7	11.6	7.2	8.4	7.4	7.0	6.8	-	1.9
Mean	6.6	4.9	11.0	7.0	8.9	7.2	8.7	6.1	4.6	4.7
S.E.±	1.8	0.6	1.7	0.7	1.3	0.5	1.9	0.4	1.3	1.3
SC	5.7	7.6	9.7	5.7	5.9	6.5	8.7	7.2	2.8	4.7
	7.6	6.1	9.9	5.3	4.4	6.8	7.4	6.6	2.8	7.4
	5.7	6.6	13.3	4.6	6.8	9.3	6.5	7.2	-	7.6
	6.1	6.3	13.3	5.7	4.4	8.4	10.6	4.2	-	2.3
Mean	6.3	6.6	11.6	5.3	7.8	7.2	8.5	6.3	2.8	5.5
S.E.±	0.5	0.4	1.0	0.3	0.6	0.7	0.9	0.7	0.0	1.2
DC	5.3	7.4	8.4	4.2	8.4	6.8	12.5	6.3	3.8	6.6
	3.6	8.5	9.5	5.9	4.7	7.8	10.0	4.2	2.3	12.5
	5.9	4.0	7.6	7.6	6.3	9.7	12.0	7.2	-	4.6
	4.9	4.4	10.3	8.5	6.5	7.4	7.4	5.1	-	6.5
Mean	4.9	6.1	8.9	6.6	6.5	8.0	10.5	5.7	3.0	4.0
S.E.±	0.5	1.2	0.6	1.0	0.8	0.6	1.2	0.7	0.8	1.7
BF	6.3	5.9	9.3	6.5	5.3	6.1	6.8	0.9	2.5	4.2
	6.1	8.4	8.5	8.0	5.9	4.2	11.4	9.1	4.4	13.1
	5.9	4.9	7.2	5.7	8.8	3.2	4.9	3.4	-	7.4
	5.7	9.7	8.7	8.4	4.7	3.8	10.3	6.8	-	7.0
Mean	5.9	7.2	8.4	7.6	4.9	4.2	8.$\overset{3}{4}$	5.1	3.4	8.0
S.E.±	0.2	1.0	0.5	0.6	0.5	0.7	1.5	1.8	0.9	1.9

Appendix XXV: Effect of cultivation treatment on ammonium-N concentration (μg/g) in the sub-surface soil (30-60 cm and 60-90 cm); Alfisol, 1980.

Treatment	30-60 cm			60-90 cm			
	5 Aug	9 Sep	22 Oct	5 Aug	9 Sep	22 Oct	22 Nov
ZC	3.4	2.6	2.5	2.4	3.6	1.3	1.0
	3.5	2.9	2.6	2.4	1.1	3.3	1.3
	2.5	3.0	3.5	3.1	1.8	1.7	3.7
	3.0	4.0	1.5	3.4	3.3	2.2	2.1
Mean	3.1	3.1	2.5	2.8	2.5	2.1	2.0
S.E ±	0.3	0.3	0.4	0.3	0.6	0.5	1.0
SC	1.4	4.0	2.0	2.0	2.9	1.7	2.1
	6.6	2.3	2.3	3.0	3.4	3.4	3.0
	4.5	1.6	3.0	2.8	2.7	1.9	3.0
	3.7	2.6	1.2	4.5	3.6	2.4	1.0
Mean	4.1	2.6	2.1	3.1	3.2	2.4	2.3
S.E ±	1.1	0.5	0.4	0.5	0.2	0.4	1.5
DC	3.5	1.9	2.9	3.7	2.7	2.0	2.1
	5.6	2.1	3.9	3.2	2.1	3.1	3.0
	4.9	3.0	4.2	3.0	3.3	1.6	0.9
	5.2	1.4	2.6	3.8	2.5	1.1	1.5
Mean	4.8	2.1	3.4	3.4	2.7	2.0	1.9
S.E. ±	0.5	0.4	0.4	0.2	0.3	0.5	1.6
BF*	2.6	2.8	3.9	3.1	2.7	2.3	2.0
	3.8	3.2	4.8	1.6	2.2	3.2	2.1
	2.8	3.6	3.8	3.0	3.4	2.5	3.0
	2.6	1.9	4.6	2.8	2.6	1.7	3.5
Mean	3.0	2.9	433	2.6	2.7	2.4	2.7
S.E ±	0.3	0.4	0.3	0.4	0.3	0.3	0.8

* Raised broad-bed and furrow system.

Appendix XXVI: Effect of cultivation treatment on amount of ammonium-N (kg/ha) in the surface soil (0-15 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	8.3	6.3	9.0	4.7	4.5	2.5	3.8	7.7	3.8	4.1
	13.7	5.8	5.4	7.0	5.9	11.5	7.7	7.2	7.7	9.9
	8.1	7.9	9.9	7.7	10.4	8.1	5.0	8.1	5.0	14.9
	9.2	5.2	4.5	4.5	10.8	8.1	9.2	5.0	9.2	6.1
Mean	9.8	6.2	7.2	6.0	7.9	7.6	6.4	7.0	6.4	8.8
S.E.±	1.3	1.2	3.4	0.8	1.6	1.9	1.3	0.7	1.3	2.4
SC	9.5	5.4	0.8	9.0	4.1	19.1	3.4	6.1	3.4	10.1
	11.5	7.9	9.5	10.8	5.2	16.2	9.2	7.9	9.2	8.3
	17.3	11.0	11.7	10.8	6.8	13.1	7.9	9.0	7.9	12.8
	12.6	7.0	6.8	9.0	9.9	11.5	7.2	6.8	7.2	9.0
Mean	12.7	7.8	9.2	9.9	6.5	15.0	6.9	7.5	6.9	10.1
S.E.±	1.7	1.2	1.0	0.5	1.3	1.7	1.3	0.7	1.3	1.1
DC	12.1	7.0	9.0	10.6	4.7	10.8	2.5	7.4	4.5	5.4
	9.7	8.3	4.1	7.4	5.9	9.9	7.7	7.0	7.7	8.8
	12.6	9.5	5.6	8.8	3.6	8.1	8.1	7.7	8.1	6.8
	14.8	10.8	7.4	4.7	5.0	9.7	7.4	6.5	7.4	9.9
Mean	12.3	8.9	6.5	7.9	4.8	7.6	6.4	7.2	6.9	7.7
S.E.±	1.1	0.8	1.1	1.3	0.5	0.6	1.3	0.3	0.8	1.0
BF*	11.7	8.3	8.8	5.6	6.3	8.3	6.5	7.2	6.5	7.2
	11.5	15.3	4.3	3.4	9.7	10.3	6.1	9.0	6.1	11.7
	18.5	9.5	7.2	7.0	14.4	10.6	5.9	7.2	5.9	7.7
	10.1	12.1	5.9	2.0	7.7	8.8	4.3	12.4	4.9	10.1
Mean	13.0	11.3	6.6	4.5	9.5	9.5	5.7	9.0	5.9	9.2
S.E.±	1.9	1.6	1.9	1.1	1.8	0.6	0.5	1.3	0.4	1.1

* Raised broad-bed and furrow system.

Appendix XXVII: Effect of cultivation treatment on amount of ammonium-N (kg/ha) in the sub-surface soil (15-30 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	9.6	4.7	4.8	6.0	1.7	12.5	3.6	8.4	6.0	7.7
	8.9	5.1	8.2	11.1	6.0	10.6	5.1	7.0	4.6	10.6
	9.8	6.2	7.5	12.0	6.0	5.1	5.5	7.9	8.4	7.7
	10.1	5.8	5.5	4.8	7.5	5.8	7.5	11.3	6.0	3.6
Mean	9.6	5.5	6.5	8.5	5.3	8.5	5.4	8.7	6.3	7.4
S.E.±	0.3	0.4	0.8	1.8	1.3	1.8	0.8	0.9	0.8	1.4
SC	3.4	2.4	7.7	4.3	3.8	12.8	6.3	10.8	6.7	8.2
	8.7	13.0	4.8	6.3	2.4	11.8	5.5	7.0	2.4	11.8
	17.1	7.2	7.0	4.8	7.2	10.8	11.5	10.1	7.5	10.1
	15.6	10.6	5.5	8.2	6.3	11.1	2.4	5.5	1.9	8.4
Mean	11.2	8.3	6.2	5.9	4.9	11.6	6.4	8.4	4.6	9.6
S.E.±	3.2	2.3	0.7	0.9	1.1	0.5	1.9	1.3	1.8	0.8
DC	8.9	9.1	8.8	5.3	1.9	8.9	3.6	5.3	7.2	9.6
	10.3	8.4	2.4	6.7	3.6	12.8	3.1	10.1	12.5	4.1
	12.5	8.9	7.2	7.0	7.2	11.3	7.2	10.3	8.2	9.6
	14.7	13.7	3.4	5.1	8.2	6.3	5.1	9.9	5.3	8.2
Mean	11.6	10.0	5.4	6.0	5.2	9.8	4.8	8.9	8.3	7.9
S.E.±	1.2	1.2	1.4	0.5	1.5	0.9	0.9	1.2	1.5	1.3
BF*	9.1	7.9	6.5	6.0	1.2	6.5	8.2	8.7	9.9	7.7
	6.0	11.3	7.0	3.1	6.7	9.4	7.2	6.0	9.1	5.3
	10.3	6.3	7.7	4.8	16.6	9.4	7.0	6.5	4.1	10.6
	10.1	7.2	5.8	4.3	7.5	11.1	9.1	10.3	7.0	10.1
Mean	8.9	8.2	6.8	4.6	8.0	9.1	7.9	7.9	7.5	8.4
S.E.±	1.0	1.1	0.4	0.6	3.1	0.9	0.5	1.0	1.3	1.2

Raised broad-bed and furrow system.

Appendix XXVIII: Effect of cultivation treatment on amount of ammonium-N (kg/ha) in the sub-surface soil (30-60 cm and 60-90 cm); Alfisol, 1980.

Treatment	30-60 cm			60-90 cm		
	5 Aug	9 Sep	22 Oct	5 Aug	9 Sep	22 Oct
ZC	18.5	14.1	13.6	13.4	20.1	7.3
	19.0	15.7	14.1	13.4	6.2	18.5
	13.6	16.3	19.0	13.3	10.1	9.5
	16.2	21.7	8.1	19.0	13.5	10.7
Mean	16.8	17.0	13.7	14.8	12.5	11.5
S.E.±	1.3	1.7	2.3	1.4	3.0	2.5
SC	7.6	21.7	10.9	11.2	16.2	9.5
	35.8	12.5	12.5	16.8	19.0	19.0
	24.4	8.7	16.3	15.7	15.1	10.6
	20.0	14.1	6.5	25.2	20.0	8.4
Mean	22.0	14.3	11.5	17.2	17.6	11.9
S.E.±	5.9	2.8	2.0	2.9	1.2	2.4
DC	19.0	10.3	15.7	20.7	15.1	10.2
	30.4	11.4	21.2	17.9	11.7	17.3
	26.6	16.3	22.8	16.8	18.5	9.0
	28.2	7.6	14.1	21.3	14.0	6.2
Mean	26.1	11.4	18.5	19.2	12.3	10.7
S.E.±	2.5	1.8	2.1	1.1	1.4	2.4
BF*	14.1	15.2	21.2	17.3	12.3	12.9
	20.6	17.4	26.1	9.0	19.0	17.9
	15.2	19.5	20.6	16.8	14.5	14.0
	14.1	10.3	25.0	15.7	15.1	9.5
Mean	16.0	15.6	23.2	14.7	15.2	13.6
S.E.±	1.6	2.0	1.4	1.9	1.4	1.7

Raised broad-bed furrow system.

Appendix XV: Effect of cultivation treatments on amount of ammonium-N (kg/ha) in the sub-surface soil (30-60 cm); Vertisol, 1980-81.

Treatment	1980			1981				
	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	22.5	9.7	10.1	6.6	18.2	14.7	5.8	12.4
	14.7	7.4	14.7	9.7	20.0	14.3	7.8	10.5
	15.5	11.6	12.0	10.5	15.1	9.3	-	9.7
	20.2	11.6	12.8	16.7	17.1	8.1	-	7.0
Mean	18.2	10.1	12.4	10.9	17.5	11.6	6.6	10.1
S.E.±	1.9	1.0	1.0	2.1	1.1	1.7	1.0	1.1
SC	10.8	9.3	12.8	7.4	16.7	11.2	10.9	13.6
	14.7	10.5	6.2	11.2	17.8	10.9	13.6	16.3
	20.9	12.8	19.0	15.1	18.6	14.7	-	11.2
	22.9	7.8	13.2	20.0	20.0	16.7	-	5.8
Mean	19.5	10.1	12.8	13.6	18.2	13.4	12.0	11.6
S.E.±	2.8	1.1	2.6	2.7	0.7	1.4	1.3	2.2
DC	19.0	9.3	20.6	12.4	20.2	7.8	5.4	13.6
	15.1	7.8	9.7	21.7	15.9	7.8	7.8	18.2
	21.3	10.9	8.1	14.0	19.0	12.8	-	9.7
	12.8	12.4	12.0	12.4	14.0	13.2	-	3.1
Mean	15.9	10.1	14.7	15.1	17.1	10.4	6.6	11.2
S.E.±	1.9	1.0	2.8	2.2	1.7	1.5	1.2	3.2
BF	18.2	14.7	9.7	9.3	19.8	9.7	8.9	13.2
	8.5	13.2	15.1	14.0	14.0	23.0	19.4	15.5
	15.1	15.5	13.2	8.5	14.0	9.7	-	18.2
	12.4	10.1	14.7	9.3	15.1	0.2	-	12.4
Mean	13.6	13.2	13.2	10.5	15.5	12.8	14.0	14.7
S.E.±	2.1	1.2	1.3	1.3	1.4	3.7	5.2	1.3

Incomplete sampling due to onset of continuous wet weather.

Appendix XVI: Effect of cultivation treatments on amount of ammonium-N (kg/ha) in the sub-surface soil (60-90 cm); Vertisol, 1980-81.

Treatment	1980			1981				
	9 Aug	12 Sep	24 Oct	6 Jan	25 Apr	13 Jun	20 Jul*	24 Aug
ZC	14.6	13.5	20.4	9.6	20.0	10.4	5.0	11.6
	10.8	14.2	10.6	12.3	20.0	15.0	12.3	13.5
	20.0	10.4	16.6	16.6	10.4	10.4	-	27.7
	21.6	12.3	12.7	17.7	14.2	11.2	-	10.4
Mean	16.6	12.3	15.0	14.2	11.9	11.8	7.7	15.8
S.E.±	2.5	0.9	2.2	1.9	2.4	1.1	3.6	3.8
SC	10.0	13.5	18.5	9.6	13.9	13.9	10.8	13.1
	10.8	12.7	8.9	13.9	10.8	10.8	11.6	14.2
	16.2	7.7	16.9	11.9	12.7	12.7	-	6.5
	17.7	11.9	13.1	19.6	12.7	12.7	-	0.4
Mean	13.9	11.6	14.2	13.9	12.5	12.5	11.2	8.5
S.E.±	1.9	1.3	2.2	2.2	0.7	0.7	0.4	3.0
DC	10.0	10.4	12.7	19.6	15.4	15.4	9.6	11.6
	16.6	14.6	21.6	16.6	6.9	6.9	5.8	29.6
	16.6	13.5	13.9	5.4	12.7	12.9	-	3.9
	16.9	13.1	12.7	19.6	13.9	13.9	-	5.0
Mean	5.0	12.7	15.4	15.4	12.2	12.2	7.7	12.7
S.E.±	1.7	0.9	2.2	2.2	1.8	1.9	1.8	6.0
BF	11.6	12.7	15.0	10.4	8.9	8.9	8.5	11.6
	12.7	8.1	18.5	11.9	7.7	17.7	16.9	16.2
	15.4	15.0	5.8	11.2	13.1	13.1	-	29.3
	20.0	13.9	14.7	13.9	20.8	20.8	-	6.9
Mean	15.0	12.3	13.5	11.9	15.1	15.1	12.7	16.2
S.E.±	1.9	1.5	2.7	0.8	2.9	2.6	2.2	3.8

Incomplete sampling due to onset of continuous wet weather.

Appendix XVII: Effect of cultivation treatments on nitrate-N concentration (μg/g) in the surface soil (0-15 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	8.7	3.6	0.7	3.8	2.1	0.5	7.0	9.4	45.0	2.4
	7.5	4.7	0.9	1.4	2.2	0.8	8.6	14.0	8.6	1.7
	2.2	2.4	2.8	2.2	1.0	0.0	5.5	6.6	5.5	4.5
	7.2	1.5	4.8	2.7	3.3	1.1	7.8	9.2	7.8	1.5
Mean	6.4	3.1	2.3	2.5	2.2	0.6	7.2	9.8	6.7	2.5
S.E±	1.5	0.7	1.0	0.5	0.45	0.25	0.65	1.5	0.9	0.7
SC	8.1	4.8	1.0	2.4	2.6	3.9	6.2	9.2	6.2	0.8
	4.9	2.6	1.8	2.9	1.6	0.2	6.1	15.6	6.1	1.0
	6.9	1.4	2.2	3.3	3.4	3.0	5.9	13.2	5.9	3.0
	5.1	1.4	1.8	1.9	6.1	0.8	5.8	9.6	4.8	1.5
Mean	6.3	2.6	1.7	2.6	3.4	2.0	6.0	11.9	5.8	1.5
SE±	0.8	0.8	0.25	0.35	0.95	0.9	0.1	1.6	0.3	0.5
DC	4.9	1.7	0.9	3.9	1.8	1.0	7.7	11.9	6.9	0.8
	4.3	2.8	1.8	0.8	2.5	4.1	9.2	11.8	8.6	0.3
	4.1	1.2	2.8	2.0	3.2	4.6	4.8	11.0	4.8	2.2
	4.6	6.0	3.0	2.6	5.3	2.2	5.9	7.5	5.9	2.0
Mean	4.5	2.9	2.1	2.3	3.2	3.0	6.9	10.6	6.6	1.3
S.E±	0.2	1.1	0.5	0.7	0.25	0.9	0.95	1.1	0.8	0.5
BBF	2.8	1.0	3.5	2.0	2.3	1.2	8.2	14.6	10.2	2.7
	3.0	4.2	2.2	4.4	3.1	3.0	5.8	4.7	8.2	0.4
	1.6	1.2	1.9	3.1	5.2	3.7	8.5	9.6	6.1	0.2
	6.0	3.5	4.5	2.8	5.0	3.6	9.8	13.7	8.1	0.5
Mean	3.4	2.5	3.0	3.1	3.9	2.9	8.1	10.7	8.2	0.9
S.E.±	1.0	0.8	0.6	1.0	0.7	0.6	0.9	2.2	0.9	0.6

Appendix XVIII : Effect of cultivation treatments on nitrate-N concentration (µg/g) in the sub-surface soil (15-30 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	7.2	9.1	4.3	0.3	3.1	2.0	3.2	5.4	2.7	1.7
	7.0	2.1	2.2	1.0	0.3	2.0	2.6	5.4	1.3	1.3
	9.8	2.6	1.1	1.5	3.1	1.9	3.5	7.4	1.5	1.2
	2.7	2.4	1.5	0.5	3.0	3.4	3.8	8.5	0.5	2.2
Mean	6.7	4.1	2.3	0.8	2.4	2.3	3.3	6.2	1.5	1.6
S.E±	1.5	1.7	0.7	0.3	0.7	0.4	0.3	0.5	0.5	0.3
SC	5.6	6.3	3.3	1.0	0.9	3.0	2.2	5.5	0.3	5.7
	2.7	2.1	2.1	0.7	1.8	1.5	4.0	3.5	2.4	0.3
	5.6	1.4	2.8	2.7	4.0	2.0	2.1	3.8	3.0	1.8
	1.2	2.4	3.4	2.3	3.3	2.0	1.8	3.5	0.8	0.5
Mean	2.8	3.1	2.9	1.7	2.5	2.1	2.5	4.1	1.6	2.1
S.E±	1.11	1.1	0.3	0.5	0.7	0.3	0.5	0.5	0.7	1.2
DC	6.6	1.8	2.8	0.4	1.6	0.7	5.5	6.2	1.0	1.6
	4.4	3.0	1.4	1.5	1.8	0.5	4.7	4.9	1.8	1.8
	6.0	2.9	1.7	0.8	1.4	0.5	4.2	4.0	2.3	2.2
	2.8	3.5	0.9	2.9	3.5	2.0	2.4	9.1	0.2	1.2
Mean	5.0	2.8	1.7	1.4	2.1	0.9	4.2	6.1	1.3	1.7
S.E±	0.9	0.4	0.4	0.6	0.5	0.5	0.7	1.1	0.5	0.2
BF	3.4	2.8	1.0	1.0	2.0	2.8	4.5	8.0	1.3	0.8
	5.8	2.1	1.6	1.3	1.1	2.0	4.3	4.0	1.8	2.4
	0.8	5.1	1.3	1.6	2.3	1.1	5.4	5.1	2.4	0.2
	7.0	5.0	1.1	1.0	3.0	3.7	6.2	3.2	1.5	0.8
Mean	4.3	3.8	1.3	1.2	2.1	2.4	5.1	5.2	1.8	1.3
S.E±	1.4	0.8	0.2	0.2	0.4	0.6	0.5	1.2	0.3	0.5

Appendix XIX : Effect of cultivation treatments on nitrate-N concentration (μg/g) in the sub-surface soil (30-60 cm and 60-90 cm); Alfisol, 1980.

Treatment	30-60 cm				60-90 cm			
	5 Aug	9 Sep	22 Oct	22 Nov	5 Aug	9 Sep	22 Oct	22 Nov
	1.4	3.0	1.5	2.3	8.2	3.0	0.5	2.2
ZC	5.0	2.3	0.8	1.0	4.4	1.2	2.1	1.4
	3.6	3.1	2.5	0.5	3.7	0.7	3.0	0.3
	3.4	1.3	2.4	2.0	5.1	0.8	0.5	0.6
Mean	3.5	2.4	1.8	1.5	5.4	1.4	1.5	1.1
S.E±	0.8	0.4	0.4	0.4	1.0	0.6	0.6	0.5
	2.1	2.8	2.7	3.0	7.2	3.4	1.2	3.4
	0.7	1.5	0.3	1.6	5.0	2.5	1.3	2.1
SC	4.2	1.3	0.9	1.2	4.9	1.0	0.6	3.2
	5.0	1.5	1.9	1.0	6.5	0.0	2.1	1.0
Mean	3.0	1.8	1.5	1.7	5.9	1.7	1.3	2.4
S.E±	1.0	0.4	0.6	0.5	0.6	0.8	0.3	0.6
	6.6	2.0	1.6	3.5	5.4	1.3	1.0	1.0
	3.7	2.1	5.6	0.5	5.2	1.0	2.2	2.2
DC	1.4	0.8	3.2	2.8	4.4	2.0	3.1	3.4
	4.6	0.9	3.0	3.2	4.2	0.3	1.1	1.2
Mean	4.1	1.5	3.4	2.5	4.8	1.2	1.9	2.0
S.E±	1.1	0.4	0.8	0.7	0.3	0.4	0.5	0.6
	3.0	3.0	3.4	3.6	7.0	2.7	2.7	2.3
	2.8	2.5	2.9	2.7	5.2	1.1	1.6	1.1
BF	3.5	2.2	1.6	1.2	1.2	0.5	1.5	1.2
	3.9	2.9	2.1	2.0	3.5	0.2	1.8	1.9
Mean	3.3	2.7	2.5	2.4	4.3	1.0	1.9	1.6
S.E±	0.3	0.2	0.4	2.0	1.2	0.4	0.3	0.3

Appendix XX : Effect of cultivation treatments on acount of nitrate-N (kg/ha) in the surface soil (0-15 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
	19.6	13.0	1.6	8.6	8.6	1.1	15.8	21.2	11.3	5.4
	16.9	10.6	2.0	3.1	5.0	1.8	19.3	31.5	19.4	8.8
ZC	5.0	5.4	6.3	5.0	2.2	0.1	12.4	14.8	12.4	10.1
	16.2	3.4	10.8	6.1	7.4	2.5	17.6	20.7	17.5	3.4
Mean	14.4	8.1	5.2	5.7	5.8	1.3	16.3	22.1	15.2	5.7
S.E±	3.2	2.3	2.2	1.2	1.4	0.6	1.5	3.5	2.0	1.6
	18.2	10.8	2.2	5.4	5.8	8.8	14.0	20.7	14.0	1.8
SC	11.0	5.9	4.1	6.5	3.6	0.4	13.7	35.2	13.7	2.2
	15.6	3.1	5.0	7.4	7.7	6.8	13.3	29.7	13.3	6.8
	11.5	3.1	4.1	4.2	13.7	1.8	13.1	21.6	10.8	2.2
Mean	14.1	5.7	3.8	5.9	7.7	4.5	13.5	26.8	13.0	3.3
S.E±	1.7	1.8	0.6	0.7	1.2	2.0	0.2	3.5	0.8	1.2
	11.0	3.8	2.0	8.8	4.2	2.2	17.3	26.8	15.5	11.8
DC	9.7	6.3	4.1	1.8	5.6	9.2	20.7	26.5	19.3	0.7
	9.2	2.7	6.3	4.5	7.2	10.3	10.8	24.7	10.8	4.9
	10.4	13.5	6.8	5.9	11.9	4.9	13.3	16.9	13.2	4.5
Mean	10.1	6.6	4.8	5.3	7.2	6.7	5.5	23.7	14.7	3.0
S.E±	0.4	2.5	1.1	1.5	1.7	1.9	2.2	22.3	1.8	1.0
	6.3	2.2	7.9	4.5	5.2	2.7	18.4	32.8	23.0	6.1
	6.7	9.4	4.9	9.9	7.0	6.7	13.0	10.6	18.4	0.5
BF	3.6	2.7	4.3	7.0	11.7	8.3	19.4	21.6	13.7	0.5
	13.5	7.9	10.1	6.3	11.2	8.1	22.0	30.8	18.2	1.1
Mean	7.5	5.5	6.8	6.9	8.8	6.5	18.1	24.0	18.3	2.0
S.E±	2.1	1.8	1.4	1.1	1.6	1.3	1.9	0.6	11.9	1.4

Appendix XXI: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the sub-surface soil (15-30 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	17.1	21.6	10.2	0.7	7.3	4.7	7.6	12.8	6.4	4.0
	16.6	5.0	5.2	2.4	0.7	4.7	6.2	12.8	3.1	3.1
	23.0	6.2	2.6	3.6	7.3	4.5	8.3	17.5	3.6	2.8
	6.4	5.7	3.6	1.2	7.1	8.1	9.0	15.4	1.2	5.2
Mean	15.8	9.6	5.4	2.0	5.6	5.5	7.8	14.6	3.6	3.8
S.E ±	3.5	1.0	1.6	0.7	1.7	0.9	0.6	1.2	1.1	0.6
SC	13.3	14.9	7.8	2.4	2.1	5.1	5.2	13.0	0.7	13.5
	6.4	5.0	5.0	1.7	4.3	3.6	10.5	8.3	5.7	0.7
	13.3	3.3	6.6	6.4	9.5	4.7	5.0	9.0	7.1	4.3
	2.8	5.7	8.1	5.5	7.8	4.7	4.3	8.3	1.9	1.2
Mean	9.0	7.2	6.9	4.0	5.9	4.5	6.2	9.7	3.9	5.7
S.E ±	2.7	2.6	0.7	1.2	0.3	0.3	1.5	1.2	1.5	3.0
DC	15.6	4.3	6.6	0.9	3.8	1.7	13.0	14.7	2.4	3.8
	10.4	7.1	3.3	3.6	4.3	1.2	11.0	11.6	4.3	4.3
	3.2	6.9	4.3	1.9	3.3	1.2	10.0	9.5	5.5	5.2
	6.6	8.3	2.1	6.9	8.3	4.7	5.7	21.6	0.5	2.8
Mean	11.7	6.7	4.1	3.3	4.9	2.2	9.9	14.4	3.2	4.0
S.E ±	2.1	0.9	1.0	1.3	1.2	0.9	1.6	2.7	1.1	0.5
BF	8.1	6.6	2.4	2.4	4.7	6.6	10.7	20.4	3.1	1.9
	13.7	5.0	3.8	3.1	2.6	4.7	10.2	9.5	4.3	5.7
	1.9	12.1	3.1	3.8	5.5	2.6	12.8	12.1	5.7	0.4
	16.6	11.9	2.6	2.4	7.1	8.8	14.7	7.6	3.6	4.3
Mean	10.1	8.9	3.0	2.9	5.0	5.7	12.1	12.4	4.3	3.1
S.E ±	3.3	1.8	0.3	0.4	1.0	1.3	1.1	2.8	0.6	1.2

Appendix XXII: Effect of cultivation treatments on amount of nitrate-N (kg/ha) in the sub-surface soil (30-60 cm and 60-90 cm); Alfisol, 1980.

Treatment	30-60 cm				60-90 cm			
	5 Aug	9 Sep	22 Oct	22 Nov	5 Aug	9 Sep	22 Oct	22 Nov
ZC	7.6	16.2	8.1	12.4	45.9	16.8	2.8	12.3
	27.0	12.4	4.3	5.4	25.6	6.7	11.8	7.8
	19.4	16.7	13.5	2.7	20.7	2.9	16.8	1.7
	21.1	7.0	13.0	10.8	28.6	4.5	2.8	3.4
Mean	18.8	13.1	9.7	7.8	30.2	7.7	8.6	6.3
S.E ±	4.1	2.2	2.2	2.3	5.5	3.1	3.5	2.4
SC	11.3	15.1	12.9	16.2	40.3	19.0	6.7	19.0
	3.8	8.1	14.6	8.6	28.0	14.0	7.3	11.8
	22.7	7.0	1.6	6.5	27.4	5.6	3.4	17.9
	27.0	8.1	10.3	5.4	36.4	0.0	11.8	5.6
Mean	16.2	9.6	9.9	9.2	33.0	9.7	9.3	13.6
S.E ±	5.3	1.9	2.9	2.5	3.2	4.3	1.8	3.1
DC	35.6	7.8	8.6	18.9	30.2	7.3	5.6	5.6
	20.0	11.3	13.2	2.7	29.1	5.6	12.3	12.3
	7.6	4.3	17.3	15.1	24.6	11.2	17.4	19.0
	24.8	4.9	16.2	17.3	23.5	1.7	6.2	6.7
Mean	22.0	7.1	13.9	13.5	26.9	6.5	10.4	10.9
S.E ±	5.8	1.6	1.9	3.7	1.7	2.0	2.8	3.1
BF	16.2	16.2	18.4	19.4	39.2	11.8	15.1	12.9
	15.1	13.5	15.7	14.6	29.1	2.8	9.0	6.2
	18.9	11.9	8.7	6.5	7.8	6.2	7.8	6.7
	21.1	15.7	11.3	10.8	19.6	1.1	10.1	10.6
Mean	17.8	14.3	13.5	12.8	23.9	5.5	10.5	9.1
S.E ±	1.4	1.3	2.2	2.8	6.7	2.4	1.6	1.6

Appendix XXIII: Effect of cultivation treatment on ammonium-N concentration (µg/g) in the surface soil (0-15 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	3.7	2.8	4.0	2.1	2.0	1.1	1.7	3.4	1.7	1.8
	6.1	2.6	2.4	3.1	2.6	5.1	3.4	3.2	2.4	4.4
	3.6	3.5	4.4	3.4	4.6	3.6	2.2	3.6	2.2	6.6
	4.1	2.3	2.0	2.0	4.8	3.6	4.1	2.2	4.1	2.7
Mean	4.4	2.8	3.2	2.7	3.5	3.4	2.9	3.1	2.9	3.9
S.E ±	0.6	0.3	0.6	0.4	0.7	0.9	0.6	0.3	0.6	1.1
SC	4.2	2.4	3.9	4.0	1.8	8.5	1.5	2.7	1.5	4.5
	5.1	3.5	4.2	4.8	2.3	7.2	4.1	3.5	4.1	3.7
	7.7	4.9	5.2	4.8	3.0	5.8	3.5	4.0	3.5	5.7
	5.6	3.1	3.0	4.0	2.4	5.1	3.2	3.0	3.2	4.0
Mean	5.7	3.5	4.1	4.4	2.9	6.7	3.1	3.3	3.1	4.5
S.E ±	0.8	0.6	0.5	0.3	0.6	0.8	0.6	0.3	0.6	0.5
DC	5.4	3.1	4.0	4.7	2.1	4.8	2.0	3.3	2.0	2.4
	4.3	3.7	1.8	3.3	2.6	4.4	3.4	3.1	3.4	3.9
	5.6	4.2	2.5	3.9	1.6	3.6	3.6	3.4	3.6	3.0
	6.6	4.8	3.3	2.1	2.2	4.3	3.3	2.9	3.3	4.4
Mean	5.5	4.0	2.9	3.5	2.1	4.3	3.1	3.2	3.1	3.4
S.E ±	0.5	0.4	0.5	0.6	0.2	0.3	0.4	0.1	0.4	0.4
BF	5.2	3.7	3.9	2.5	2.8	3.7	2.9	3.2	2.9	3.2
	5.1	6.8	1.9	1.5	4.3	5.0	2.7	4.0	2.7	5.2
	8.2	4.2	3.2	3.1	6.4	4.7	2.6	3.2	2.6	3.4
	4.5	5.4	2.6	0.9	3.4	3.9	1.9	5.5	1.3	4.5
Mean	5.8	5.0	2.9	2.0	4.2	4.3	2.5	4.0	2.4	4.1
S.E ±	0.9	0.7	0.4	0.5	0.8	0.3	0.2	0.6	0.4	0.5

Appendix XXIV: Effect of cultivation treatment on ammonium-N concentration(μg/g) in the sub-surface soil (15-30 cm); Alfisol, 1980-81.

Treatment	1980					1981				
	11 Jul	5 Aug	15 Sep	22 Oct	22 Nov	8 Jan	20 Apr	23 Jun	24 Jul	31 Aug
ZC	4.0	1.9	2.0	2.5	0.7	5.2	1.5	3.5	2.5	3.2
	3.7	2.1	3.4	4.6	2.5	4.4	2.1	2.9	1.9	4.4
	4.1	2.6	3.1	5.0	2.5	2.1	2.3	3.3	3.5	3.2
	4.2	2.4	2.3	2.0	3.1	2.4	3.1	4.7	2.5	1.5
Mean	4.0	2.3	2.7	3.5	2.2	3.5	2.3	3.6	2.6	3.1
S.E ±	0.1	0.2	0.7	0.8	0.5	0.8	0.4	0.4	0.4	0.6
SC	1.4	1.0	3.2	1.8	1.6	5.3	2.6	4.5	2.8	3.4
	3.6	5.4	2.0	2.6	1.0	4.9	2.3	2.9	1.0	4.9
	7.1	3.0	2.9	2.0	3.0	4.5	4.8	4.2	3.1	4.2
	6.5	4.4	2.3	3.4	2.6	4.6	1.0	2.3	0.8	3.5
Mean	4.7	3.5	2.6	2.5	2.1	4.8	2.7	3.5	1.9	4.0
S.E ±	1.4	0.2	0.3	0.4	0.5	0.2	0.8	0.6	0.6	0.3
DC	3.7	3.8	3.4	2.2	0.8	3.7	1.5	2.2	3.0	4.0
	4.3	3.5	1.0	2.8	1.5	5.3	1.3	4.2	5.2	1.7
	5.2	3.7	3.0	2.9	3.0	4.7	3.0	4.3	3.4	4.0
	6.1	5.7	1.4	2.1	3.4	5.1	2.1	4.1	2.2	3.4
Mean	4.8	4.2	2.2	2.5	2.2	4.7	2.0	3.7	3.5	3.3
S.E ±	0.6	0.5	0.6	0.2	0.6	0.4	1.4	0.5	0.7	0.6
BF*	3.8	3.3	2.7	2.5	0.5	2.7	3.4	3.6	4.1	3.2
	2.5	4.7	2.9	1.3	2.8	3.9	3.0	2.5	3.8	2.2
	4.3	2.6	3.2	2.0	6.9	3.9	2.9	2.7	1.7	4.4
	4.2	3.0	2.4	1.8	3.1	4.6	3.8	4.3	2.9	4.2
Mean	3.7	3.4	2.8	1.9	3.3	3.8	3.3	3.3	3.1	3.5
S.E ±	0.4	0.5	0.15	0.3	1.4	0.4	0.2	0.4	0.6	0.5

* Raised broad-bed and furrow system.