

TREE-CROP INTERACTION STUDIES IN AGROFORESTRY SYSTEM - PRODUCTIVITY, MOISTURE AND NUTRIENT DYNAMICS

THESIS

by

MANOJ KUMAR

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for the Degree of*

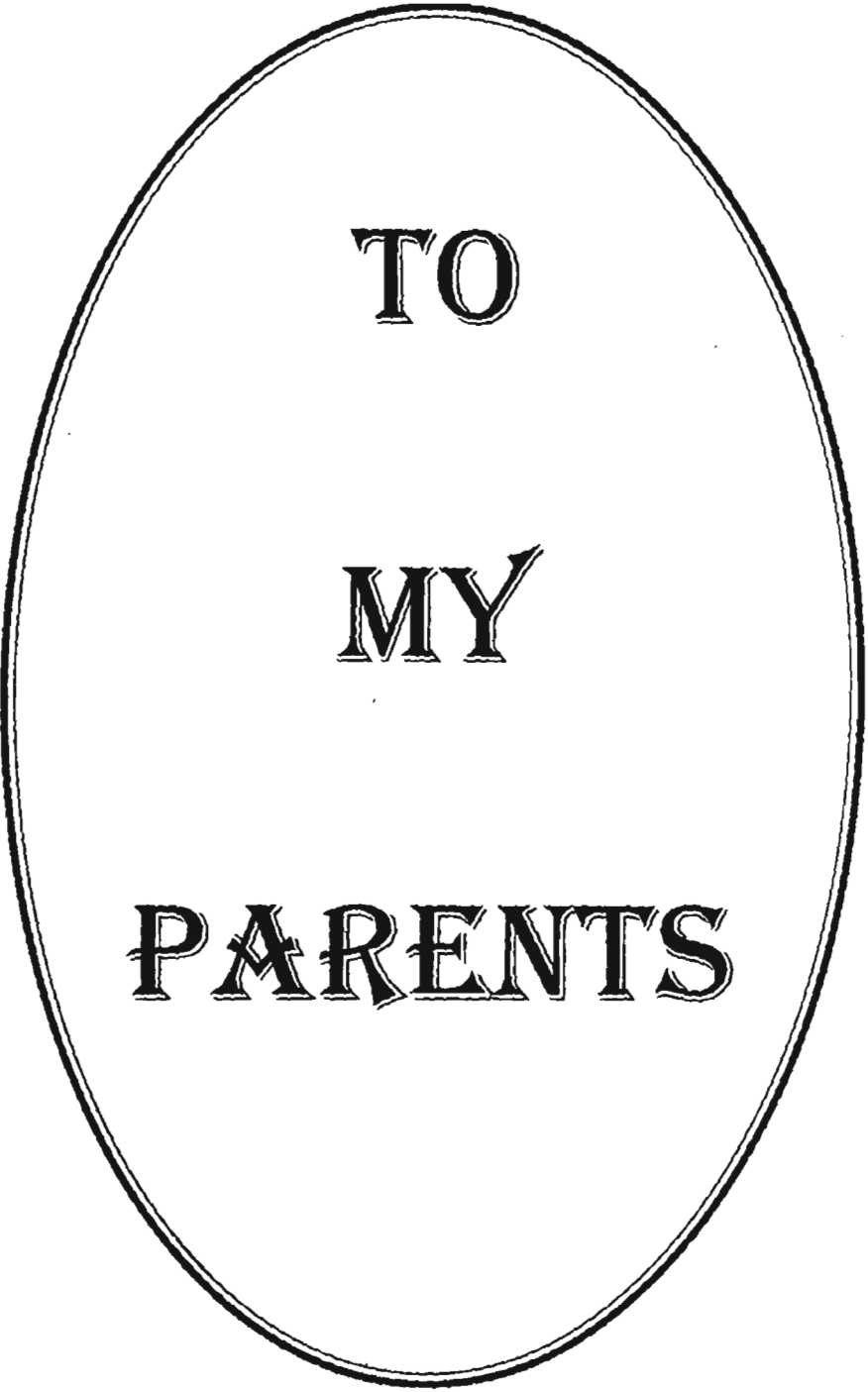
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TO

MY

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C E R T I F I C A T E - I

This is to certify that the Thesis entitled "**Tree-crop interaction studies in agroforestry system - productivity, moisture and nutrient dynamics**", submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY in AGROFORESTRY** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan is a faithful record of bonafide research work carried out by **Mr. Manoj Kumar (F-95-3-D)** under my supervision and that no part of this Thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of the investigation has been fully acknowledged.

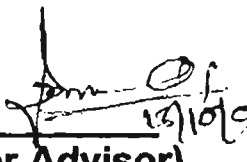
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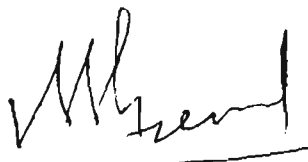
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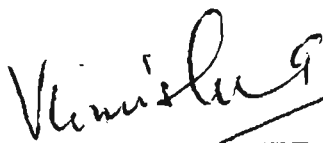

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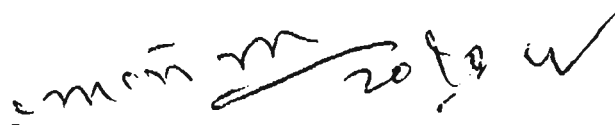
CERTIFICATE-II

This is to certify that the Thesis entitled "Tree-crop interaction studies in agroforestry system - productivity, moisture and nutrient dynamics", submitted by **Mr. Manoj Kumar** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan, in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY in AGROFORESTRY** has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the External Examiner.


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Needless to mention, errors and omissions are mine.

Place : Nauni, Solan

Dated : 30th July, 1999.


(Manoj Kumar)

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CHAPTER - 1

INTRODUCTION

The performance of trees and crops in an agroforestry system primarily depends upon their relative ability to tap the resource pools of light, water and mineral nutrients. Resilience of a component to respond to sub-optimal level of resources at any growth stage in a tree-crop system will stabilize or destabilise the tree-crop association which ultimately will influence the yield advantage of an agroforestry system. Understanding the way, system components respond to optimal or sub-optimal level of resources, forms the basis for selection of compatible and suitable components.

Agroforestry research has so far placed high emphasis on technologies that stress the service functions of trees viz. soil fertility improvement and/or soil conservation. Too little attention has been given to high-value or income generating trees. The choice of tree species is an important management decision that influence the resource use of any tree-crop system. Mixing of species with different growth habits, rooting patterns, and quality of leaf residues may lead to higher biomass productivity by enhancing complementary use of growth resources, reducing pest problems, and promoting greater synchrony in the release of nutrients from litter in relation to crop requirements. Conceptually too, the "Central" hypothesis to justify agroforestry is that trees must utilize resources such as water and nutrients that are not utilized by crops (Cannell *et al.*, 1996). This means that if the existing resources are under-utilized or unutilised in a crop - only system because they are inaccessible to crop roots, then spatial and/or temporal differences in rooting and root dynamics in an agroforestry system (complementarity) would be an advantage (ICRAF, 1996).

Early assessments of the potential benefits of agroforestry were based largely on the assumption that it is possible to evaluate existing information on forestry and agriculture and extrapolate from it (Huxley, 1983; Nair, 1984), and partly based on the observations of traditional agroforestry systems which show increased growth of understorey vegetation (Felker, 1978).

However, a number of negative effects such as excessive shading, competition for moisture, nutrients and allelopathy have also been recognized.

Whenever a tree-crop combination is tried as an agroforestry intervention, there can be strong above-ground and below-ground interaction for critical and limited resources. In general, trees have been found to improve soil physical and chemical properties by various means (Nair, 1984; Lal, 1989a). Trees act as nutrient pumps i.e. exploiting the nutrients from the deeper depths and in the process of recycling make it accessible to the companion shallow rooted ground crop (Kellman, 1979; Yamoah *et al.*, 1986). This situation although is not applicable where “cut and carry” practice is a common feature which depletes the soil nutrients year after year and may result into unsustainable proposition (Nair, 1993). The intensity and severity of interaction for nutrients between the trees and crops will depend on the planting geometry and density of each component. However, direct evidence as to where, and how severely, nutrient competition occurs is limited due to the difficulties of separating nutrient competition from competition for light, water and from allelochemical interactions (Young, 1989).

Similarly, tree-crop combination compete for available moisture in the soil, more severely under rainfed agroforestry system. So inadequate moisture will become the limiting factor which will deleteriously affect the growth and yield of the components (Singh *et al.*, 1989; Corlett *et al.*, 1989).

In addition, the potential productivity of field crops in an agroforestry system also depends on the amount of photosynthetically active radiation (PAR) falling on the ground (Hazara and Tripathi, 1986). It has generally been observed that trees and crops both compete strongly for light where shade effect resulting from the tree crown detrimentally influence the productivity potential of annual crop (Srinivasan *et al.*, 1990). Production of allelochemicals from trees further interfere with the growth and yield of associated crops. However, there are several difficulties associated with rigorous research in allelopathy (Williamson,

1990). So there is a need to screen commonly grown tree species in agroforestry for their allelopathic influences.

A scientific frame work for a quantitative analysis of tree-crop interactions explaining the productivity potential and resource use between the components of an agroforestry system is thus necessary as the magnitude of these interactions and their affects are not quantified and well researched with respect to local edaphic and agroecological conditions. This will help in comprehending the nature and extent of these interactions at the tree-crop interface (TCI) the way agroforestry systems function. It will not only provide a reliable method to determine which benefits are likely to be realized for a given agroforestry technology in a defined situation and enable researchers to evaluate the relative importance to each interaction in order to guide them more precisely in the choice of research priorities (Anderson and Sinclair, 1993), but also offer the scientific basis for designing yet more productive and sustainable land use system.

The three basic biophysical elements affecting crop productivity are light, water and mineral nutrients. Therefore, the present studies have been envisaged to be undertaken in agrihortisilviculture system to test the hypothesis that “because being deep rooted and non-exacting, growing of compatible income generating trees together with shade loving arable crops in a suitable spatial arrangement using standard management practices, can help in better nutrient cycling and, in turn, a greater potential to improve soil fertility vis-a-vis efficient spatial and temporal utilization of soil pools of nutrients and water. Also that a mixed canopy can intercept more solar energy than sole crop alone thereby increasing biomass production and/or economic returns per unit area of land”. To verify the said hypothesis following objectives have been laid out :

1. Nutrient availability and their utilization in an agroforestry system.
2. Soil moisture and its availability to system components.
3. Productivity and economic returns from the system.

CHAPTER - 2

REVIEW OF LITERATURE

Agroforestry systems are biologically more complex than other means of using land either through arable farming, fruit cultivation or forest farming. A common hypothesis is strongly implied to the agroforestry systems that integration of trees with annual crops increases the overall productivity and improves physical and chemical properties of the soil. The relevant literature on biomass productivity, nutrient cycling, systematic economics as well as competitive or complementary reciprocal effects of tree-crop components of the system is scanty and also more general in nature. For the purpose of present studies available literature has been reviewed as under.

2.1 Growth and yield

2.1.1 Field crops

2.1.2 Fodder trees

2.1.3 Fruit trees

2.2 Plant nutrient concentration and removal

2.2.1 Field Crops

2.2.2 Fodder trees

2.2.3 Fruit trees

2.3 Litter production, decomposition, nutrient concentration and return

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2.1 Growth and yield

2.1.1 Field crops

Field crops as well as plantation crops respond differently to the association of their woody components in an agro-ecosystem. Tree species ranking high in terms of height and diameter growth also compete most with field crops. Similarly, species with wide crown tends to suppress crop yield (Rao and Coe, 1992). Increase in age of the tree also influence the crops viz. mung bean, ground nut and maize yield adversely (Laosuwan *et al.*, 1987).

Hedge row plantation of *Leucaena leucocephala* caused reduction of 38, 34 and 29 per cent in the yield of intercrops viz. maize, black gram and cluster bean respectively over pure crops (Mittal and Singh, 1989). Reduction in crop yields (Singh *et al.*, 1987) ranging from 61-62 per cent in pigeonpea and castor, 48 per cent in sorghum, and 30 per cent in pearl millet intercropped with leucaena was also observed. Maize and cowpea yields too were lower from alley cropped system than the sole cropping system (Lal, 1989). Kumar (1996) evaluated the growth and yield performance of soybean, maize, wheat and lentil grown in association with mulberry and peach. He reported reduced crop height, number of plants m^{-2} , number of pods/cobs/spikes $plant^{-1}$, grain yield, straw yield and harvest index with tree association compared to tree less control. Similar observations were also made by Dinssa (1993) and Kaushal (1998). Root competition between the alley crops and shade has been the two major reasons for comparatively poor performance of field crops (Szott, 1987; Fernades, 1990). Physically impeding of seedlings emergence, due to surface mulch; temporary immobilization of nutrients through decomposing mulch thus reducing amount of nutrients available to young seedlings at a critical growth stage; inherent low levels of nutrients in the soil and its influence on the recycling mechanisms by tree roots, are other plausible explanations for low yields of intercrops in hedgerow systems.

2.1.2 Fodder trees

When trees are introduced on agricultural fields, the field crops exert a considerable influence on the establishment and growth of trees in any agroforestry practice.

Tree-crop interactions study for 13 years from 1977-1990 (Khybri *et al.*, 1992) revealed that *Grewia optiva* and *Morus alba* each attained height of 6.5m and collar diameter of 26cm. *Grewia* produced $1.09 \text{ t ha}^{-1} \text{ yr}^{-1}$ of branch wood and $0.26 \text{ t ha}^{-1} \text{ yr}^{-1}$ of leaves (air dry) whereas, *morus* produced $1.25 \text{ t ha}^{-1} \text{ yr}^{-1}$ of branch wood and $0.28 \text{ t ha}^{-1} \text{ yr}^{-1}$ of leaves. In mulberry - soybean intercropping studies, Yadav and Kumar (1998) reported that mulberry leaf yield decreased to 7.95 t ha^{-1} in 1-row planting, 7.85 t ha^{-1} in 2-rows planting and 7.34 t ha^{-1} in 3-rows of soybean compared with the sole mulberry crop (9.80 t ha^{-1}). Likewise, a reduction in the leucaena biomass upto 12 per cent with sorghum and 3 per cent with bengal gram was obtained (Srivastava, 1993). However, Leucaena biomass was increased by 5 per cent with safflower. Herbage yield of subabul studied by Maiti *et al.* (1993) was highest ($290 \text{ q ha}^{-1} \text{ yr}^{-1}$) in sole cropping system which decreased by 3.8, 2.4 and 6.6 per cent, respectively in alley cropping system using cropping sequence of maize-cowpea-mustard, fallow-rice-mustard and maize-sorghum-mustard. Kumar (1996) reported that 6-year old *Morus alba* tree attained height of 3.22-3.60m, diameter of 6.65-7.80cm and produced $10.45\text{-}12.88 \text{ kg plant}^{-1}$ branch wood, and $4.24\text{-}7.24 \text{ kg plant}^{-1}$ leaf fodder.

2.1.3 Fruit trees

Intercropping field crops / legumes with fruit trees in different agroforestry systems have shown vivid behaviour of fruit trees. Gupta *et al.* (1982) reported that intercropping of kharif and rabi crops with five year old

peach trees yielded about 10-15 kg tree⁻¹ of pruned wood and 10 kg of leaf litter. Short duration companion crops like cowpea and soybean had no marked adverse effect on the height and crown diameter of the peach trees over control (tree alone) upto 7th year (Arora and Mohan, 1986). The fruit yield was 36 kg tree⁻¹ with cowpea and 43 kg tree⁻¹ with soybean as compared to 33 kg tree⁻¹ in the control.

2.2 Plant nutrient concentration and removal

The amount of nutrients taken up by the plants primarily depends upon the concentration of nutrient in the close proximity to the root surface (Black, 1968 and Russell, 1973). Thus two or more tree-crop components exploring the same soil volume for their respective nutrient requirements are liable to be influenced due to one another's reciprocal effect in agroforestry situations.

2.2.1 Field crops

Monocrops of soybean grain generally had the nutrient levels ranging from 4.69 - 4.80 per cent N, 0.44 - 0.92 per cent P, 0.93 - 1.95 per cent K (Aulakh *et al.*, 1985; Manuja, 1992), whereas, Ca, Mg and S concentration being 0.45 per cent, 0.20 per cent and 0.38 per cent respectively (Aulakh *et al.*, 1985) while in straw per cent nutrient concentration ranges from 0.21-3.02 N, 0.9 - 0.53 P, 0.62 - 1.40 K (Aulakh *et al.*, 1985; Manuja, 1992) and 0.63 Ca, 0.39 Mg and 0.33 S (Aulakh *et al.*, 1985). Nutrient uptake in soybean grain + straw for N, P, K, Ca, Mg and S has been found to the magnitude of 125, 43, 101, 135, 19 and 22 kg ha⁻¹ (Aulakh *et al.*, 1983). Nutrient concentration and their uptake by soybean grain and straw intercropped with fodder/fruit tree species experienced a depressing effect as compared to tree less control (Kumar, 1996; Kaushal, 1998). The pattern of nutrient removal by grain followed the order N > K > Ca > Mg > P > S whereas, by straw N > Ca > K > Mg > S > P (Kaushal, 1998).

2.2.2 Fodder Trees

When leaf buds break and new foliage begins to grow, the leaf tissues often have high concentrations of N, P and K. As the foliage matures, these concentrations often decrease, while Ca, Mg and Fe usually increase (Chapin, 1980). The initial concentration of N and P are diluted as the leaf tissues accumulate carbohydrates and cellulose. Increases in calcium concentration with leaf age result from secondary thickening, including calcium pectate deposition in cell walls, and from increasing storage of calcium oxalate in cell vacuoles.

Verma and Mishra (1989) reported that in *Robinia pseudoacacia* and *Grewia optiva* leaves N, P, K and S concentration decreased towards the end of the active growth period, whereas, Ca, Mg and Na increased. The variation in leaf nutrient concentration intended to stabilize during the month of October and November, and thereafter N, P, S contents showed a decreasing trend, whereas, K, Ca, Mg and Na did not vary appreciably. Kaushal (1998) while working on component interactions in agroforestry systems reported that foliar N, P, K and S content of *Morus alba* decreased while Ca and Mg increased from July to October. The N, P, K, Ca, Mg and S content of branchwood ranged between 0.87-0.88, 0.078-0.083, 0.93-0.98, 1.31-1.36, 0.166-0.233 and 0.083-0.090 per cent respectively. While their removal by the harvested branchwood followed the order $Ca > K > N > Mg > S > P$, and removal through leaf fodder was highest of Ca followed by N, K, Mg, S and P.

Singh (1982) investigated the chemical composition of *Morus alba* leaf and found 17.2, 11.4, 3.4 and 0.34 per cent of crude protein, crude fiber, calcium and phosphorus, respectively. Bowersox and Ward (1977) reported that foliar concentrations of N, P, K and Mg were dependent on sampling date.

2.2.3 Fruit Trees

Ghosh and Chand (1984) while studying the nutrient status of peach leaf as influenced by intercrops reported that leaf N was high (2%) in trees intercropped with soybean and pineapple, and very low (0.94%) in trees intercropped with lemon grass. Leaf P and K were below normal level in all variants. Arora and Mohan (1986) observed N, P and K content of peach leaf to be 1.98, 0.17 and 1.23 per cent, respectively when intercropped with soybean as compared to 1.75, 0.28 and 1.80 per cent of control (no soybean). In an intercropping study with soybean, Kaushal (1998) found that foliar N, P, K and S content of almond decreased whereas, Ca and Mg increased from July to October. In a study with 15 pomegranate cultivars, Yamdagni *et al.* (1988) reported that recently matured leaves sampled in August will contain 2.30 - 2.80 per cent N, 0.28 - 0.40 per cent P, 1.51 - 2.18 per cent K, 1.96 - 2.60 per cent Ca and 0.19 - 0.32 per cent Mg.

Singh (1997) reported that apricot pruned wood contain 0.92 per cent N, 0.21 per cent P, 0.60 per cent K, 0.99 per cent Ca, 0.15 per cent Mg and 0.11 per cent S whereas, plum pruned wood contain 0.93 per cent N, 0.22 per cent P, 0.80 per cent K, 0.94 per cent Ca, 0.10 per cent Mg and 0.08 per cent S. Kaushal (1998) reported that N, P, K, Ca, Mg, S content of almond pruned wood ranged between 0.654 - 0.656, 0.078 - 0.083, 0.81 - 0.88, 1.30 - 1.34, 0.200 - 0.233 and 0.064 - 0.070 per cent, respectively. Vitanova (1985) studied the effect of fruit load on chemical composition of plum tree cv. Stanley and reported that the content of N, Ca and Mg were higher in the leaves of shoot and scaffold branches greatly loaded with fruit.

Vitanova (1990) concluded that fruit bearing was responsible for taking great quantities of N and K in plum tree plantations. He further reported that one ton of plum produced, approximately removed 1.61 kg N, 0.32 kg P, 1.56 kg K, 0.28 kg Ca and 0.16 kg Mg from the soil. Singh (1997) reported that

through fruits, litter fall and pruned wood of apricot and plum, N is the element which is removed in highest quantity followed by K, Ca, P, Mg and S. Kaushal (1998) observed highest removal of Ca followed by K, N, Mg, P and S through pruned wood in almond.

2.3 Litter production, decomposition, nutrient concentration and return

Tree species vary in their nutrient uptake rates and recycling capacity. Litter production is a major process in the transfer of organic matter and nutrients from above-ground tree parts to the soil (Szott *et al.*, 1991). The addition of tree leaves and branches as mulches to soils has been shown to improve site micro-environmental conditions (Budelman, 1989) and increase the productivity of agricultural crops (Duguma *et al.*, 1988). The nutrient content (especially N and P) and the lignin and polyphenolic concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Szott *et al.*, 1991). Nutrients in litter fall are more slowly released into the soil from organic matter (Parker, 1983). Rapid decomposition of plant litter at the onset of the rainy season, however, usually enhances major increases in nutrient accumulation over a relatively short period (Swift *et al.*, 1981).

Litter production

Pattern of litter production in six tree species of age from 13-16 years spaced at 2 x 2m was studied by Hosur *et al.* (1977) and reported that litterfall by the tree species varied from 4099 kg ha⁻¹ yr⁻¹ in teak to 8313 kg ha⁻¹ yr⁻¹ in eucalyptus. Singh *et al.* (1989) reported that on an average, dry litter production of *Populus deltoides* was 5.0 kg tree⁻¹ yr⁻¹ whereas of *Eucalyptus* hybrid 1.5 kg tree⁻¹ yr⁻¹. Puri *et al.* (1992) reported that in *Leucaena leucocephala* the litter fall occurred throughout the year but was highest in the dry

season. Singh (1997) reported that 8-year-old apricot and plum trees produced 205.65 gm tree⁻¹ yr⁻¹ and 158.33 gm tree⁻¹ yr⁻¹ leaf litter, respectively.

Litter decomposition

Studies with buried litter bags indicated that litter decomposition of *Leucaena leucocephala* was rapid during the high rainfall period in June to August (Puri *et al.*, 1992). Yamoah *et al.* (1986) found that the mulch of *Gliricidia sepium* disappeared completely within 120 days whereas, *Flemingia macrophylla* prunings lost 73 per cent of the original amount of dry matter applied. Tanner (1981) studied the decomposition of freshly fallen litter of 15 species and found that the weight loss varied between 27 to 79.6 per cent yr⁻¹. Ovington (1961) observed complete decay of temperate deciduous forest species in Britain in 6-9 months. Madge (1965) reported that the leaf discs of different species disappeared at different rates. Usually greater decomposition in most of the species in the rainy season is perhaps due to pronounced microbial activity under favourable temperature and moisture conditions and accentuated leaching due to rainfall (Pandey and Singh, 1982). The higher weight loss in initial periods, according to Vossbrink *et al.* (1979), occurs due to leaching of soluble materials that may happen in the presence or absence of microflora and fauna.

Litter nutrient concentration and return

Toky *et al.* (1989b) while studying the agroforestry systems in the mid hills of Himachal Pradesh, reported that in agrihortisilviculture and agrihorticulture system, considerable quantity of nutrients upto N-169, P-14, K-165, Ca-97 and Mg-65 kg ha⁻¹ was recycled through crop debris and tree leaf litter, while the recycling rate was almost half in agrisilviculture system. Majumdar (1991) observed maximum input and withdrawal of nutrients in horticulture and maximum storage in hortisilviculture system. Inter-cropping of peach with Rabi and Kharif crops, Gupta *et al.* (1982) reported that 5 year old tree produced 10 kg

of leaf litter and return 35 kg N, 80 kg P, 25 kg K and 15 kg Ca ha⁻¹ yr⁻¹. Hosur *et al.* (1977) reported that nutrient returned through litter in six tree species of age from 13 - 16 years spaced at 2 x 2m followed the order : Ca > K > N in sissoo and catechu ; Ca> N > K in teak and casuarina and K > Ca > N in bomboo and eucalyptus. The return of P and Mg were lower in all the cases. While, the concentration of Ca, K and N were more than Mg and S in all the plantation. Singh (1997) reported that apricot litter contain 1.45 per cent N, 0.20 per cent P, 1.36 per cent K, 3.08 per cent Ca, 1.30 per cent Mg and 0.14 per cent S whereas, N, P, K, Ca, Mg and S concentration in plum litter being 1.26 per cent, 0.18 per cent, 1.19 per cent, 4.58 per cent, 1.46 per cent and 0.15 per cent, respectively.

2.4 Soil studies

2.4.1 Nutrient dynamics

Nutrient cycling occurs to varying degree in all land use systems (Roswall, 1980). Agroforestry and other tree based systems are commonly credited with more efficient nutrient cycling and, in turn, a greater potential to improve soil fertility than many other systems because of the presence of woody perennials in the system and their suggested beneficial effects on soil (Nair, 1984). In addition to translocation of nutrients from soil layers beyond the reach of annual crops (Kellman, 1979), enhancement of nutrient status beneath tree canopies is attributed to canopy capture of precipitation. Yamoah *et al.* (1986) reported that even without addition of prunings, maize performed better near to alleys than those in middle of alleys, implying that there was transfer of nutrients by root turnover or some other means of below ground improvement.

Rao *et al.* (1998) reported that increase in soil fertility is due to nitrogen input into the system through biological nitrogen fixation, reduced soil erosion, reduced leaching of nutrients and uptake from deep soil layers. Kater *et*

al. (1992) reported more soil organic carbon, available - Mg, Ca and K in soils in zone covered by the crowns of karite and nere trees as compared to soils in the open. This fertility improvement was mostly noted in the top soil (0-20cm). Higher soil organic matter and organic forms of nutrients nearer the tree suggests that there could be increased mineralization and greater availability of plant available nutrients under trees than in open areas during the cropping season (Rhoades, 1995).

Maiti *et al.* (1993) reported that the nitrogen, phosphorus and potassium content of soil was appreciably reduced after harvesting of non-leguminous crops like maize, sorghum and mustard but nitrogen content increased with cowpea. The magnitude of reduction was greater under the sole cropping system than under alley cropping system. Similar observations were also reported by Thind *et al.* (1979) and Misra *et al.* (1985). The relative rate of decline over a period of six years (12 cropping season), in the status of nitrogen, pH and exchangeable bases of soil were much less under alley cropping than under non alley cropped (continuous cropping without trees) control plots (Lal, 1989). Comparing the effects of *C. siamea*, *G. sepium* and *F. macrophylla* in alley cropping trials, Yamoah *et al.* (1986a) found that soil organic matter and nutrient status were maintained at higher levels with *C. siamea* which, surprisingly is not a N₂ fixing species. Atta-Krah *et al.* during 1985 had also shown that soil under alley cropping was high in organic matter and nitrogen content than soil without trees. Yadav and Kumar (1998) reported that intercropping soybean with mulberry resulted in an increase of 13.4 kg ha⁻¹ in available nitrogen after harvesting of soybean. Singh and Kashyap (1983) reported that nitrogen content in soil increased with increase in soybean plant density due to biological nitrogen fixation. Kaushal (1998) while studying component interactions in agroforestry systems observed that after harvesting soybean, there was a decrease in soil organic carbon, P, K, Ca, Mg, S but N content increased slightly over its initial value.

It is argued that agricultural crops absorb nutrients from the soil usually from the top layer of a 30cm soil depth and to extent upto 50cm. A higher concentration of fine tree roots in the soil layer upto 50 cm suggests that trees also obtain most of the nutrient requirements from the soil layer upto 50cm. The low concentration of fine roots below 50 cm soil depth suggests that the nutrient absorption from deeper soil layers may be small. The main function of the roots reaching greater depths appear to be water uptake, particularly during period of water stress (Bowen, 1984).

2.4.2 Soil moisture

With the exception of areas with well distributed rainfall, or azonal sites with a continuous supply of below ground water, water competition is likely to occur in most agroforestry systems at some period of time. Tree-crop system have been known to influence the availability and utilization of available moisture both horizontally as well as vertically in the field. Joffre and Rambal (1993) reported that both soil water storage and evapo-transpiration were greater when *Quercus ilex* was grown with grasses as compared to grasses alone. In water limited areas, low yield of hedgerow prunings and competition of hedgerow for water was the major reasons for negative results (Ong *et al.*, 1991a, Rao *et al.* 1991).

Khybri *et al.* (1992) reported least soil moisture under eucalyptus followed by grewia, morus and control when grown with wheat and paddy. However, after harvest of eucalyptus, the lowest soil moisture was under grewia followed by morus, eucalyptus and highest was under control. This was due to the fact that leaves of grewia remain green during growth period of wheat. Huck *et al.* (1986) recorded significant reduction in total shoot weight and seed weight but increased total root length with respect to water stress in soybean. Apparent harvest index varied between 0.36 and 0.56 for soybean. Malik and Sharma (1990) reported reduction of over 30 per cent of the crops (Wheat and Mustard)

growing at a distance less than 10 m from 3.5 year old *Eucalyptus tereticornis*. The reduction in the yield of the crops was due to competition for soil moisture. Alley cropping induces competition for moisture between the trees and crops which may severely reduce crop yield (Singh *et al.* 1989; Corlett *et al.*, 1989). Alley cropping experiments at ICRISAT, India; and ICRAF, Kenya; in which annual crops were grown between woody hedges of *Leucaena leucocephala* showed that though marked decrease in crop yield was observed when alley width was reduced below 5m, the results suggested that changes in crop growth were predominantly due to below ground competition between trees and crops for water, nutrients or both (Rao *et al.*, 1990; Ong *et al.*, 1991b). Substantial reduction of crop yields even when crops were fertilized at recommended rates confirms that inadequacy of water to meet the demands of hedgerows and crops is the principal factor determining crop yields in hedgerow inter cropping in semi-arid climates (Jama *et al.*, 1995). Srivastava and Rao (1993) noticed better soil moisture regime under leucaena in 4.50 m alleys compared to pure stand spaced at 0.75 m. The combination of leucaena + sorghum resulted in more soil moisture depletion than leucaena alone in alleys and the depletion was faster in 30 to 45 cm and 45 to 60 cm layers under leucaena planted at 0.75 and 4.50m, respectively. On the other hand, while evaluating the performance and effect of common tree species viz. *Acacia nilotica*, *Azadirachta indica* and *Eucalyptus hybrid* on sorghum and safflower these authors indicated poor moisture regime near the tree row. The moisture being 20.8 cm in 0-1 m and 24.1 cm at 5-10 m distance. Tree-safflower combinations resulted in faster depletion of soil moisture (24.7 to 14.0 cm) than in sorghum (22.6 to 17.8 cm) at 30 and 60 days after sowing (DAS), respectively. Connor (1983) also reported that the higher evaporative demands of woody species caused a rapid depletion of water resources. Thus, water competition is likely to play a major role in the productivity of agroforestry systems, especially in dry areas.

2.5 Xylem water potential

All functional living cells in a tree must remain turgid with relative water content above 75 per cent (Bradford and Hsiao, 1982). The actual water potential in a wide variety of forest trees and shrubs rarely drops below -2.0 MPa irrespective of the size or amount of canopy (Scholander *et al.*, 1965). As the water content of the soil decreases, so does the water potential of trees (Ulrich *et al.*, 1981). When soil water is unavailable, predawn water potentials in trees fall until irreversible damage occurs. Different species exploit the soil to different extents. Shallow rooted trees or shrubs exhibit more negative water potentials than more deeply rooted associates under droughty conditions (Hinckley *et al.*, 1983).

Pushkala and Yagarajarao (1988) reported that 41 days after sowing the leaf water potential of soybean ranged between -2.4 to -4.6 bars. Webber *et al.* (1987) reported soybean predawn leaf water potential to be -0.39, -0.42 and -1.79 MPa at 51, 70 and 77 days after planting in 1983. Whearas, in 1984 the leaf water potential being -0.35, -0.50, -0.36 and -0.39 MPa at 69, 80, 83 and 88 days after planting. Cortes and Sinclair (1986) measured the water potential of upper most fully expanded leaves of soybean and reported that cultivar SRF exhibited -0.29, -0.17, -0.30, -0.22 and -0.16 MPa on 12 July, 19 July, 26 July, 7 August and 4 September respectively. While cultivar Wilkin, registered -0.49, -0.30, -0.12, -0.08, -0.32, -0.31 and -0.34 MPa on 7 June, 20 July, 25 July, 1 August, 3 August, 10 August, 17 August and 26 August, respectively.

The leaf water potential of stressed mulberry plants (Reddy and Sudhakar, 1992) varied between -13.3 to -17.14 bars whereas, controlled plants have -4.0 to -4.6 bars values. Sharma (1995) studied the leaf water potential in 42 days old mulberry plants and reported that controlled plants had -1.256 MPa and phosphorus deficient plants showed -1.790 Mpa leaf water potential.

Torrecillas *et al.* (1988) reported that in six year old almond trees, the sun-exposed leaves from the middle third of the tree and from extension shoots of the current year showed predawn leaf water potential of -0.09, -0.11 and -2.0 MPa in the month of May, July and October, respectively.

2.6 Relative Light Intensity

Donald (1961) emphasized that light differed from the other resources in that it could not be regarded as a reservoir from which demands could be made as required : light is 'instantaneously available' and has to be 'instantaneously intercepted' if it is to be used for photosynthesis. Because of this Willey and Roberts (1976) emphasized that light was probably the most important factor when better temporal use of resources was achieved. In studies examining the resource sharing ability of multipurpose trees in an intercropping system, crop yield was found to be depressed by competition with the trees for light (Srinivasan *et al.*, 1990).

In a field study to determine the effect of various degrees of shading, Wahna and Miller (1978) noticed that the dry weight of soybean decreased curvilinearly with the increase in shade. Eriksen and Whitney (1984) reported that shading caused 34 per cent average reduction in dry matter and grain yield of soybean, cowpea and bush bean. The response of soybean to shade was recorded to be intermediate with no reduction in dry matter and grain yield at 70 per cent sun light. Bush bean was least affected by shading. Conversely, the cowpea was noticed to be least shade tolerant. In fact maximum yield was obtained at 70 per cent sun light. At 27 per cent sun light, dry matter yield was similar for all the three crops. Crookston *et al.* (1975) reported that shading reduced leaf number, area and thickness of two dry beans (*Phaseolus Vulgaris L.*) cultivars. Photosynthesis per unit area of shaded leaves decreased by an average of 38 per cent whereas, the effect of transpiration was non-significant. Iorquebiau and Akyeampong (1994) reported that beans were not

affected at all by a 27 per cent reduction in light whereas, a decrease of light to 42 per cent of total radiation decreased yield of dry grain to 37 per cent of the control.

Biomass production in the understory is a function of photosynthetic active radiation (PAR) falling on the ground surface (Hazara and Tripathi, 1986). Singh *et al.*, (1989) reported that leucaena hedgerows in a 10 m wide alley cropping system caused a light reduction of 30 to 85 per cent of full sun light. Arora and Mohan (1986) in a study on agrihorticulture land use system reported that out of the short duration intercrops, cowpea (587 kg ha⁻¹) and sesame (398 kg ha⁻¹) can be grown until 6 years and beyond this the yield decline to uneconomic levels due to shade effect of peach trees.

Jaswal *et al.* (1993) while studying the performance of ginger and turmeric as intercrops with 5 year old poplars, planted at three spacings viz. 5X5m, 5X4m and 5X3m, reported an average illumination of 53, 46 and 38 per cent of incident radiation under the canopies, respectively. Likewise, Dinssa (1993) reported relative illumination of 40 and 48 per cent of incident radiation below popular canopies spaced at 5X3m and 5X4m, respectively, while below morus spaced at 8X2m it was 35 per cent under the mid hill conditions of Himachal Pradesh. In the same study area, Kumar (1996) reported that relative illumination under mulberry ranged between 35-46 per cent in October and 59-66 per cent in May whereas, under peach the respective values were 31-38 per cent and 50-58 per cent.

2.7 Allelopathy

Literature reveals that higher plant (tree crops) release some phytotoxins into soil, which adversely affect the germination and yield of crops. This type of tree-crop interactions was named phytochemical ecology/ecological biochemistry by Harborne (1977). Little attention has been paid to the tree-crop

allelopathy, but there are numerous reports in the literature indicating that the germination and biomass of herbaceous plants may decrease when grown under the influence of woody species (Rice, 1979; Singh and Bawa, 1982). Compared to rainy and winter season, the summer materials have more allelopathic influences (Rice, 1974). The allelopathic effects are selective (Melkania, 1983) and vary with different trees since these plants will vary in the amount of indigenous secondary metabolites and would release different amounts of the phytotoxins. Further, the secondary compounds released from litter or formed by microbes decomposing the litter will be influenced by the type of crop being leached or decomposed (Putnam and Duke, 1978). In fact, litter leaching and decay are the major pathways of the release of allelochemicals from plants (Tukey, 1969).

Compared to the forest tree species, the farm tree species have been less investigated for allelopathic influences. Melkania (1984) recorded allelopathic potential in non-forest tree species of Himalayan region in the order : *Celtis australis* > *Juglans regia* > *Grewia optiva* > *Bauhinia retusa* > *Melia azedarach*. Among the agro-crops studied as phytomer species, the inhibitory effects varied. Germination of *Glycine soja* seed was inhibited by 51.57 and 53.13 per cent when treated with *Celtis australis* and *Melia azedarach*, respectively. Waks (1936) observed that the bark and wood of *Robinia pseudoacacia* contain toxins that inhibit the growth of barley.

Bhardwaj (1993) conducted laboratory studies to notice the effect of leaf leachates of *Robinia pseudoacacia* on maize, wheat, mustard, soybean and urd and observed reduced germination per cent, root shoot length and vigour index as compared to control. Srinivasan *et al.* (1990) conducted a pot experiment where in *Vigna mungo*, *Vigna radiata*, cowpeas, pigeon peas and soybeans were grown for 30 days in top soil taken from under *Eucalyptus tereticornis*, *Casuarina equisetifolia*, *Leucaena leucocephala* and *Acacia holosericea*. Top soil from under all 4 tree species reduced crop germination and

growth. *E. tereticornis* had the greatest inhibitory effect. Soybeans were the most sensitive crop. Soybean germination in top soil under *E. tereticornis* was 69 per cent of germination in control plants and dry matter production was reduced by 10 per cent. Bhatt and Todaria (1990) studied the allelopathic effect of *Adina cordifolia*, *Alnus nepalensis*, *Celtis australis* and *Prunus cerasoides* by growing crops of *Eleusine coracana*, *Glycine max* and *Hordeum Vulgare* on top soil, rhizosphere soil from the plantation of these trees and on field soil either mulched with dry leaves or irrigated with aqueous leaf extracts of the tree species. Maximum reduction in germination percentage, root-shoot length and dry matter production was obtained with experimental garden soil mulched with dry leaves of trees and by the effect of *A. cordifolia* followed by *P. cerasoides*. *H. vulgare* proved most susceptible and *E. coracana* highly resistant to these tree-crop interactions.

2.8 Economic evaluation

Data on economic evaluation of arable crops either in isolation or in association are available. But for tree based farming systems such information appear to scanty. Riley (1986) suggested that it would be better to compare the biomass in terms of money to get a conclusive idea about the system. The incorporation of trees in agriculture will increase the overall productivity and the marginal fall in agricultural production will be compensated by the general beneficial environmental impacts. For individual farmers, the financial returns from sale of wood will compensate the reduction in agricultural yields (Chaturvedi, 1991). Whereas, Harsh and Tewari (1993) reported that overall economics favour tree-crop combination rather than the sole cultivation of a crop or a simple plantation of a tree species.

While evaluating the effect of row arrangement on yield and monetary benefits in mulberry + soybean intercropping, Yadav and Kumar (1998) reported that net income under intercropping was higher than in pure stand either

of mulberry or soybean. Maximum net income of Rs. 17240 ha⁻¹ was obtained from 1:3 row ratio followed by Rs. 16430 ha⁻¹ in 1:2 and Rs. 14860 ha⁻¹ in 1:1. The sole crop of mulberry yielded a net income of Rs. 12250 ha⁻¹ from 2 leaf harvest and soybean crop alone of Rs. 9790 ha⁻¹. Mittal and Singh (1989) after conducting a field study for six years (1981-86) on intercropping hedgerows of *Leucaena leucocephala* with maize, black gram and cluster bean and reported that net returns from intercrops of leucaena and cluster bean (Rs. 3540 ha⁻¹ yr⁻¹) were significantly higher than from pure crop of cluster bean. Leucaena with maize (Rs. 3273 ha⁻¹ yr⁻¹) and black gram (Rs. 3225 ha⁻¹ yr⁻¹) gave significant higher net returns over pure crop of leucaena. Agrisilvihorticulture system could provide an average net return of Rs. 17066 ha⁻¹ over a period of 4 years as compared to Rs. 7852 ha⁻¹ from cropping alone (Grewal et al., 1992).

Kumar (1996) conducted a study on bioeconomic appraisal of agroforestry systems in Himachal Pradesh and found that agrihorticulture system furnished highest net returns followed by agrihortisilvicuslture, agrisilviculture and minimum in sole cropping. In another study, Majumdar (1991) studied four production systems of Himachal and found that horticultural system provided highest gross returns amounting to Rs. 91,557.20 annually which was about 6.6 and 31.5 fold higher than those of hortisilvipastoral and grassland systems, respectively.

CHAPTER - 3

MATERIALS AND METHODS

The present investigations entitled **“Tree-crop interaction studies in agroforestry system - productivity, moisture and nutrient dynamics”** were conducted at the Experimental Farm, Department of Silviculture and Agroforestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan (H.P.) during the Kharif season, 1997 and 1998. The details about experimental site, materials used and methodology adopted in undertaking these studies are given below :

3.1 Site description

3.1.1 Location

The Departmental research farm, the study area, is at an elevation of 1250m above m.s.l. It is located 15 km South-east of Solan, representing 30°51'N latitude and 76°11'E longitude (Survey of India Toposheet No. 55 F/1). It falls in the mid-hill zone of Himachal Pradesh.

3.1.2 Climate

The climate of the area is transitional between sub-humid sub-tropical to sub-temperate with maximum temperature rising upto 34°C during summer. The mean annual temperature is 18°C. May and June are the hottest months whereas, December and January are the coldest and experiences severe frost. The annual rainfall ranges between 800-1300mm of which 75 per cent is received during mid June to mid September. Some amount of rains is, also received during the winter months of January and February. These winter rains also follow occasional snowfall and hails. The meteorological data for the study period are presented in Appendix-I.

3.2 Experimental Methodology

The experimental details and methods used are described as below.

A) Structure of the system

System type	Components	Functional units	Purpose/role
Agrihortisilviculture	i) Agriculture	Soybean (<i>Glycine max</i> L. Merr.)	Production of food grains
	ii) Horticulture	a) Plum (<i>Prunus salicina</i> L.)	Production of fruits
		b) Pomegranate (<i>Punica granatum</i> L.)	
	iii) Forestry	Mulberry (<i>Morus alba</i> L.)	Production of fodder and fuelwood.

B) Planting geometry

The trees have been planted in lines drawn from North to South, at a distance of 2.5m x 5m (plant x row) in different combinations (Table 1) and proportions. Alley space is cultivated with seasonal crops (soybean in the present case).

Management practices

Mulberry (*Morus alba* L.) : Complete lopping for fodder and fuel purpose.

Plum (*Prunus salicina* L.): Manures and fertilizers in the form of FYM 20kg, CAN 1kg, SSP 800 gm and MOP 500gm tree⁻¹ were applied during January 1997 and 1998. Light pruning was also used.

Table 1. Experimental details indicating specific tree-crop combinations and their distribution

Tree – crop combinations	Combination Code	Agroforestry System	Plot Size (m)	Net Cropped area (ha ⁻¹)	Area under trees (h ⁻¹)	Number of trees (ha ⁻¹)			
						Plum	Mulberry	Pomegranate	Total
Plum - Mulberry – Pomegranate - Soybean	T ₁	Agrihortisilviculture	7.5 X 5	0.80	0.20	267	267	267	801
Plum - Mulberry – Soybean	T ₂	Agrihortisilviculture	5 X 5	0.80	0.20	400	400	-	800
Pomegranate - Mulberry – Soybean	T ₃	Agrihortisilviculture	5 X 5	0.80	0.20	-	400	400	800
Plum – Soybean	T ₄	Agrihorticulture	2.5 X 5	0.80	0.20	800	-	-	800
Mulberry - Soybean	T ₅	Agrisilviculture	2.5 X 5	0.80	0.20	-	800	-	800
Pomegranate - Soybean	T ₆	Agrihorticulture	2.5 X 5	0.80	0.20	-	-	800	800
Soybean	T ₇	Agriculture	5 X 5	1.0	0.00	-	-	-	-

Date of tree planting : July, 1991
 Date of sowing field crop : 7.7.1997 and 9.7.1998.
 No. of treatments : 7
 Replications : 3
 Design : RBD Systematic

Pomegranate (*Punica granatum* L.) : Due to the non-availability of standard recommended package of practices about the species for this region, no FYM and fertilizers were applied. This was done to simulate the farmer's field conditions.

Soybean (*Glycine max* 'L'. Merr.) :

Variety	:	Punjab No. 1		
Seed rate	:	70 kg ha ⁻¹		
Spacing	:	45 x 10cm		
Fertilizer application	:	Nutrient	Dose (kg ha ⁻¹)	Source
		N	10	CAN
		P ₂ O ₅	30	SSP
		K ₂ O	30	MoP
Weedicide	:	Lasso @ 3 lt. ha ⁻¹ in 800 L water was sprayed as pre-emergence.		
Date of sowing	:	7.7.1997 and 9.7.1998		
Date of harvesting	:	20.10.1997 and 28.10.1998		

3.3 Observations recorded

3.3.1 Plant growth and yield

Soybean : Plant height, number of plants m⁻², number of pods plant⁻¹, grain yield, straw yield and harvest index.

Mulberry : Collar diameter at 5cm above the ground, height, crown spread, branch and leaf biomass yield.

Plum : Collar diameter at 5cm above graft union, height, crown spread, fruit and pruned wood yield.

Pomegranate : Collar diameter at 5cm above the ground, height and crown spread.

3.3.2 Plant nutrient concentration and removal

Field crop :

N, P, K, Ca, Mg and S concentration and removal through soybean grain and straw.

Trees :

- Mulberry, plum and pomegranate foliar analysis for N, P, K, Ca, Mg, S during the soybean crop season (July to October).
- Harvested biomass samples of leaves and branches of mulberry; fruits and pruned wood of plum were analysed for N, P, K, Ca, Mg and S to calculate their removal.

3.3.3. Litter production, nutrient concentration and return by mulberry, plum and pomegranate.

3.3.4 Litter decomposition of mulberry, plum and pomegranate during the soybean crop season (July-October).

3.3.5 Surface (0-15cm) and sub-surface (15-30cm) estimation of soil pH, organic carbon, available N, P, K, S, exchangeable Ca and Mg at an interval of one month, during the soybean crop season (June-October).

- 3.3.6 Nutrient addition and removal from the system.
- 3.3.7 Nutrient balance in the soils.
- 3.3.8 Surface (0-15cm) and sub-surface (15-30cm) estimation of soil moisture at an interval of one month, during the soybean crop season (July-October).
- 3.3.9 Monthly variation in pre-dawn xylem water potential of soybean and mulberry, plum, pomegranate during the soybean crop season (July to October).
- 3.3.10 Monthly variation in relative light intensity under mulberry, plum and pomegranate during the soybean crop season (July-October).
- 3.3.11 Allelopathic effect of mulberry, plum and pomegranate on soybean.
- 3.3.12 Economic evaluation of the system.

3.4 Observational procedure

3.4.1 Plant growth and yield

A) Field Crop : Sampling plots (1m^2) were randomly laid out in each treatment and the average was worked out for recording the observations on growth and yield attributes of soybean. The observations were recorded in October.

Plant height : Plant height was measured from ground level to the top of the plant in cm and expressed as average plant height by dividing the total number of plants in 1m^2 sampling plot.

Number of plants m^{-2} : Total number of plants in 1m^2 sampling plot were counted and expressed as number of plants m^{-2} .

Number of pods plant⁻¹ : All the pods occurring in 1m² sampling plot were counted and the number was divided by total number of plants in the 1m² sampling plot to get the number of pods plant⁻¹.

Grain and straw yield : The produce of 1m² plot was sun dried for 7 days. The total weight of the produce was recorded. After threshing, the grain yield was recorded and subtracted from total produce to get straw yield. Grain and straw yields were expressed in gm m⁻² and q ha⁻¹ on the basis of net cropped area.

Harvest index : Harvest index was calculated as per the standard formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield (grain+Straw)}} \times 100$$

B. Trees

Collar diameter : Collar diameter was measured in centimeters at 5cm above the ground level in case of mulberry and pomegranate, and 5cm above the graft union in plum with the help of calliper, in two directions corresponding to major and minor axis of the tree trunk and the average of the two was computed to get collar diameter. The measurements were taken in July and October i.e. at sowing and harvesting of soybean crop.

Height : Height was measured in metres from ground level to the tip of main shoot with the help of properly graduated wooden rod. The measurements were taken in July and October i.e. at sowing and harvesting of soybean crop.

Crown spread : Crown spread was measured in meters from the tree trunk in East, West, North and South directions with the help of properly graduated wooden rod. The measurements were taken in July and October i.e. at sowing and harvesting of soybean crop.

Branch and leaf biomass : Branch and leaf biomass of mulberry was recorded in last week of October. The branches were lopped completely, separated from leaves and their individual fresh weight was taken in the field. Branch and leaf samples were oven dried at 110°C and $65 \pm 2^\circ\text{C}$ respectively till constant weight to calculate dry weight expressed in kg plant^{-1} as well as q ha^{-1} .

Pruned wood : The weight of plum pruned wood was recorded at the time of pruning during dormant season. The pruned wood samples were oven dried at 110°C till constant weight to calculate dry weight expressed in kg plant^{-1} and q ha^{-1} .

Fruit yield : The plum fruit yield was recorded during June/July by weighing the total number of fruits on a plant at the time of harvest and expressed in kg plant^{-1} as well as q ha^{-1} on fresh weight basis.

The pomegranate trees did not bear fruit hence, no observations on yield.

3.4.2 Plant nutrient concentration and removal

Collection of samples : Representative samples of the harvested biomass of soybean (grain and straw), plum (fruit and pruned wood) and mulberry (leaves and branches) were collected from each sampling unit at their respective harvesting period and brought to laboratory in paper bags.

For estimation of monthly variation of nutrient elements in mulberry during its association with soybean (July to October) full grown leaves from current season growth were collected, in a composite sample on 30th of each month. Each sample composed of 30-40 leaves. Leaf samples were collected from each tree starting from the branch terminal and proceeding towards the main stem ignoring the mutilated ones (Cain, 1959). In case of plum median leaves (Kenworthy, 1964) and for pomegranate 8th pair of leaf from new growth (Bhargava and Dhandar, 1987) were collected for nutrient analysis.

Preparation of samples : The leaf samples were washed serially with tap water, 0.1N HCl and distilled water. The washed samples were first air dried and subsequently in oven at $60 \pm 2^{\circ}\text{C}$ for 48 hours. Branch wood was dried till it attained constant weight. The dried samples were then ground in Willy Mill and stored in butter paper bags.

Chemical analysis : Plant samples were digested in Conc. H_2SO_4 using standard kjeltabs in place of digestion mixture. After digestion, N was determined in kjeltec auto analyzer 1030. P, K, Ca, Mg and S were extracted by digesting the plant samples in 4:1 nitro-perchloric acid mixture. P in the digest was determined by Vanado-molybdo-phosphoric yellow colour method using Spectronic 20-D.K, Ca and Mg were determined using atomic absorption spectrophotometer whereas, S was determined by turbidimetric method (Jackson, 1973).

Nutrient removal : Removal of total N, P, K, Ca, Mg and S by harvested components of soybean (Grain and straw), mulberry (branchwood and leaf), plum (pruned wood) was worked out by multiplying the concentration of each nutrient with respective dry matter yield using the following formulae :

$$\text{Nutrient removal (kg ha}^{-1}\text{)} = \text{Nutrient concentration} \times 10^{-2} \times \text{Dry matter (kg ha}^{-1}\text{)} \\ (\% \text{ dry weight basis})$$

The nutrient removed by plum fruits were calculated on fresh weight basis :

$$\text{Nutrient removal (kg ha}^{-1}\text{)} = \text{Nutrient concentration in fruits} \times 10^{-5} \times \text{yield (kg ha}^{-1}\text{)} \\ (\text{mg/100g fresh weight basis})$$

3.4.3 Litter production, nutrient concentration and return

To determine natural litter fall of mulberry, plum and pomegranate; four litter traps (1m^2 iron frame with fine mesh iron gauge) were placed 25cm

above the ground level under each tree in East, West, North and South directions. The litter collection was made for soybean growth period (July-October). Litter samples were oven dried at $65\pm2^{\circ}\text{C}$ and weighed to know the quantity of litter produced. The average of four collecting traps per tree was computed to find out the litter produced $\text{m}^{-2}\text{tree}^{-1}$, which was multiplied with ground area covered by the crown to estimate litter production tree^{-1} and was expressed in kg ha^{-1} after multiplying with number of trees ha^{-1} . Ground area covered by the tree crown was determined by the formula :

$$A = \pi r^2$$

Where,

A = Ground area covered by the tree crown in meter square.

r = Crown radius

$$r = \frac{r_1 + r_2 + r_3 + r_4}{4}$$

r_1, r_2, r_3, r_4 are the crown radii along East, West, North, South directions, respectively.

The oven dried litter samples were powdered and passed through 0.5mm sieve. The samples were analyzed for N, P, K, Ca, Mg and S by following chemical analysis methods given by Jackson (1973). Nutrient concentration was multiplied by corresponding annual litterfall to assess the annual nutrient input by litterfall from each of the tree species viz. mulberry, plum and pomegranate.

3.4.4 Litter decomposition

Leaf litter decomposition was studied following Heuvelop *et al.* (1988) procedure.

Fresh leaves of mulberry, plum and pomegranate were collected from the middle canopy just before the sowing of soybean. Nylon netting bags of 30 x 30cm size and of 1mm mesh containing 100gm of leaves were exposed on the soil in the experimental field. Three litter bags of each species were recovered at fortnightly interval till the harvest of soybean for further analysis. In the laboratory, the residual litter was separated from the bags and carefully cleaned to remove the attached soil particles. This material was then oven dried at 65±2°C to constant weight to calculate the decomposition loss as follows :

$$\text{Dry weight of remaining samples (\%)} = \frac{\text{Dry wt. at subsequent intervals}}{\text{Dry weight at 1st day}} \times 100$$

$$\text{Decomposition loss (\%)} = \text{Per cent dry weight of samples at 1st day} - \text{Per cent dry weight of remaining samples at subsequent interval}$$

The data obtained was analysed in Complete Randomized Design (CRD) following Gomez and Gomez (1984).

3.4.5 Soil chemical analysis

Collection and preparation of samples : For estimation of monthly variation in soil chemical properties during soybean growth period (June-October), soil samples were collected on 30th of each month from two different depths viz. 0-15cm and 15-30cm. Random samples were collected from five places in each treatment with the help of post hole auger, composited treatment wise, air dried in shade, ground with wooden pestle and mortar, passed through 2mm sieve and stored in cloth bags for chemical analysis.

Chemical analysis : The following standard procedures have been used to analyse the chemical properties of the soil.

S.No.	Parameters	Method employed
1.	pH	1:2.5 soil water suspension with the help of digital pH meter (Jackson, 1973).
2.	Organic carbon(%)	Walkley and Black (1934).
3.	Available N (kg ha ⁻¹)	Subbiah and Asija (1956).
4.	Available P (kg ha ⁻¹)	Olsen <i>et al.</i> (1954)
5.	Available K (kg ha ⁻¹)	Merwin and Peech (1951)
6.	Exchangeable Ca and Mg (kg ha ⁻¹)	Extracted with neutral normal ammonium acetate (Chapman, 1965) and determined with atomic absorption spectrophotometer.
7.	Available S (kg ha ⁻¹)	Extracted with monocalcium phosphate (Fox <i>et al.</i> , 1964) and determined turbidimetrically (Jackson, 1973).

3.4.6 Nutrient addition and removal from the system

Amount of nutrients N, P, K, Ca, Mg and S added to the system through FYM, fertilizers and litter (Appendix 17 and 18) was worked out on the basis of net cropped area and number of trees ha⁻¹. Nutrient content of FYM and fertilizers has been appended in Appendix-33.

Nutrient removal from the system was worked out by adding up the nutrients removed in the form of grain, straw, leaves, branchwood, fruits and pruned wood from the respective treatments (Appendix 19-22).

3.4.7 Nutrient balance in the soil

An attempt has been made to work out nutrient balance in the soil after the harvest of soybean, as effected by different tree-crop combinations. For this purpose, the following assumptions were made :

1. Detailed considerations, such as loss of nutrients by leaching, weeds and the rate of release of slowly available forms of these nutrients as well as immobilization of nutrients were not considered through different inputs such as fertilizers, FYM, leaf litter.
2. Amount of nutrients added by the crop residue and retained by the non-harvested tree components were not included since complete harvest was not practicable.
3. Net gain or net loss of a particular nutrient in the soil was worked out by computing the difference between expected balance and actual balance of that nutrient in soil.

Expected balance in soil was worked out as follows :

$$\text{Expected balance} = \text{Initial status} + \text{Quantity added} - \text{Quantity removed by field crop and trees in sequence}$$

3.4.8 Soil moisture

For estimation of monthly variation in soil moisture content during the soybean crop season (June-October), composite soil samples were taken from five random places in each treatment, on 30th of each month at two different depths viz. 0-15cm and 15-30cm. The gravimetric method was employed for soil moisture determination. After collection, the samples were kept in keen boxes and dried in oven at 105°C until a constant weight was attained. The difference in weight between the initial and oven dry samples gave the moisture content.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

3.4.9 Pre-dawn xylem water potential

Xylem water potential of soybean, mulberry, plum and pomegranate was determined by pressure chamber technique for which the method of Scholander *et al.* (1965) was followed. Measurements were recorded during early morning hours before dawn at monthly interval during the soybean crop season (July to October). A shoot sample below the terminal end, containing young leaves was placed in the chamber with the cut end protruding through a rubber stopper sealing the chamber. The air pressure in the chamber was then gradually increased using nitrogen gas under pressure, till the first appearance of sap at cut ends of xylem elements. At this point, the chamber pressure was recorded and equals the hydrostatic pressure inside xylem elements as being exactly balanced by applied external pressure. The units used are - MPa. Each value was replicated thrice.

3.4.10 Relative light intensity

The light intensity was measured using two Digital DX-100 (1-1 lac lux), Taiwan Make, Luxmeters i.e. one under the tree canopy and other in the open, simultaneously for calculating the relative illumination under mulberry, plum and pomegranate. The measurements were recorded on cloudy days (Blackman and Wilson, 1951) at monthly interval during the soybean crop season (July-October).

3.4.11 Allelopathy

Fresh leaves of mulberry, plum and pomegranate were collected in July, 1998 and following methods were employed in order to assess the allelopathic effect on soybean.

Leachate method : 5, 10, 20 and 40 gm of freshly collected foliage were loosely packed into glass columns (5cm x 75cm i.d.) 100 ml of water was cycled in a Soxhlet - siphoning fashion through the columns for 24 hours to get 5, 10, 20 and 40 per cent of leachate (Hollis *et al.*, 1982). Similarly, 5, 10, 20 and 40 gm of freshly collected foliage were immersed in 100 ml of water for 24 hours to get 5, 10, 20 and 40 per cent leachate (Tukey and Mecklenberg, 1964). The resulting leachate was filtered and refrigerated (1°C) for immediate use. 100 ml of leachate was added to the pots before seed sowing.

Mulch method : 5, 10, 20 and 40 gm of freshly collected foliage were mulched in the upper layer of the pots followed by addition of 100 ml of water before seed sowing.

Details of treatments

T₁ : 5% leachate (Hollis *et al.*, 1982)

T₂ : 10% leachate (Hollis *et al.*, 1982)

T₃ : 20% leachate (Hollis *et al.*, 1982)

T₄ : 40% leachate (Hollis *et al.*, 1982)

T₅ : 5% leachate (Tukey and Mecklenberg, 1964).

T₆ : 10% leachate (Tukey and Mecklenberg, 1964).

T₇ : 20% leachate (Tukey and Mecklenberg, 1964).

T₈ : 40% leachate (Tukey and Mecklenberg, 1964).

T₉ : 5 gm foliage as mulch

T₁₀ : 10 gm foliage as mulch

T₁₁ : 20 gm foliage as mulch

T₁₂ : 40 gm foliage as mulch

T₁₃ : Control (100ml of water added to the pots before seed sowing)

The soybean seeds were sown in shallow pots (5 seeds pot⁻¹) having 5 kg of field soil and protected from rains. There were 3 pots for each treatment. The data obtained for various attributes of soybean was analysed in Complete Randomized Design (CRD) following Gomez and Gomez (1984).

Observations recorded

a) Germination : Germination was recorded after 24 hours interval upto 7 days till no more seed germinated and expressed as percentage of the total seeds sown per p.ot.

b) Germination relative index (GRI) : According to Srivastava and Sareen (1972), GRI was calculated as : $\sum X_n (h-n)$

Where,

X_n = number of seeds germinated at nth count

h = total number of counts

n = count number

c) Vigour index (VI) : According to Abdul-Baki and Anderson (1973), VI was calculated as germination per cent x seedling length.

d) Root and shoot length : Root and shoot length of the plants were measured 30 days after sowing and expressed in centimeters.

e) Dry matter yield : After 30 days of sowing the plants were uprooted and kept for drying in oven at $65 \pm 2^{\circ}\text{C}$ till constant weight. The dry weight was recorded and expressed as dry matter yield gm plant^{-1} .

3.4.12 Economic studies

Cost of cultivation : The cost of cultivation of field crop (Appendix-30) as well as maintenance of fodder and fruit trees and harvesting of their produce (Appendix-31) was worked out on the basis of net cropped area and number of trees ha^{-1} . The requirements of labour and mechanical power for different operations such as ploughing, harrowing, sowing, weeding, harvesting, threshing, lopping, pruning, basin preparation, plant protection measures, FYM and fertilizer application were calculated per hectare as per the rates prevalent at Experimental Farm (Appendix - 32). Cost of inputs such as seed, FYM, fertilizers, insecticides, fungicides, weedicide (Appendix-32) were calculated based on the actual amount applied in each treatment (Appendix -30 and 31).

Gross returns : The prevailing local market prices (Appendix -32) were used to convert the yield of field crop, fodder and fruit trees in rupees ha^{-1} . The fuelwood value of mulberry branchwood and plum pruned wood was computed on the basis of calorific value.

Net returns : Net returns were calculated by deducting the total costs from the gross returns :

$$\text{Net returns} = \text{Gross returns} - \text{total costs}$$

Tree-crop combination preference : In order to work out the preference for a particular tree-crop combination for designing economically viable, sustainable, more productive and diversified land use system following two criterion have been used :

1. Economic : Net returns and total costs

2. Biophysical : Total biomass, product diversification and soil nutrients.

Each of the seven tree-crop combinations were given score from 1 to 7 on the basis of performance of above mentioned (1 and 2) economic and biophysical parameters. Lowest numerical score i.e. one (1) was assigned to that combination having maximum value of a particular parameter under consideration and highest numerical score i.e. seven (7) was given to the minimum valued combination. However, this scoring pattern was reversed for total costs. Mean score for each tree-crop combination was worked out. The combination obtaining the lowest mean score was taken as the first preference whereas, the highest as last preference.

Statistical analysis

The data obtained were subjected to statistical analysis using RBD of experimentation as per the procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. Analysis was carried out on computer using the Package "STATISTICS".

Data presentation

The year wise data for 1997 and 1998 obtained from the present studies have been appended in the appendices whereas, the pooled data are given in the text for explaining and discussing the relevant inferences.

CHAPTER - 4

EXPERIMENTAL RESULTS

The experimental results obtained from the present studies are given in this chapter under the following heads.

4.1 Plant growth and yield

4.1.1 Soybean

4.1.2 Mulberry, Plum and Pomegranate

4.2 Plant nutrient concentration

4.2.1 Soybean

4.2.2 Mulberry, Plum and Pomegranate

4.3 Litter studies

4.3.1 Litter production and nutrient concentration-mulberry, plum and pomegranate

4.3.2 Litter decomposition - mulberry, plum and pomegranate

4.4 Soil characteristics

4.4.1 Chemical properties

4.4.2 Nutrient addition and removal through system components

4.4.3 Nutrient balance

4.4.4 Soil moisture

4.5 Pre-dawn xylem water potential-soybean, mulberry, plum and pomegranate

4.6 Relative light intensity under mulberry, plum and pomegranate

4.7 Allelopathic effect of mulberry, plum and pomegranate on soybean

4.8 Total biomass and economic returns

4.1 Plant growth and yield

4.1.1 Soybean

The influence of different tree-crop combinations was studied on the soybean growth and yield attributes.

4.1.1.1 Growth

The growth attributes studied were plant height and number of plants m^{-2} . The results obtained have been tabulated in Table 2 and described as below.

Plant height (cm) : Plant height was influenced significantly by different tree-crop combinations. The maximum (64.17) plant height was obtained in T_7 i.e. sole soybean crop, which remained statistically at par with T_6 (63.96). All other tree-crop combinations viz. T_5 , T_4 , T_2 , T_3 and T_1 significantly lesser height compared to T_6 and T_7 . Minimum plant height (53.50) was observed in T_1 .

Number of plants (m^{-2}) : The number of plants m^{-2} were significantly influenced by different tree-crop combinations. Maximum number of plants (17.83) were observed in T_6 followed by T_7 (17.67), T_4 (15.72), T_5 (15.50), T_3 (14.50), T_2 (13.00) and T_1 (12.50).

4.1.1.2 Yield

The data on yield attributes studied viz. number of pods $plant^{-1}$, grain and straw yield m^{-2} as well as per unit net cropped area and harvest index are presented in Table 2.

Table 2. Growth and Yield attributes of soybean as influenced by tree-crop combinations

Tree – crop combinations	Growth		Yield					
	Plant height (cm)	No. of plants (m ⁻²)	No. of pods (plant ⁻¹)	Grain (gm m ⁻²)	Grain* (q)	Straw (gm m ⁻²)	Straw* (q)	Harvest index* (%)
T ₁	53.50	12.50	28.67	112.70	9.02	287.70	23.02	28.14
T ₂	56.95	13.00	29.00	116.20	9.29	293.30	23.47	28.35
T ₃	56.67	14.50	30.67	119.30	9.55	297.80	23.83	28.72
T ₄	59.50	15.72	32.33	126.70	10.13	310.20	24.81	28.99
T ₅	60.59	15.50	31.64	124.80	9.99	307.50	24.60	28.86
T ₆	63.96	17.83	33.17	136.70	10.94	325.30	26.03	29.57
T ₇	64.17	17.67	34.67	143.20	11.46 (14.32)**	334.00	26.72 (33.23)**	30.02 (30.11)**
S. Ed.	0.99	1.03	0.77	1.34	0.11	3.49	0.32	0.10
CD _(0.05)	2.16	2.24	1.69	2.93	0.24	7.50	0.70	0.22

* Values on the basis of net cropped area of agrihortisilviculture system (0.80 ha)

** Values in the parentheses are on the basis of net cropped area of sole cropping (1 ha.)

Number of pods plant⁻¹ : Different tree-crop combinations (Table 2) had shown significant effect on the number of pods plant⁻¹. The maximum number (34.67) was recorded in T₇ and the minimum (28.67) in T₁. However, T₁, T₂; T₂, T₃; T₃, T₄ T₅; T₄, T₅, T₆ and T₆, T₇ behaved statistically alike.

Grain yield : Grain yield was recorded per meter square as well as per unit net cropped area (8000 m²) both (Table 2). Grain yield m⁻² was significantly higher in T₇ (143.20gm) and minimum (112.70gm) in T₁ compared to all other tree-crop combinations. Grain yield per unit of net cropped area expressed in quintals experienced a depressing effect due to different tree-crop combinations over open control. The highest (11.46) grain yield was in T₇ (soybean alone). Among the different tree-crop combinations, the maximum yield (10.94) was recorded in T₆ followed by T₄ (10.13), T₅ (9.99), T₃ (9.55), T₂ (9.29) and T₁ (9.02).

Straw yield : Straw yield m⁻² expressed in gm was significantly higher in T₇ (334.00) i.e. open control over all other tree-crop combination. Minimum (287.70) straw yield m⁻² was noticed in T₁. Straw yield per unit net cropped area (q) followed the similar trend to grain yield depicting its maximum (26.72) value in T₇ (soybean alone) and minimum (23.02) in T₁.

Harvest index (%) : It was influenced significantly due to tree-crop combinations. Leaving apart T₇ i.e. soybean alone showing the maximum harvest index value (30.02), among others T₆ recorded maximum (29.57) and T₁ the lowest (28.14) harvest index.

4.1.2 Mulberry, plum and pomegranate

4.1.2.1 Growth

Growth characters namely height, diameter and crown spread were measured at sowing as well as at harvesting of the soybean. The results so obtained were significantly different in various tree-crop combinations and described species-wise as below :

Mulberry : Mulberry represented T_1 (Plum-Mulberry-Pomegranate-Soybean), T_2 (Plum-Mulberry-Soybean), T_3 (Pomegranate-Mulberry-Soybean) and T_5 (Mulberry-Soybean) tree-crop combinations (Table 3). At the time of sowing of soybean crop, maximum height (4.73m) was in T_5 . The minimum (3.57m) height was observed in T_1 . Diameter was maximum in T_5 followed by T_3 , T_2 and T_1 . Maximum (1.74m) crown spread was in T_5 and minimum (1.04m) in T_1 . Directionally it was more towards west followed by south, east and north. The interaction between tree-crop combination x direction for crown was statistically non-significant. Similar results for height, diameter and crown spread of mulberry were observed at harvesting of soybean except directionally crown spread was noticed to be maximum (1.77m) in east followed by west (1.74m), south (1.56m) and north (1.53m).

Plum : Tree-crop combination T_1 (Plum-Mulberry-Pomegranate), T_2 (Plum-Mulberry-Soybean) and T_4 (Plum-Soybean) involved plum trees. At sowing of soybean crop, its maximum (5.21cm) height was in T_2 followed by T_4 (5.04cm) and T_1 (4.00cm). Diameter was highest in T_4 and lowest in T_1 . Crown spread depicted maximum (1.74m) value in T_4 followed by T_2 (1.49m) and T_1 (1.28m). It was more in west and east directions as compared to south and north. The interaction between tree-crop combination x direction for crown was significant. At harvesting of soybean, plum height was maximum in T_4

Table 3. Height, diameter and crown spread of mulberry, plum and pomegranate during the soybean crop season

Tree-crop	At sowing of Soybean							At harvesting of Soybean						
Combi-nations	Height (m)	Diameter (cm)	Crown spread (m)					Height (m)	Diameter (cm)	Crown spread (m)				
			East	West	North	South	Mean			East	West	North	South	Mean
Mulberry														
T ₁	3.57	10.93	1.05	1.03	1.03	1.04	1.04	4.21	11.43	1.35	1.26	1.20	1.25	1.27
T ₂	4.35	12.48	1.19	1.10	0.96	1.22	1.12	4.91	12.80	1.76	1.42	1.26	1.45	1.47
T ₃	4.61	15.55	1.24	1.84	1.31	1.47	1.47	4.78	15.78	1.88	2.13	1.61	1.66	1.82
T ₅	4.73	15.59	1.75	1.82	1.78	1.60	1.74	5.19	15.92	2.08	2.15	2.03	1.85	2.03
Mean			1.31	1.45	1.27	1.34				1.77	1.74	1.53	1.56	
T*	S.Ed 0.06	CD _(0.05) 0.14	S.Ed 0.06	CD _(0.05) 0.14				S.Ed 0.05	CD _(0.05) 0.10	S.Ed 0.51	CD _(0.05) 1.12			
D**			0.03	0.06						0.02	0.04			
T x D			0.15	NS						0.10	NS			
Plum														
T ₁	4.00	10.10	1.33	1.28	1.05	1.46	1.28	4.63	10.20	1.75	1.43	1.30	1.58	1.51
T ₂	5.21	10.95	1.58	1.78	1.02	1.57	1.49	5.53	11.19	2.03	2.05	1.45	1.74	1.82
T ₄	5.04	12.90	2.03	2.08	1.10	1.74	1.74	5.63	13.33	2.30	2.39	1.60	2.21	2.13
Mean			1.64	1.71	1.06	1.59				2.03	1.96	1.45	1.84	
T*	S.Ed 0.06	CD _(0.05) 0.12	S.Ed 0.05	CD _(0.05) 0.10				S.Ed 0.03	CD _(0.05) 0.07	S.Ed 0.20	CD _(0.05) 0.43			
D**			0.03	0.06						0.04	0.08			
T x D			0.12	0.26						0.22	0.48			
Pomegranate														
T ₁	3.03	7.28	1.11	1.30	0.98	1.33	1.18	3.30	7.50	1.29	1.45	1.15	1.45	1.34
T ₃	2.61	6.60	1.40	1.29	1.20	1.35	1.31	2.80	6.98	1.64	1.63	1.43	1.60	1.58
T ₆	3.40	8.23	1.45	1.73	1.26	1.63	1.52	3.52	8.45	1.73	2.00	1.58	1.80	1.78
Mean			1.32	1.44	1.15	1.44				1.55	1.69	1.39	1.59	
T*	S.Ed 0.10	CD _(0.05) 0.22	S.Ed 0.05	CD _(0.05) 0.11				S.Ed 0.13	CD _(0.05) 0.28	S.Ed 0.20	CD _(0.05) 0.44			
D**			0.04	0.08						0.03	0.07			
T x D			0.12	0.26						0.10	0.22			

* Tree-crop combinations

** Direction

followed by T_2 and T_1 . Directionally crown spread was maximum in east followed by west, south and north. Diameter and crown spread showed similar trends as was observed at sowing of soybean. The interaction between tree-crop combination x direction for crown was also observed to be significant (Table 3).

Pomegranate : Pomegranate was present in tree-crop combination T_1 (Plum-Mulberry-Pomegranate-Soybean), T_3 (Pomegranate-Mulberry-Soybean) and T_6 (Pomegranate-soybean). The height and diameter were maximum in T_6 followed by T_1 and T_3 , both at sowing as well as harvesting of soybean. But crown spread was maximum in T_6 followed by T_3 and T_1 , both at sowing as well as harvesting of soybean. Directionally crown spread was more in west and south direction as compared to east and north. The interaction between tree-crop combination x direction for crown was also observed to be significant at sowing as well as harvesting of soybean (Table 3).

4.1.2.3 Harvested biomass yield

Leaf and branch biomass yield of mulberry and pruned wood and fruit yield of plum expressed per tree and per hectare basis are given in Table 4 and 5, respectively. The results obtained from the analysis of pooled data were significant and have been described as below.

Mulberry : The leaf and branch biomass yield of mulberry expressed in kg tree^{-1} as well as q ha^{-1} was observed to be maximum in tree-crop combination T_5 followed by T_3 , T_2 and T_1 (Table 4).

Plum : Pruned wood as well as fruit yield of plum in kg tree^{-1} and q ha^{-1} was maximum in tree-crop combination T_4 followed by T_2 and minimum in T_1 . The highest pruned wood yield on q ha^{-1} basis was 45.40 and lowest 13.82.

Table 4. Leaf and branch biomass yield of mulberry during the soybean crop season

Tree-crop Combinat -ions	1997				1998				Pooled			
	*Leaf		Branch		*Leaf		Branch		*Leaf		Branch	
	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)
T ₁	1.58 (5.25)	4.22 (14.01)	7.10	18.96	1.74 (5.80)	4.65 (15.49)	9.50	25.37	1.66 (5.53)	4.44 (14.75)	8.30	22.17
T ₂	1.67 (5.55)	6.68 (22.20)	7.90	31.60	1.83 (6.10)	7.32 (24.40)	9.75	39.00	1.75 (5.83)	7.00 (23.30)	8.83	35.30
T ₃	1.71 (5.70)	6.84 (22.80)	8.00	32.00	2.70 (9.00)	10.80 (36.00)	10.40	41.60	2.21 (7.35)	8.82 (29.40)	9.20	36.80
T ₅	2.07 (6.90)	16.56 (55.20)	9.40	75.20	2.91 (9.70)	23.28 (77.60)	12.50	100.00	2.49 (8.30)	19.92 (66.40)	10.95	87.50
S.Ed.	0.06	0.63	0.10	0.61	0.04	0.85	0.15	0.84	0.03	0.60	0.08	0.52
CD _(0.05)	0.12	1.37	0.21	1.32	0.09	1.95	0.32	1.82	0.07	1.30	0.18	1.14

* Figures in the parenthesis are leaf yield on fresh weight basis

Table 5. Pruned wood and fruit yield of plum during the soybean crop season

Tree-crop Combinat -ions	1997				1998				Pooled			
	Pruned wood		Fruit		Pruned wood		Fruit		Pruned wood		Fruit	
	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)	(kg tree ⁻¹)	(q ha ⁻¹)
T ₁	4.75	12.68	8.500	22.70	5.60	14.95	5.400	14.42	5.18	13.82	6.950	18.56
T ₂	4.85	19.40	9.200	36.80	6.95	23.80	7.180	28.72	5.40	21.60	8.190	32.76
T ₄	5.10	40.80	11.750	94.00	6.25	50.00	7.800	62.40	5.68	45.40	9.775	78.20
S.Ed.	0.04	1.08	0.16	1.53	0.06	2.06	0.13	1.33	0.03	0.97	0.10	1.13
CD _(0.05)	0.08	2.35	0.35	3.34	0.14	4.48	0.28	2.90	0.06	2.12	0.22	2.46

Similarly, fruit yield $q\ ha^{-1}$ was maximum (78.20) in T_4 and minimum (18.56) in T_1 (Table 5).

4.2 Plant nutrient concentration (%)

4.2.1 Soybean

N, P, K, Ca, Mg and S concentration in soybean grain and straw was influenced significantly due to different tree-crop combinations. The results obtained have been given in Fig. 1 and described as below :

Grain : It is clear from Fig. 1 that N, P, K, Ca, Mg and S concentration in grain was less in all tree-crop combinations (T_1 - T_6) over soybean alone (T_7). Among various tree-crop combinations, maximum (4.74) N concentration was observed in T_4/T_6 followed by T_5 (4.70), T_3/T_2 (4.67) whereas, minimum (4.63) in T_1 . P concentration was highest (0.28) in T_6 closely followed by T_4 (0.27), T_5 (0.26), T_2 and T_3 (0.24) and T_1 (0.23). K and S concentration was found to be maximum in T_6 followed by T_4 , T_5 , T_3 , T_2 and T_1 . Mg concentration was highest (0.20) in T_5 and T_6 followed by $T_2/T_3/T_4$ (0.19) and minimum (0.18) in T_1 .

Straw : N concentration in soybean straw was found to be maximum (1.34) in T_7 (soybean alone) followed by T_6 (1.25), T_4/T_5 (1.20), T_3 (1.16), T_2 (1.15) and minimum in T_1 (1.13). Likewise, P, K and S concentration exhibited the similar trend to that of N. However, P concentration in T_1 , T_2 , T_3 and K concentration in T_2 and T_3 was same. S concentration in T_5 was less than T_4 . Ca was maximum (0.63) in T_6 followed by T_7 (0.62), T_5 (0.61), T_4 (0.60), T_3 and T_2 (0.58) and minimum in T_1 (0.56). Mg concentration also behaved similar to that of Ca but depicted similar values in T_3/T_4 ; and T_1/T_2 (Fig. 1).

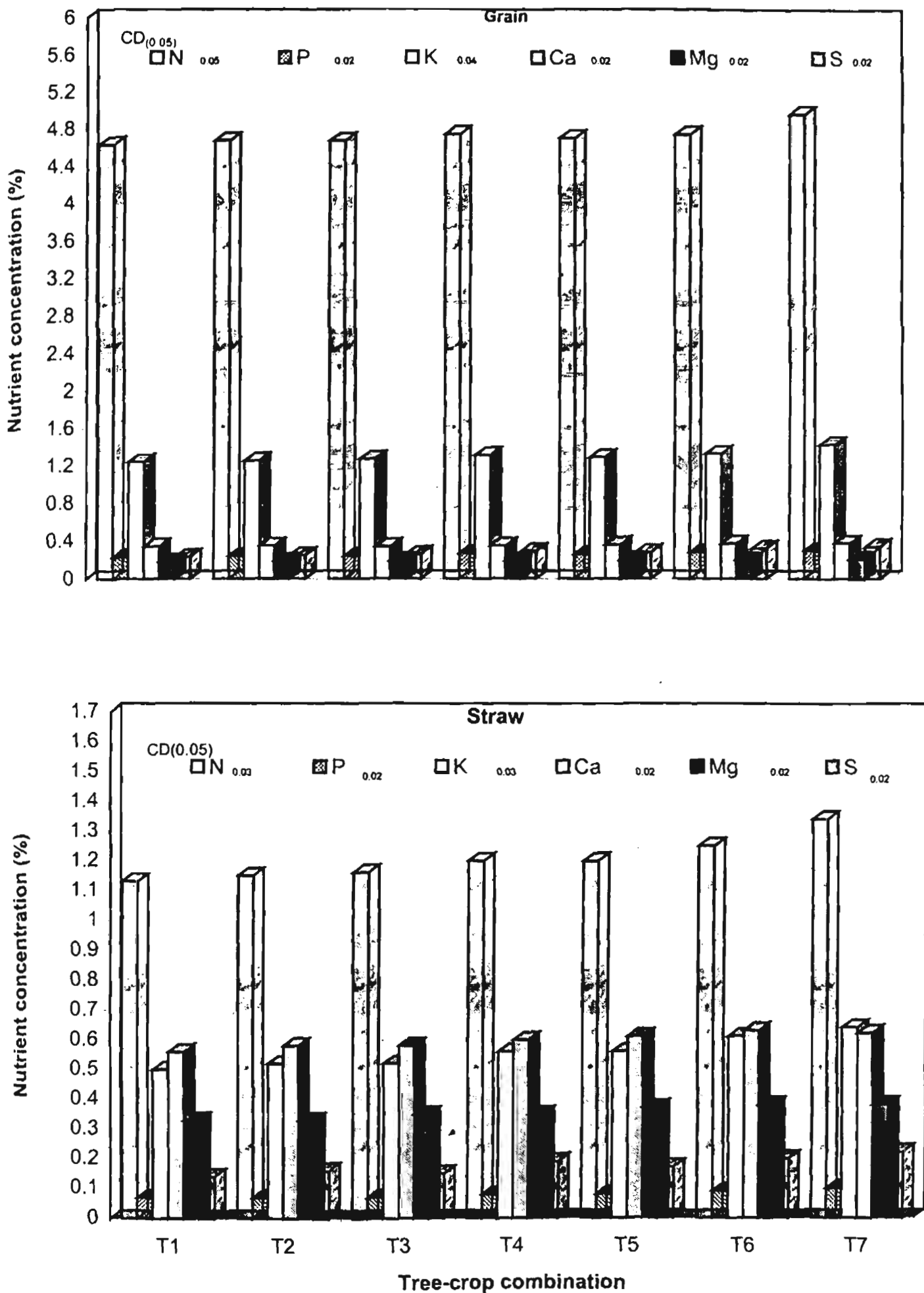


Fig. 1. Effect of tree-crop combinations on nutrient concentration in soybean grain and straw

4.2.2 Mulberry, Plum and Pomegranate

The nutrient concentration in the mulberry, plum and pomegranate leaves were analyzed at monthly intervals beginning from July (sowing period of soybean) upto October (harvesting period of soybean). Besides leaves, mulberry branchwood as well as plum pruned wood and fruits were also analyzed for nutrient concentration at their respective harvestable time to estimate the nutrient removal.

Nutrient concentration of harvestable biomass (%)

The data pertaining to nutrient concentration in harvested biomass viz. branch wood and leaf of mulberry and, pruned wood and fruit of plum are given in Fig. 2 and 3, respectively.

Mulberry : The variation in N, K and Ca concentration of mulberry branch wood; and N, Ca and Mg concentration of leaf (Fig. 2) were statistically significant in different tree-crop combinations. However, P, Mg and S concentration of branch wood and P, K and S concentration of leaf showed non-significant results. In general, N and Ca concentration of branch wood and N and Mg concentration of leaf showed maximum values in tree-crop combination T₅ and minimum in T₁. P, K, Mg and S concentration of branch wood and P, K, Ca and S concentration of leaf did not exhibit any definite trend.

Plum : In different tree-crop combinations K concentration of pruned wood and N, P, K, Ca and Mg concentration of fruit was statistically significant whereas, N, P, Ca, Mg and S concentration of pruned wood and S concentration of fruit did not show significant effects (Fig. 3). K concentration of pruned wood, and N, P, Ca and S concentration of fruits was maximum in tree-crop combination T₄ followed by T₂ and minimum in T₁. However, N, P,

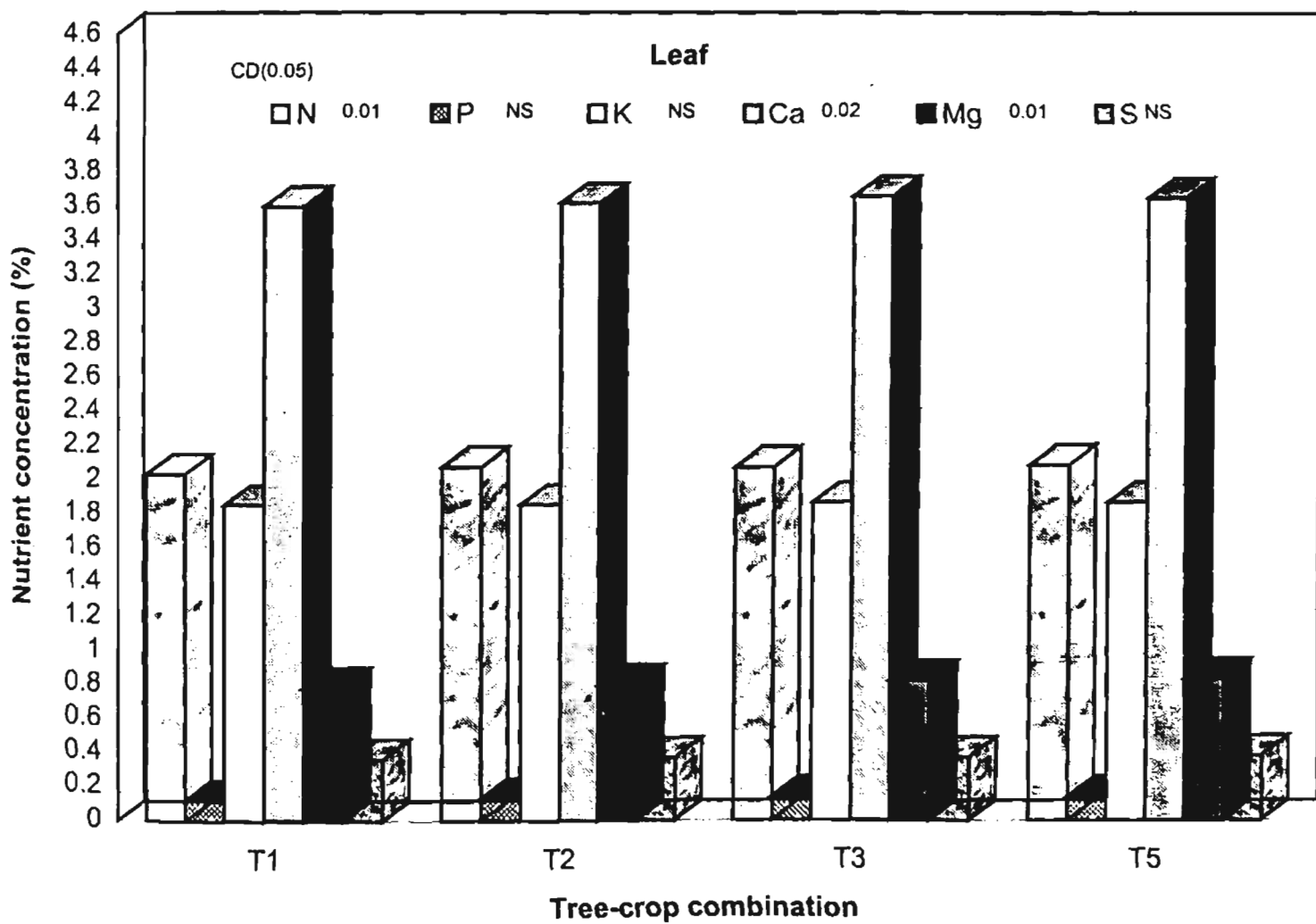
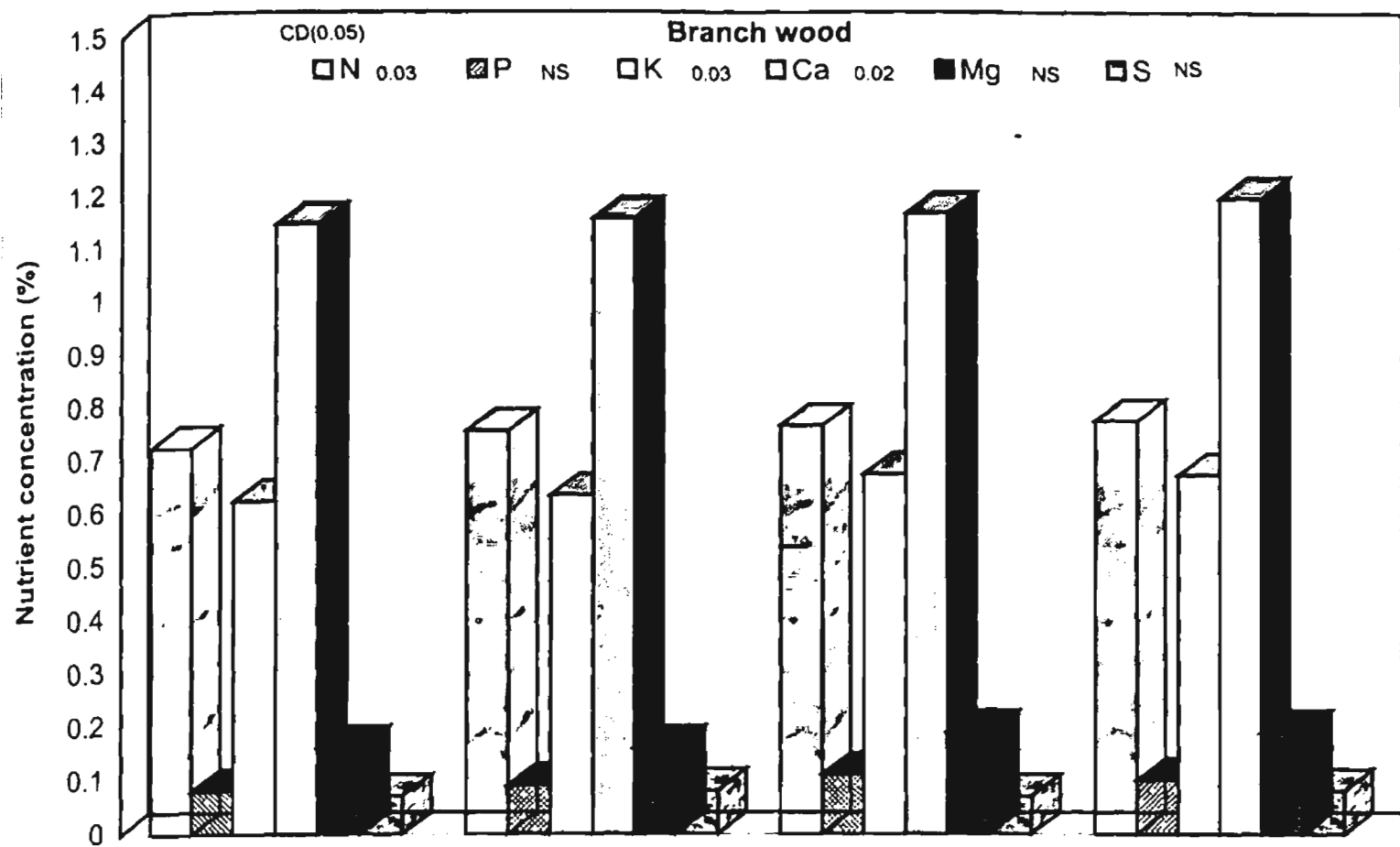


Fig. 2. Nutrient concentration in mulberry branch wood and leaf at their harvestable period

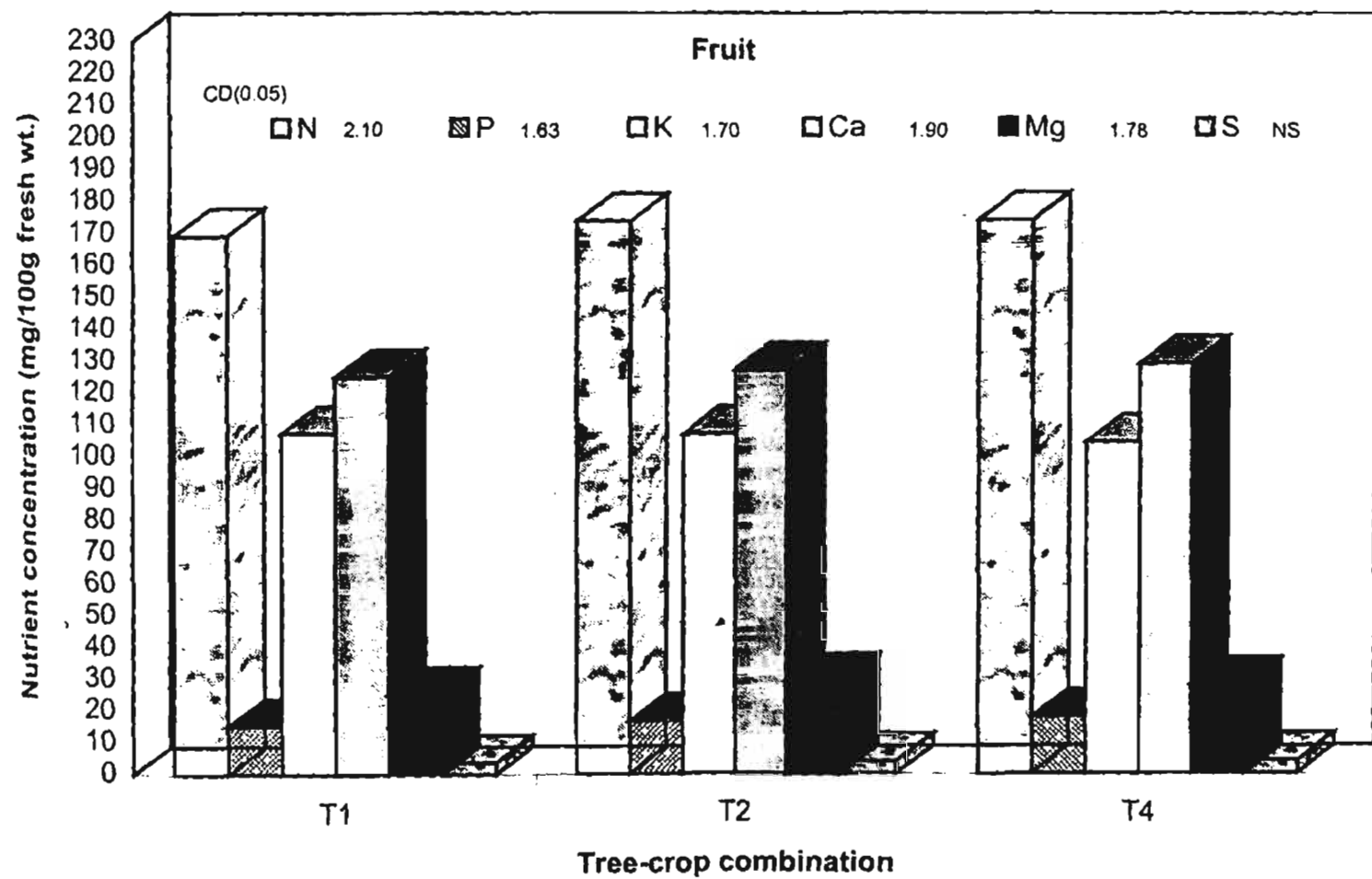
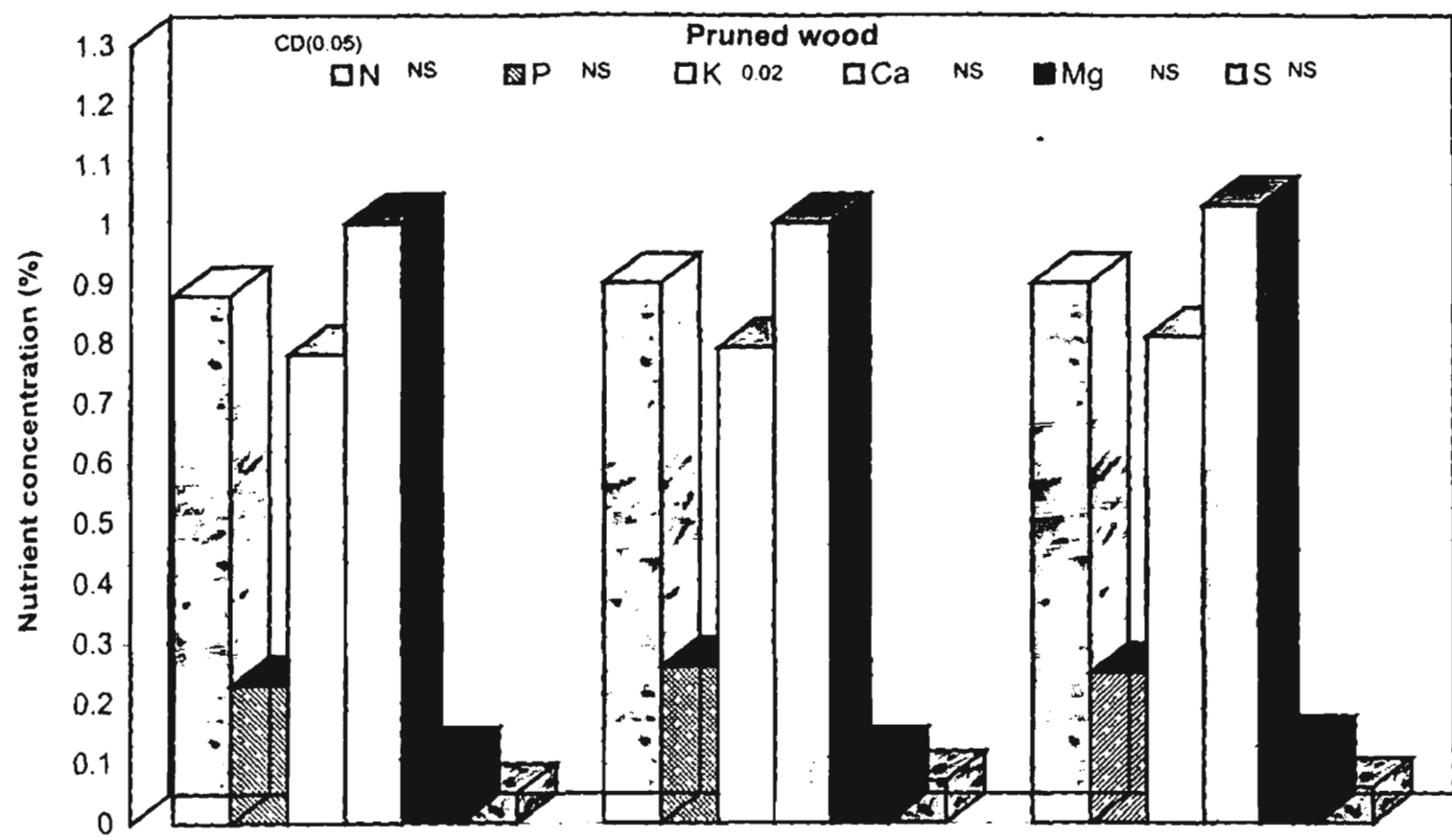


Fig. 3. Nutrient concentration in plum pruned wood and fruit at their respective harvestable period

Ca, Mg and S concentration of pruned wood, and K and Mg concentration of fruit showed variable trend.

Monthly variation in foliar nutrient concentration (%)

Monthly variation in foliar nutrient concentration of mulberry, plum and pomegranate were observed to be statistically significant (Fig. 4).

In mulberry, the N, P, K and S concentration decreased from July to October whereas, Ca and Mg concentration increased. The foliar nutrient concentration of plum exhibited a trend similar to mulberry except Mg which showed its highest value in August (0.88) followed by September (0.86), October (0.85) and lowest in July (0.84). In pomegranate, N and K concentration was lowest in July which increased to its maximum in August and thereafter, decreased. The P concentration was 0.20 in July, and rose to 0.27 in August but again fell to 0.19 and 0.15 during September and October, respectively. The Ca concentration showed an upward trend from July to October similar to that of mulberry and plum. However, Mg concentration was 0.81 in July and attained a value of 0.91 in August, 0.94 in September and 0.83 in October. The S concentration was 0.10 in July, 0.14 in August followed by 0.11 in September and 0.10 during October.

4.3 Litter studies

4.3.1 Litter production and nutrient concentration (kg ha⁻¹)

Litter produced by mulberry, plum and pomegranate under different tree-crop combinations was statistically significant (Table 6). Litter produced by mulberry depicted significantly different values under different tree-crop combinations showing maximum (330.80) value in T₅ followed by T₃ (143.60), T₂ (107.40) and T₁ (58.88). Plum produced 1562.05 kg ha⁻¹ of litter under tree-crop combination T₄ which was significantly higher than T₂ and T₁.

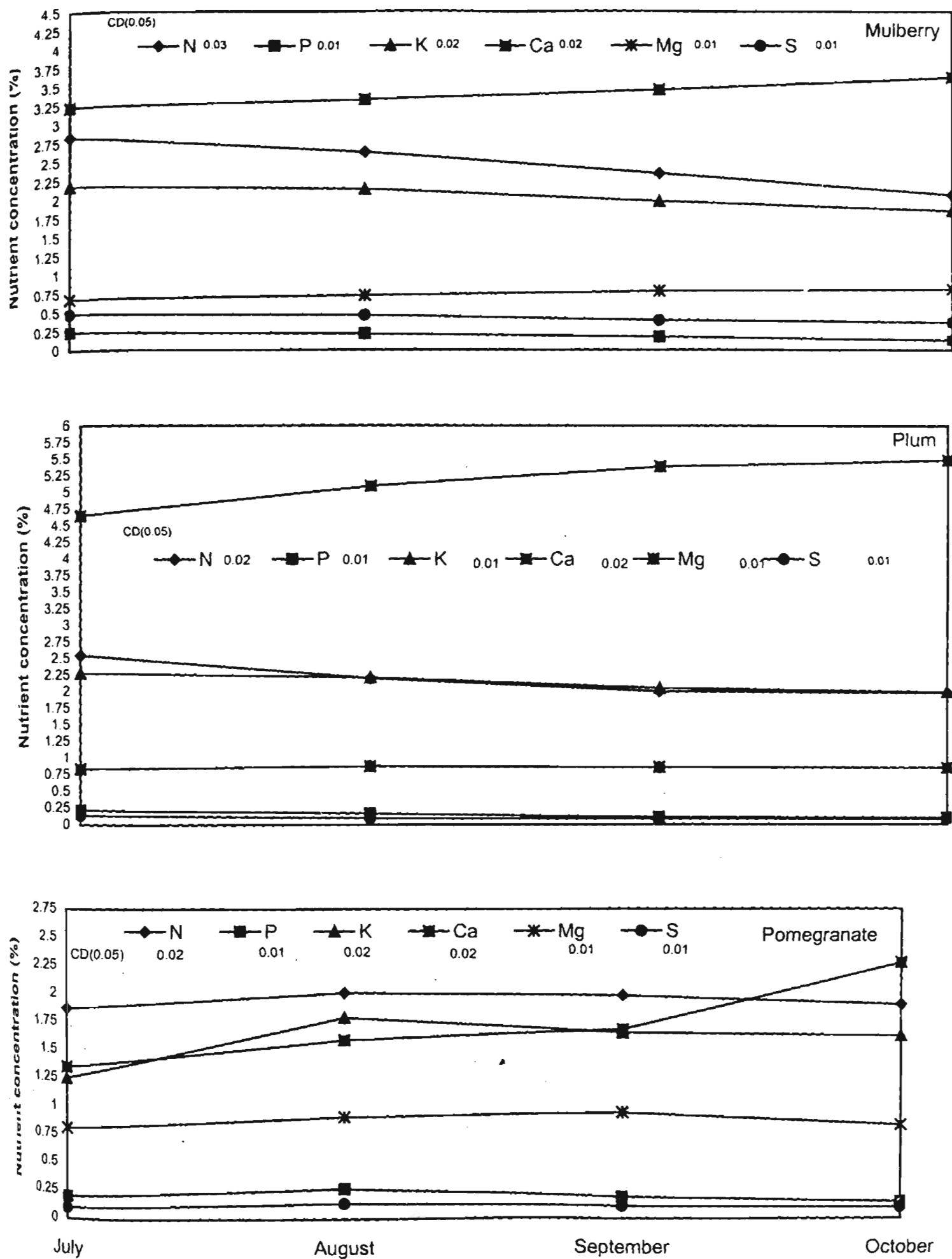


Fig.4. Monthly variation in nutrient concentration of mulberry, plum and pomegranate leaves during the soybean crop season.

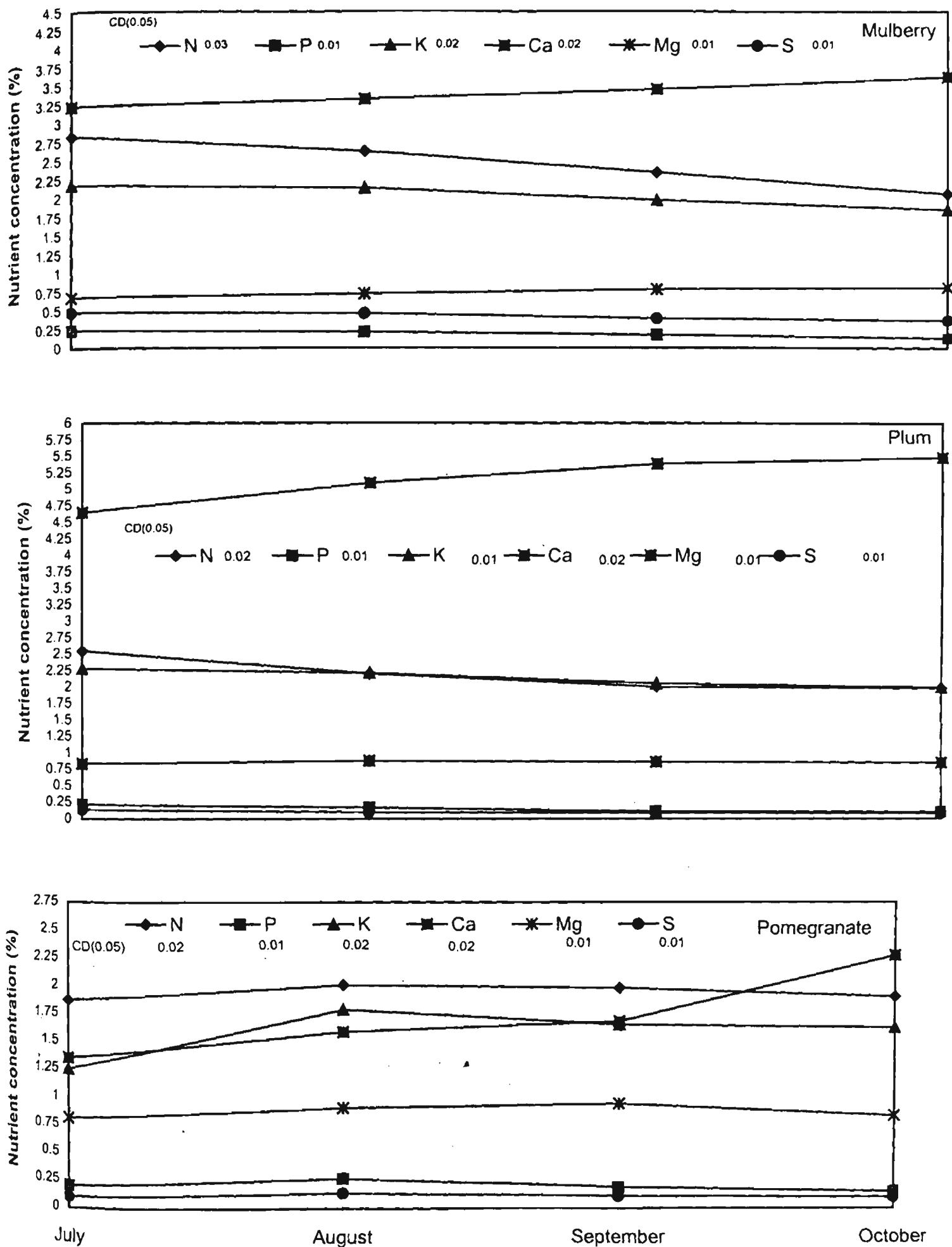


Fig.4. Monthly variation in nutrient concentration of mulberry, plum and pomegranate leaves during the soybean crop season.

Table 6. Litter production (kg ha⁻¹) under different tree-crop combinations

Tree-crop combinations	1997	1998	Pooled
Mulberry			
T ₁	63.55	54.20	58.88
T ₂	103.60	111.20	107.40
T ₃	133.60	153.60	143.60
T ₅	315.20	346.40	330.80
S.Ed.	3.75	3.44	2.41
CD _(0.05)	8.18	7.50	5.25
Plum			
T ₁	350.30	355.50	352.90
T ₂	691.20	672.45	681.83
T ₄	1536.00	1558.10	1562.05
S.Ed.	7.43	10.43	6.47
CD _(0.05)	16.20	22.72	14.10
Pomegranate			
T ₁	183.70	152.45	168.08
T ₃	336.80	348.41	342.61
T ₆	813.60	791.72	802.66
S.Ed.	5.84	4.28	2.96
CD _(0.05)	12.72	9.32	6.45

The respective values for T_1 and T_2 were 352.90 and 681.83 kg ha⁻¹, which were also significantly different from one another. Litter produced by pomegranate indicate maximum value in T_6 (802.66) and minimum (168.08) in T_1 combination.

Nutrient concentration (%)

Under different tree-crop combinations the nutrient concentration in mulberry, plum and pomegranate litter was statistically significant (Fig. 5). N, P, K, Ca, Mg and S concentration in mulberry litter was maximum in tree-crop combination T_5 followed by T_3 , T_2 and T_1 . However, S concentration in T_2 and T_3 exhibited similar values. N, P, K, Ca, Mg and S concentration in plum litter was minimum in tree-crop combination T_1 following T_2 and T_4 however, P and Mg concentration in T_1 and T_2 depicted similar values. Pomegranate litter exhibited maximum N, P, K, Ca, Mg and S concentration in tree-crop combination T_6 followed by T_3 and T_1 . However, P concentration in T_3 and T_6 , and Mg concentration in T_1 and T_3 were the same.

4.3.2 Litter decomposition (%)

Litter decomposition rate of mulberry, plum and pomegranate was studied during July to October i.e. soybean crop season. The data are presented in Fig. 6.

On 1st sampling date i.e. 15th July, the decomposition rate was maximum in mulberry followed by plum and pomegranate (Fig. 6). However, on 30th July plum depicted higher decomposition rate than mulberry and minimum in pomegranate. On 15th and 30th August litter decomposition rate was maximum in pomegranate and minimum in mulberry following plum.

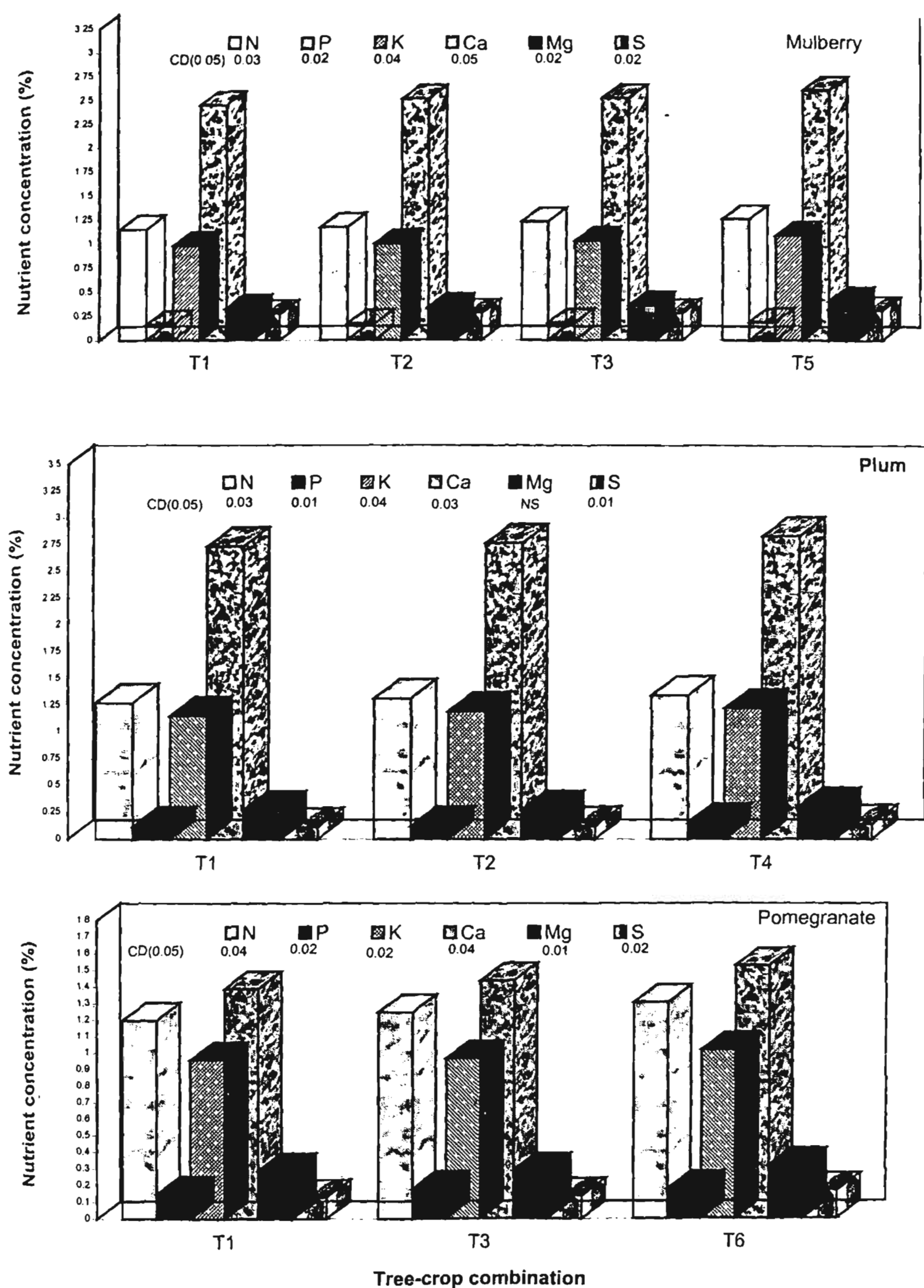


Fig. 5. Nutrient concentration in mulberry, plum and pomegranate litter under different tree-crop combinations.

On 15th September, the decomposition rate was highest in plum than pomegranate and minimum in mulberry. Plum excelled in its decomposition rate even on 30th September however, the values were closely followed by mulberry and pomegranate. On last two sampling dates i.e. 15th and 30th October, the decomposition rate followed the order plum > pomegranate > mulberry.

In the beginning i.e. during month of July, all of the three species viz. mulberry, plum and pomegranate showed higher per cent decomposition rate. The latter two species exhibited highest per cent decomposition rate in this month when compared to other months. Thereafter, a decrease was observed in August as compared to July which was more pronounced in mulberry than plum and pomegranate. In September an increase in the per cent decomposition rate was observed for all the three species, showing highest value for mulberry as compared to other sampling months. At the termination of the experiment i.e. in the month of October the per cent decomposition rate declined depicting values almost similar to that in August (Fig. 6).

4.4 Soil characteristics

4.4.1 Chemical properties

Effect of various tree-crop combinations on chemical properties of soils viz. pH, organic carbon, available N, P, K, S, exchangeable Ca and Mg at 0-15 and 15-30 cm soil depths hereafter, referred to surface and sub-surface soils, respectively was determined at monthly intervals during soybean growth period (July to October). The data presented in Fig 7-22 were statistically significant.

pH : In all the tree-crop combinations (T₁-T₇) surface soil pH was maximum in June followed by October, July, September and minimum in August. Whereas, in sub-surface soils it was highest in June followed by October, remained the

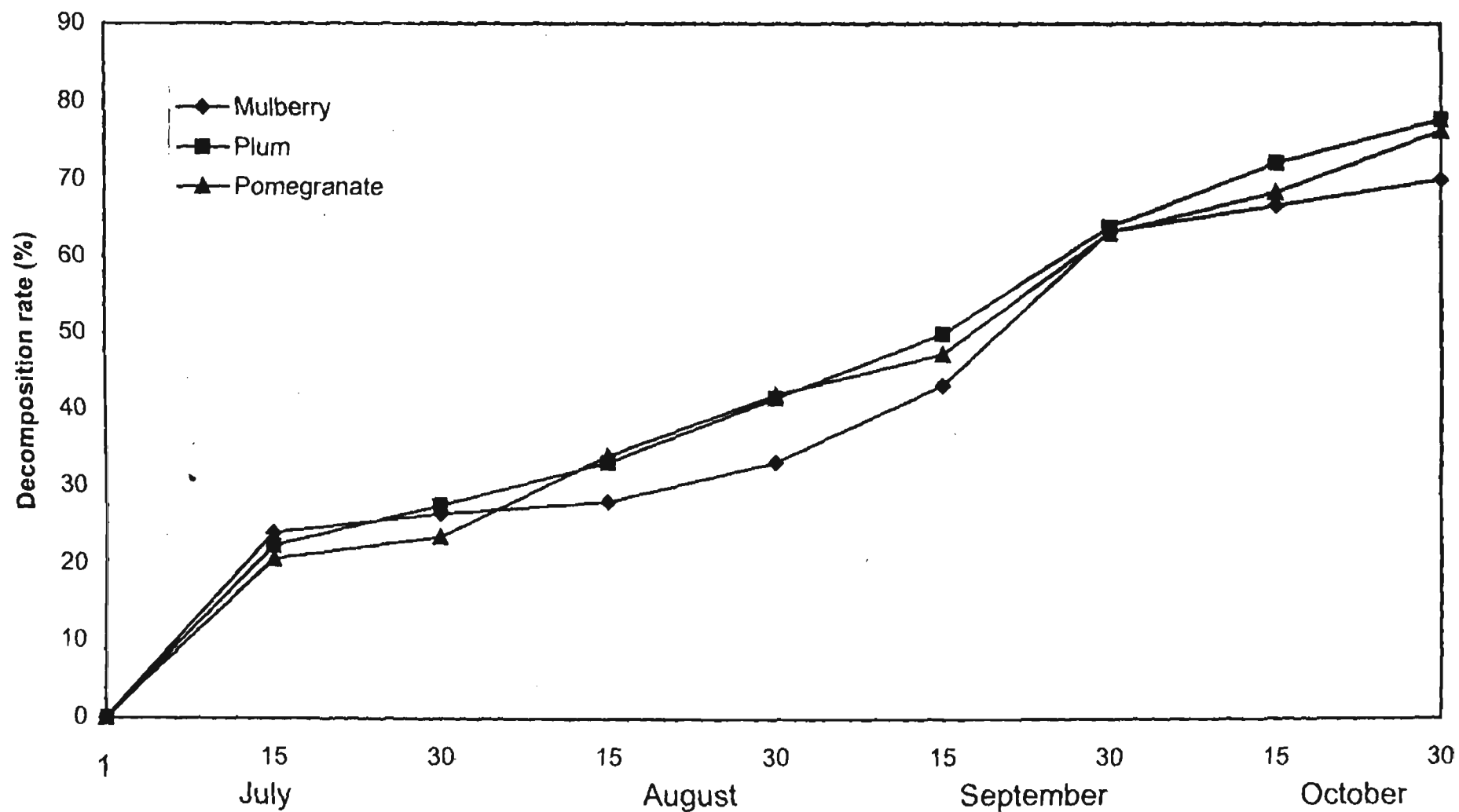


Fig. 6. Litter decomposition rate of mulberry, plum and pomegranate during soybean crop season.
{CD(0.05) to compare the interaction time interval x tree species 7.80}

same in July and September and minimum in August. Monthly variation both in surface and sub-surface soils treatmentwise did not show a specific pattern (Fig.7).

Leaving sampling months apart, surface as well as sub-surface soil pH was maximum in sole cropping (T_7) followed by T_5 , T_4 , T_2 , T_3 , T_6 and minimum in T_1 however, in sub-surface soils its values were higher in T_6 than T_3 . Monthwise the tree-crop treatments did not follow a specific trend (Fig. 8). Overall the pH was higher in sub-surface soils than surface one.

Organic Carbon (%) : Organic carbon both in surface and sub-surface soils exhibited a slight increase in the month of July and then declined as the crop season advanced i.e in August, September and October in all the treatments (Fig. 9).

In surface soils organic carbon content was maximum in combination T_4 followed by T_1 , T_2/T_6 , T_3 , T_5 and T_7 during the entire crop season. However, in sub-surface layer it was highest in T_4 followed by T_6 , T_1/T_2 , T_5 , T_3 and T_7 (Fig. 10). Overall the organic carbon content was higher in surface soils than sub-surface one.

Available N (Kg ha^{-1}) : Treatmentwise surface and sub-surface soils N content increased with the advancement of season from June to October (Fig. 11). Monthwise, it was maximum in combination T_4 followed by T_2 , T_1 , T_6 , T_5 , T_3 and minimum in T_7 both in surface as well as sub-surface layer (Fig. 12). However, in surface layer during the month of June, September and October the N content was higher in T_3 than T_5 . Available N was higher in surface soils compared to sub-surface soils.

Available P (Kg ha^{-1}) : Available P content of surface and sub-surface soils in all the tree-crop combinations (T_1 - T_7) was maximum in the month of June

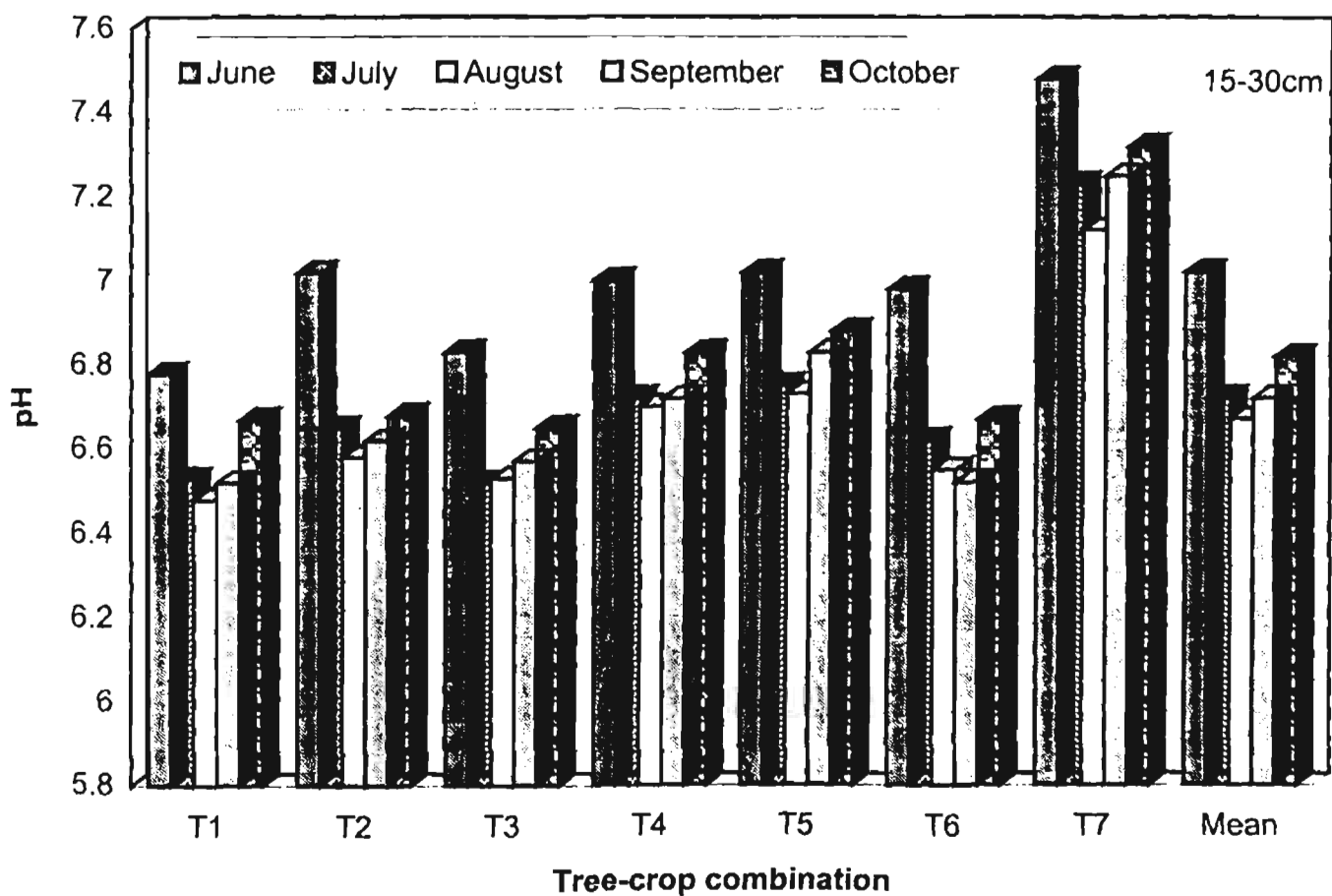
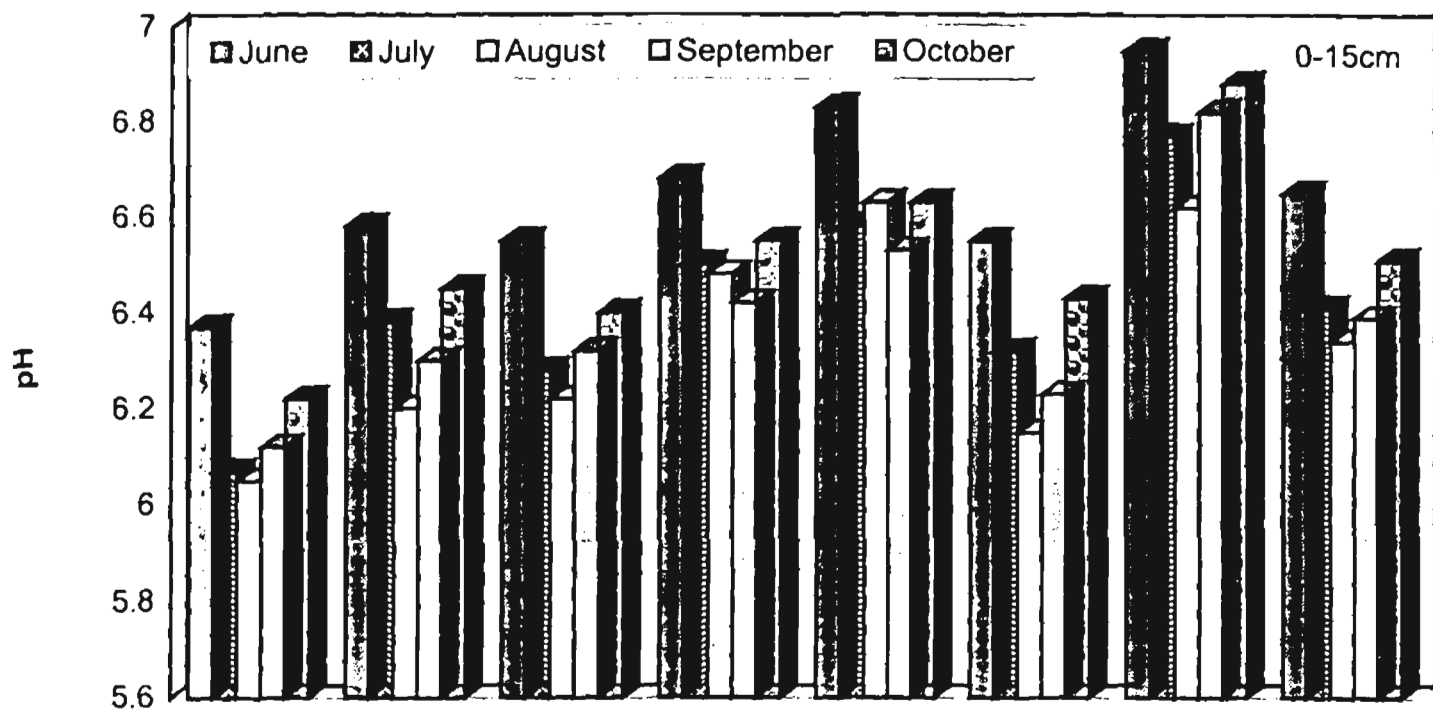


Fig. 7. Effect of tree-crop combinations on pH in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 0.10 and tree-crop combination x month x depth 0.27)

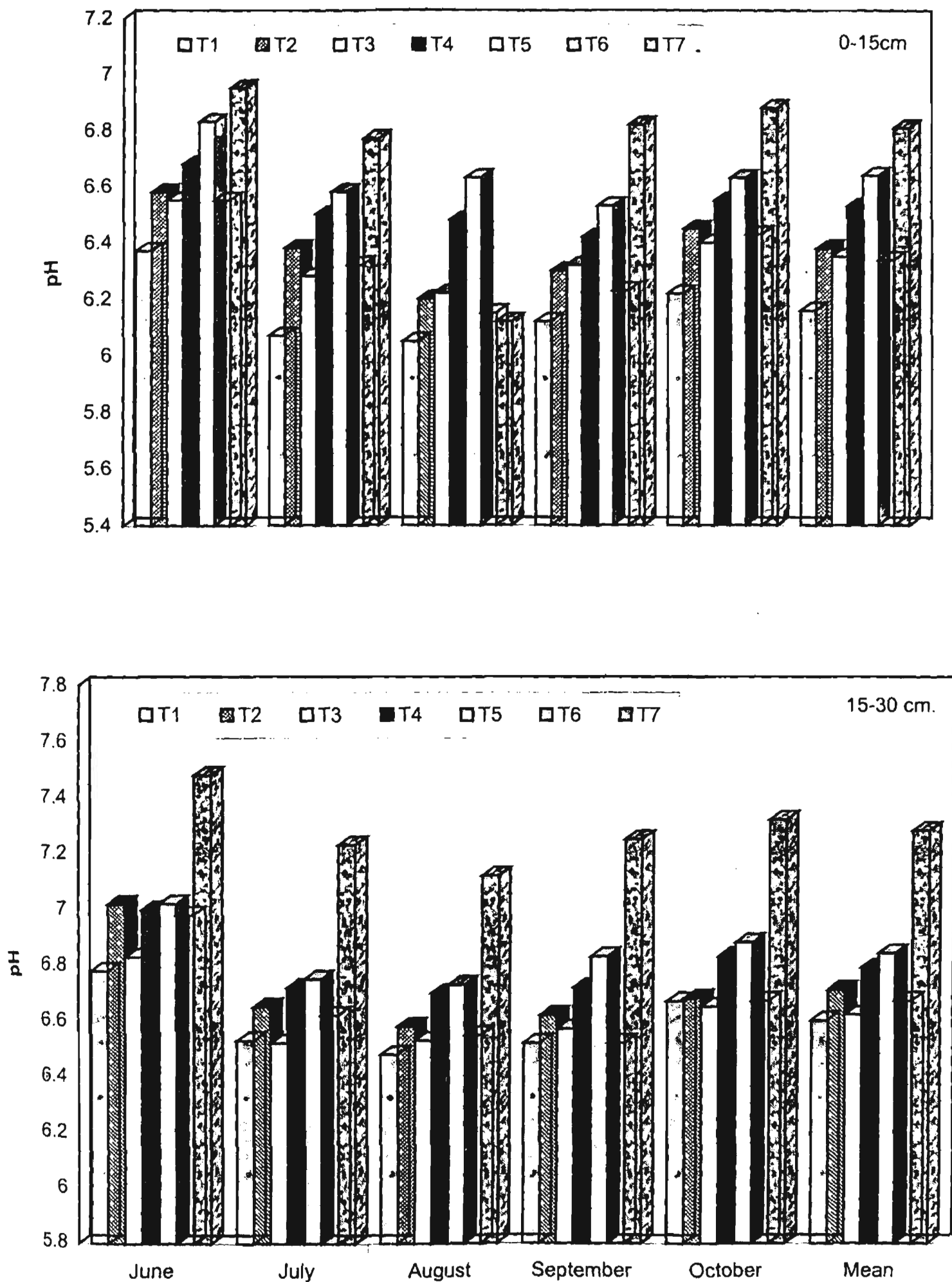


Fig. 8. Monthly variation in pH in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 0.12 and T x M x D 0.27}

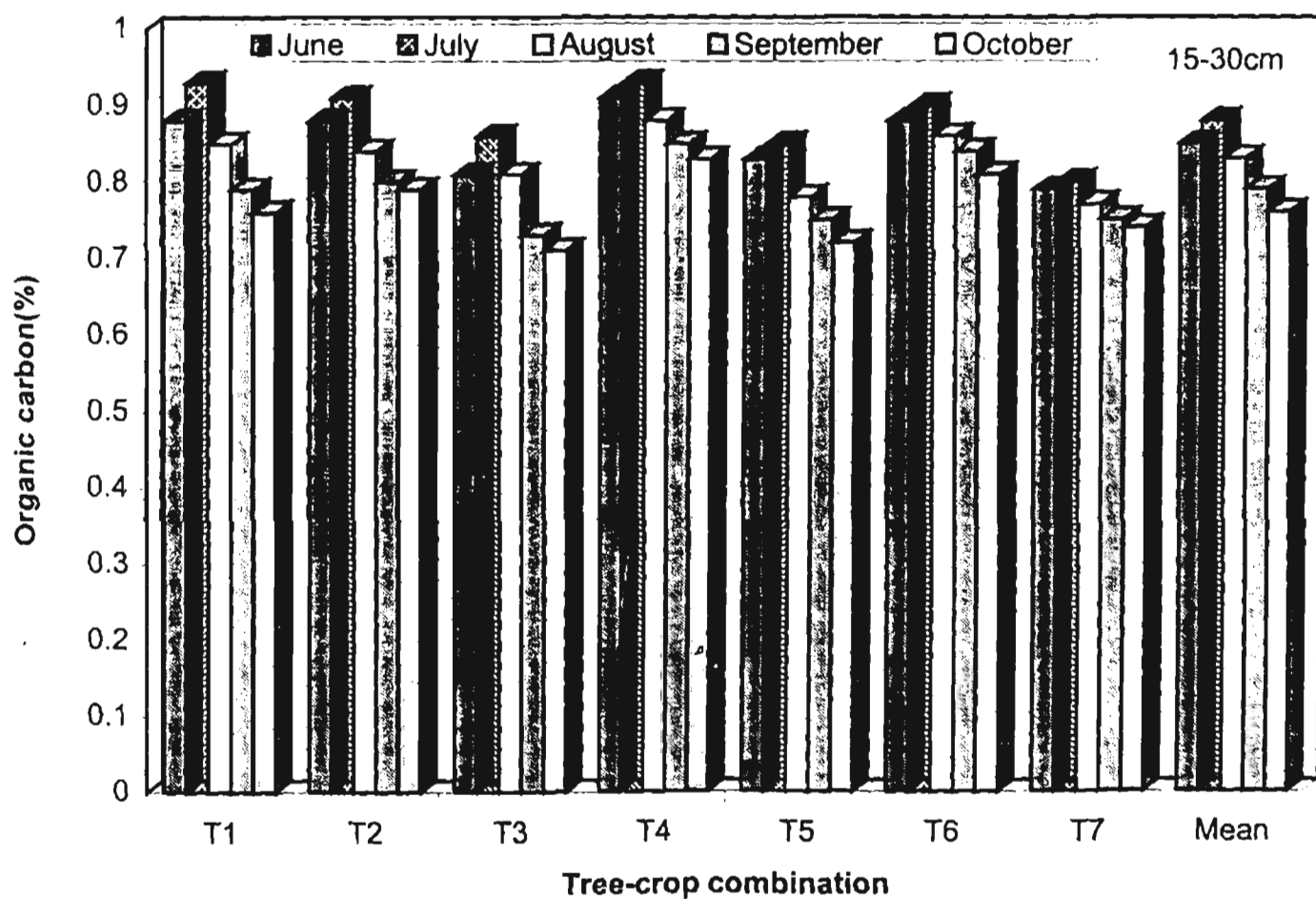
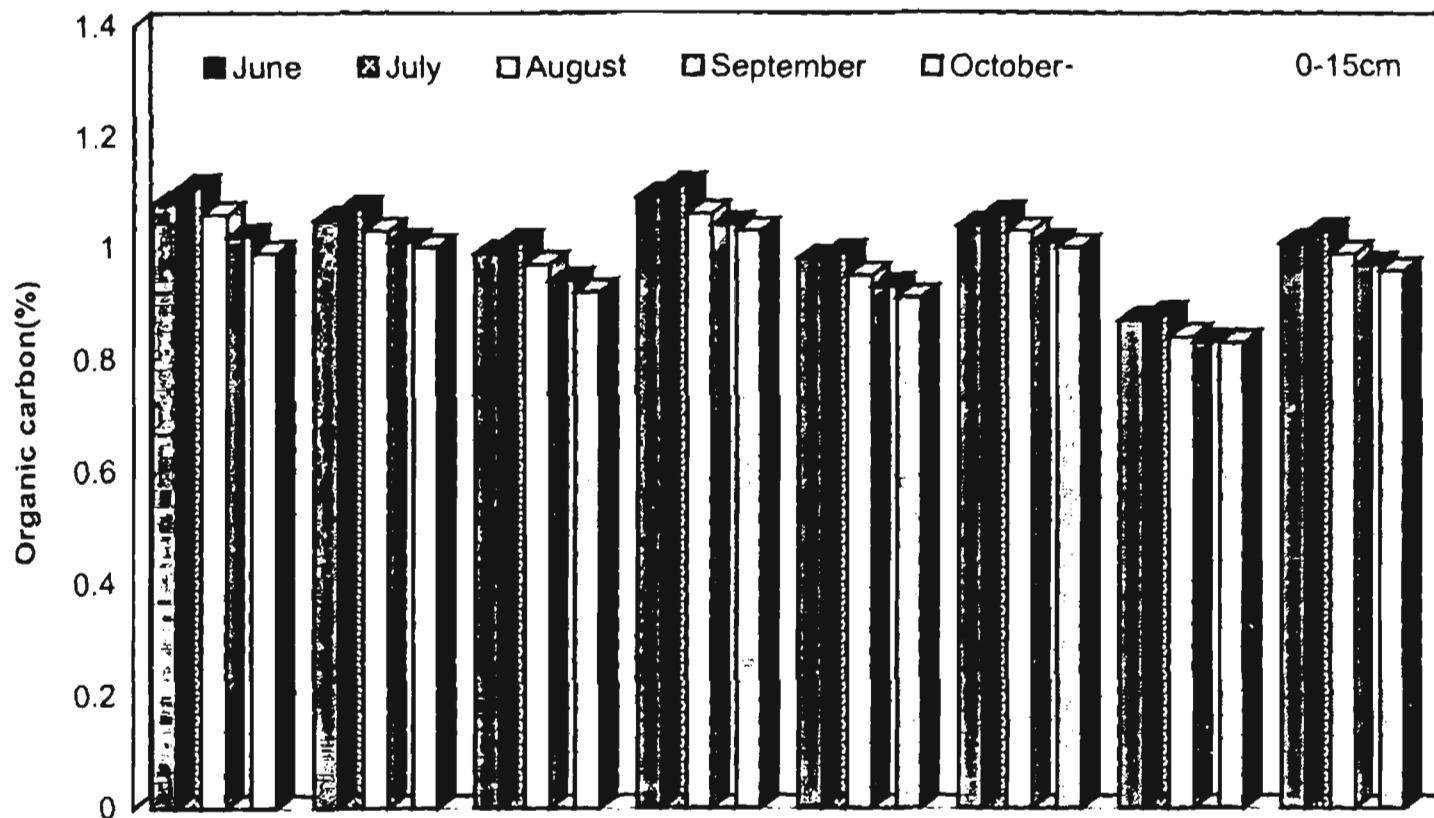


Fig. 9. Effect of tree-crop combinations on organic carbon in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 0.01 and tree-crop combination x month x depth 0.03}

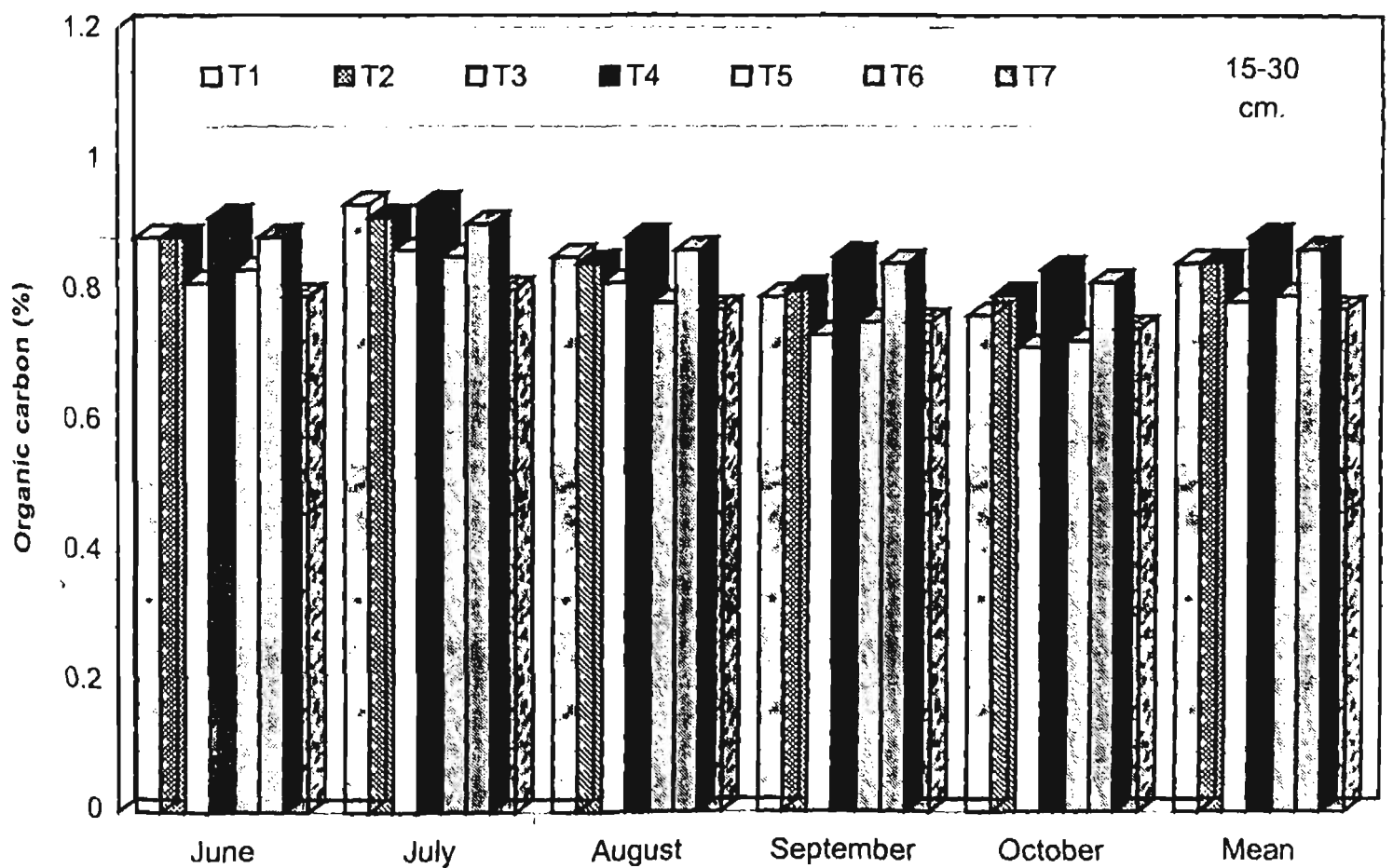
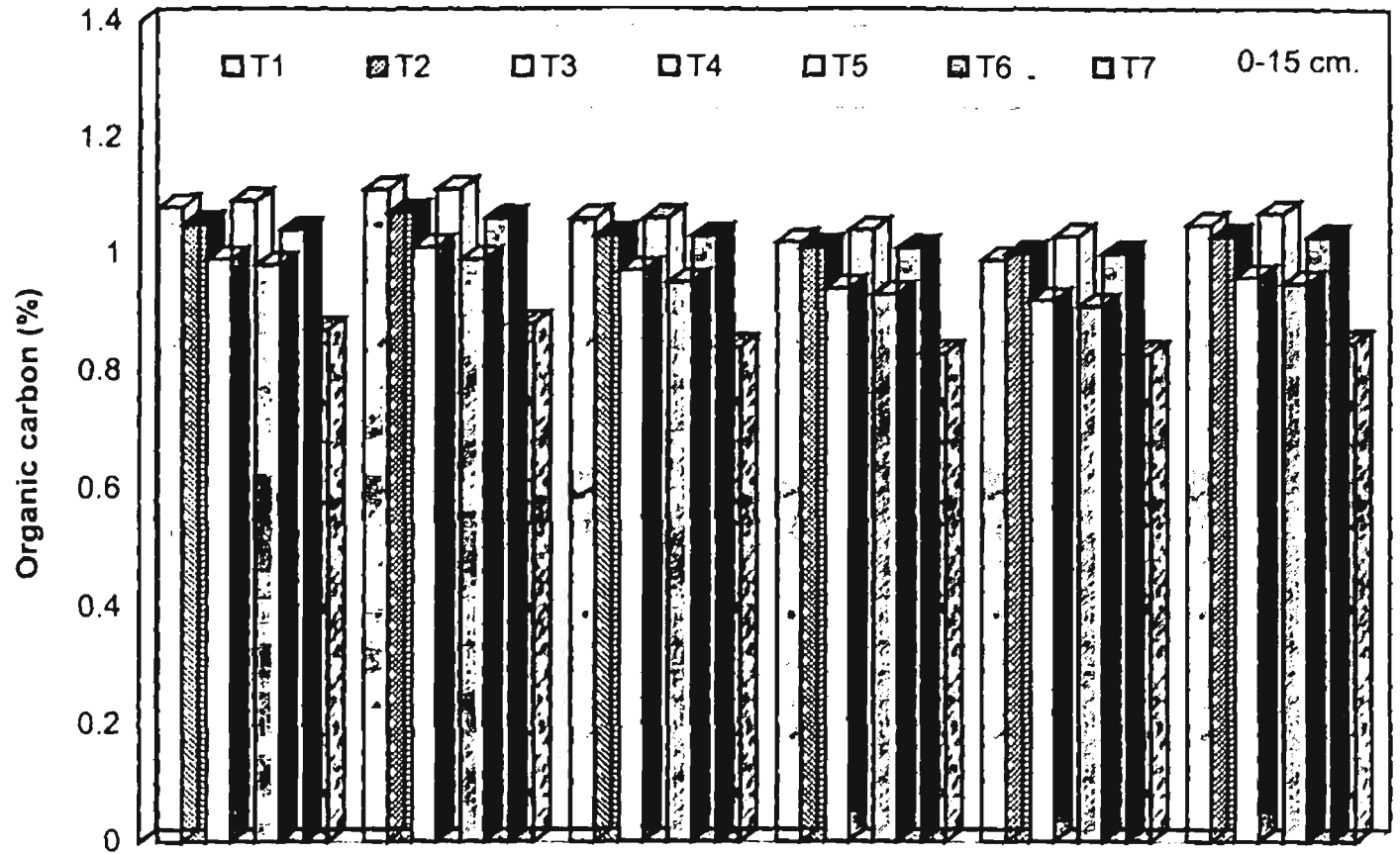
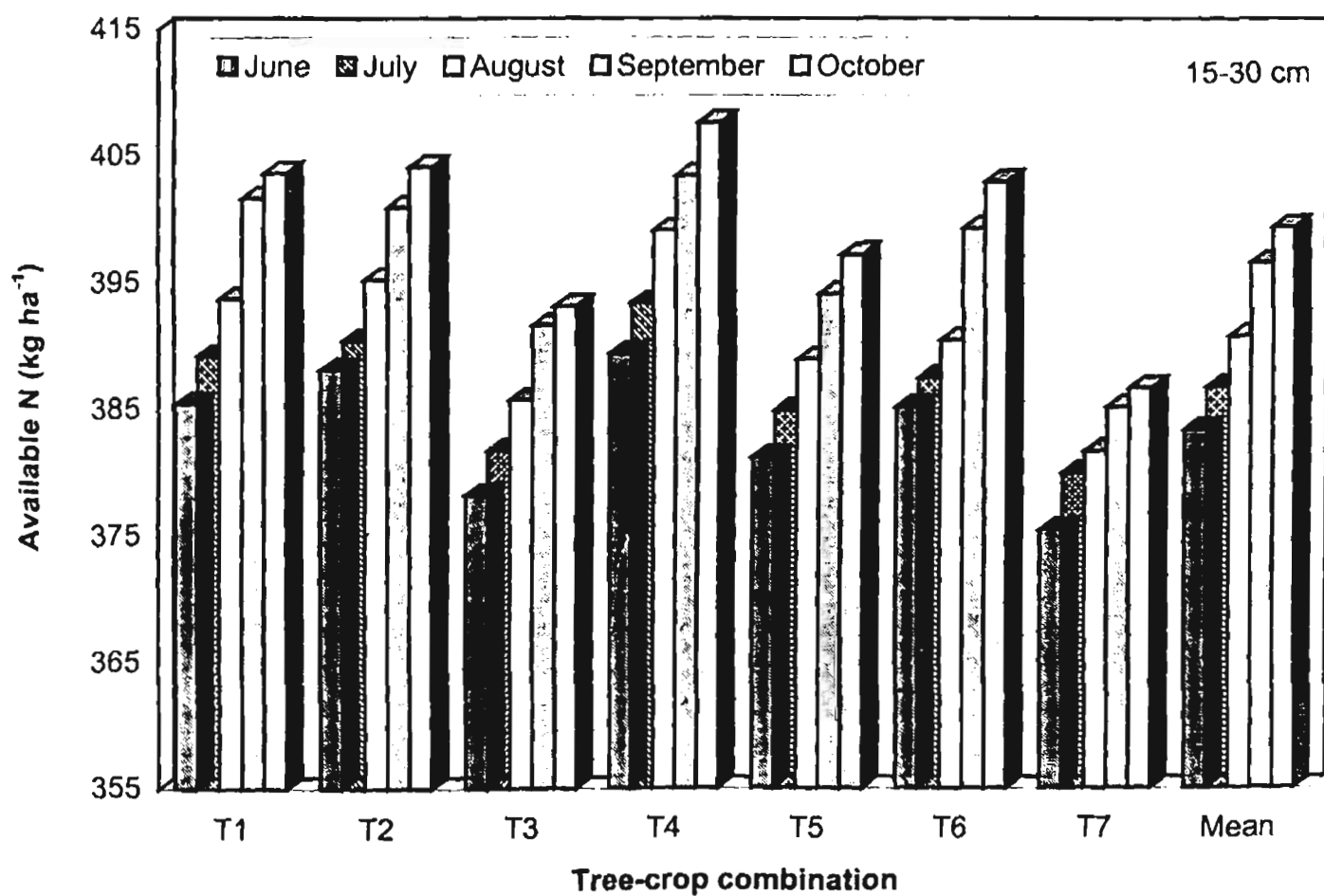
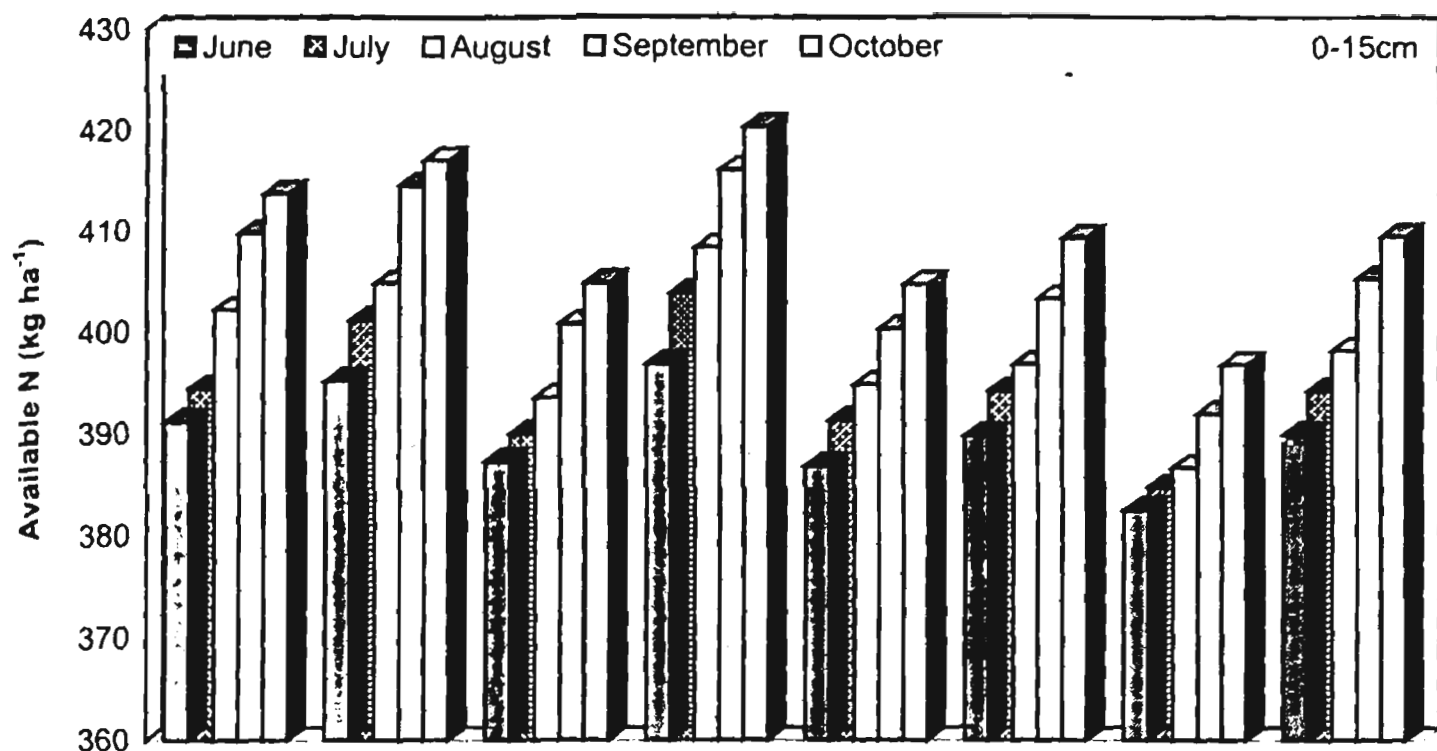


Fig. 10. Monthly variation in organic carbon in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 0.01 and T x M x D 0.03}



11. Effect of tree-crop combinations on available N in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 1.92 and tree-crop combination x month x depth 5.08)

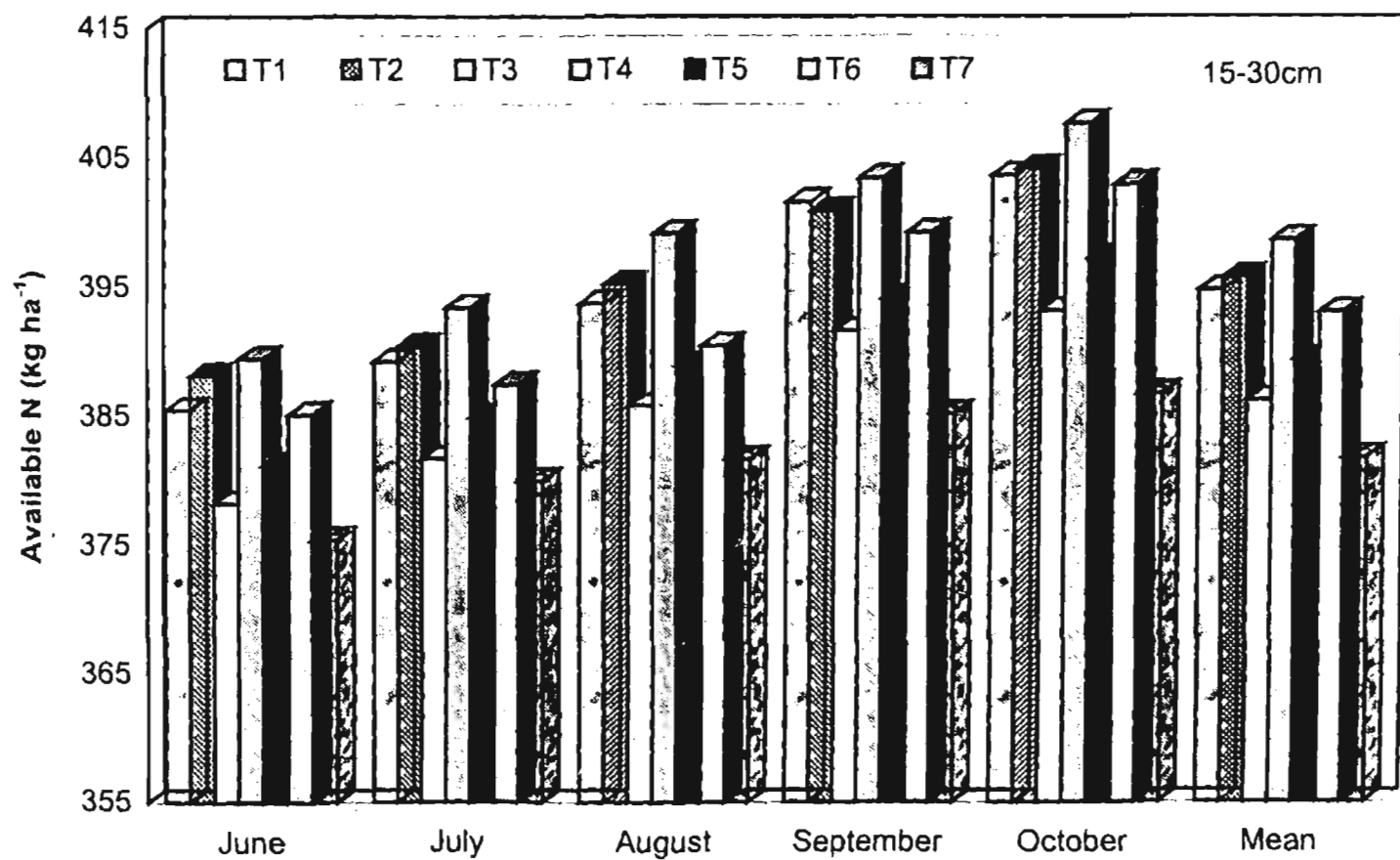
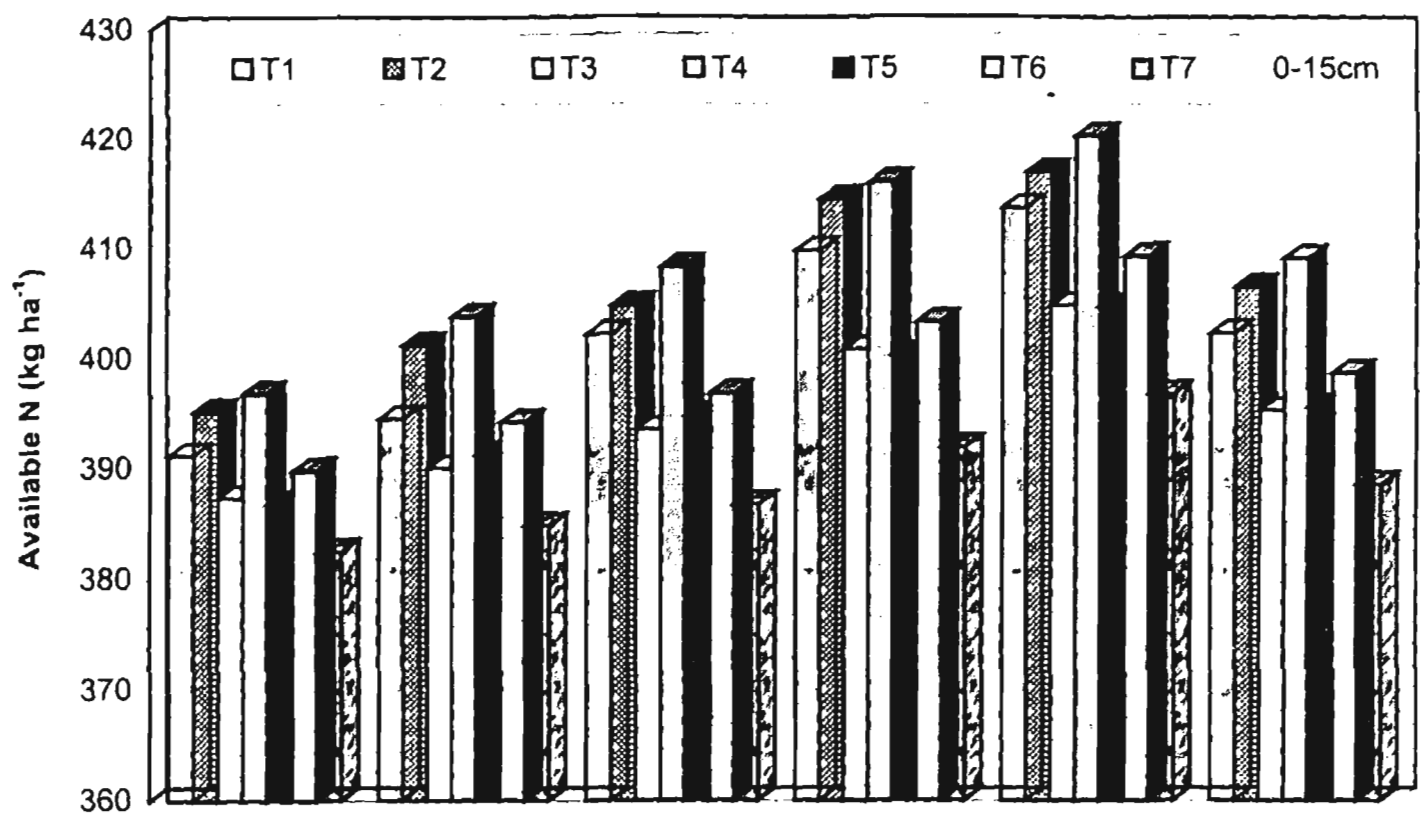


Fig. 12. Monthly variation in available N in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 2.99 and T x M x D 5.08}

and there after showed a decreasing trend till the harvest of soybean depicting minimum mean value in October (Fig. 13). However, tree-crop combinations T₃, T₄ and T₆ exhibited slightly higher P content in the surface layer during the month of October over September and gave similar value in the month of July and August. Similarly in the Sub-surface layer, T₆ showed more P content during August than July. The latter being equal to the content found in September.

P content among the various tree-crop combinations during the growth season of soybean (Fig. 14) was higher in T₄ followed by T₆, T₂, T₁, T₅, T₃ and minimum in T₇ (soybean alone) in surface layer. Similarly, in the sub-surface layer its values were higher in T₄ followed by T₂, T₆, T₁, T₅, T₃ and minimum in T₇ during the each month. Mean values irrespective of the month followed the similar pattern. Available P was higher in surface soils than sub-surface soils.

Available K (Kg ha^{-1}) : Available K content of surface as well as sub - surface soils due to tree-crop combinations decreased with the advancement of season showing maximum value in June and minimum in October. However, in surface soils under tree-crop combination T₅ and T₆ it was found to be higher in October than September. Likewise, in sub-surface soil its value were higher in October compared to September under T₁ and T₃. Under T₄ more K content was observed in September than August and the former showed value similar to that of July. Its values were also higher in August than July under T₅ and T₆ (Fig. 15).

Among the different tree-crop combinations (Fig. 16), monthwise available K content of surface soil was maximum in T₄ followed by T₂, T₁, T₆, T₅, T₃ and minimum in T₇ (soybean alone). However, T₇ showed higher K content than T₅ and T₃ in the month of June, and also more in T₆

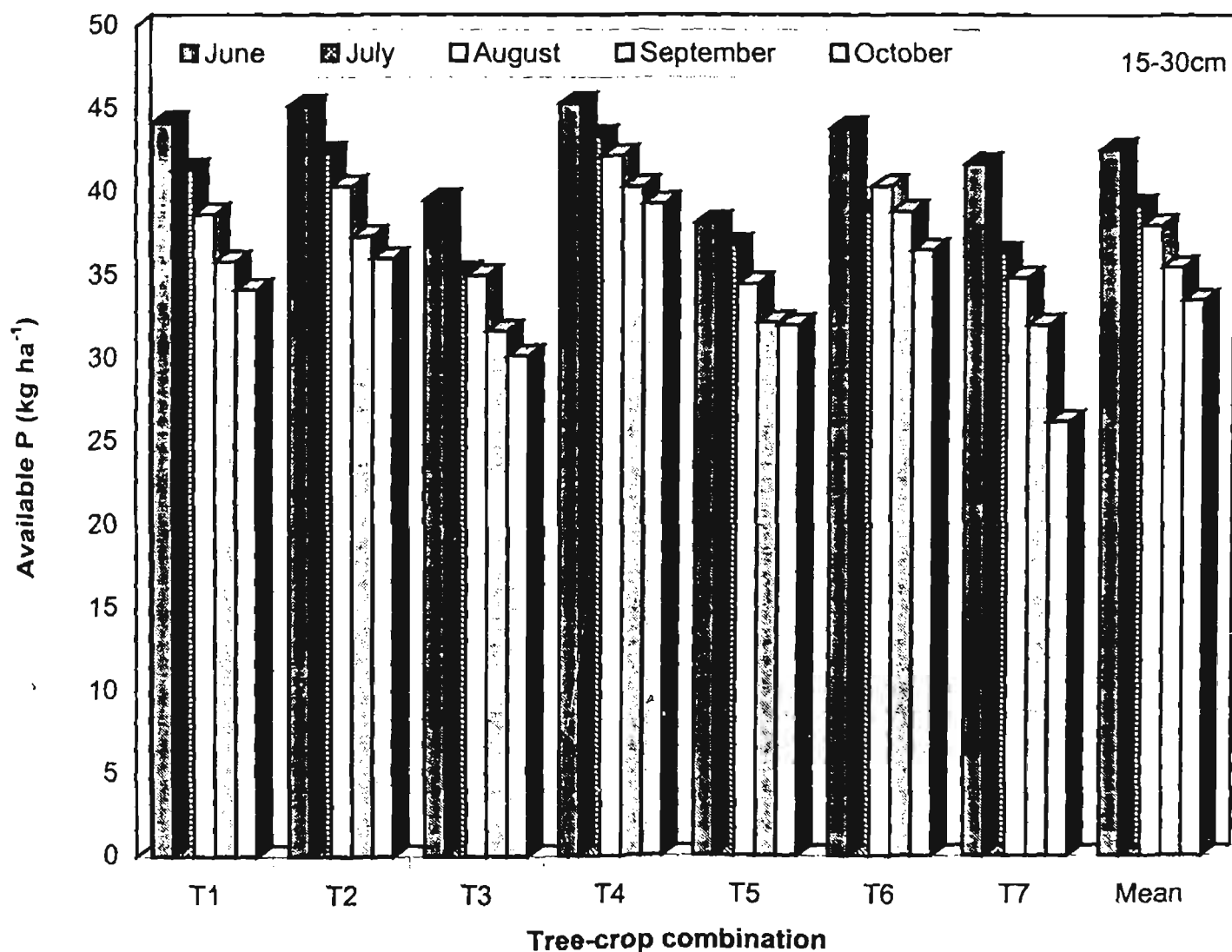
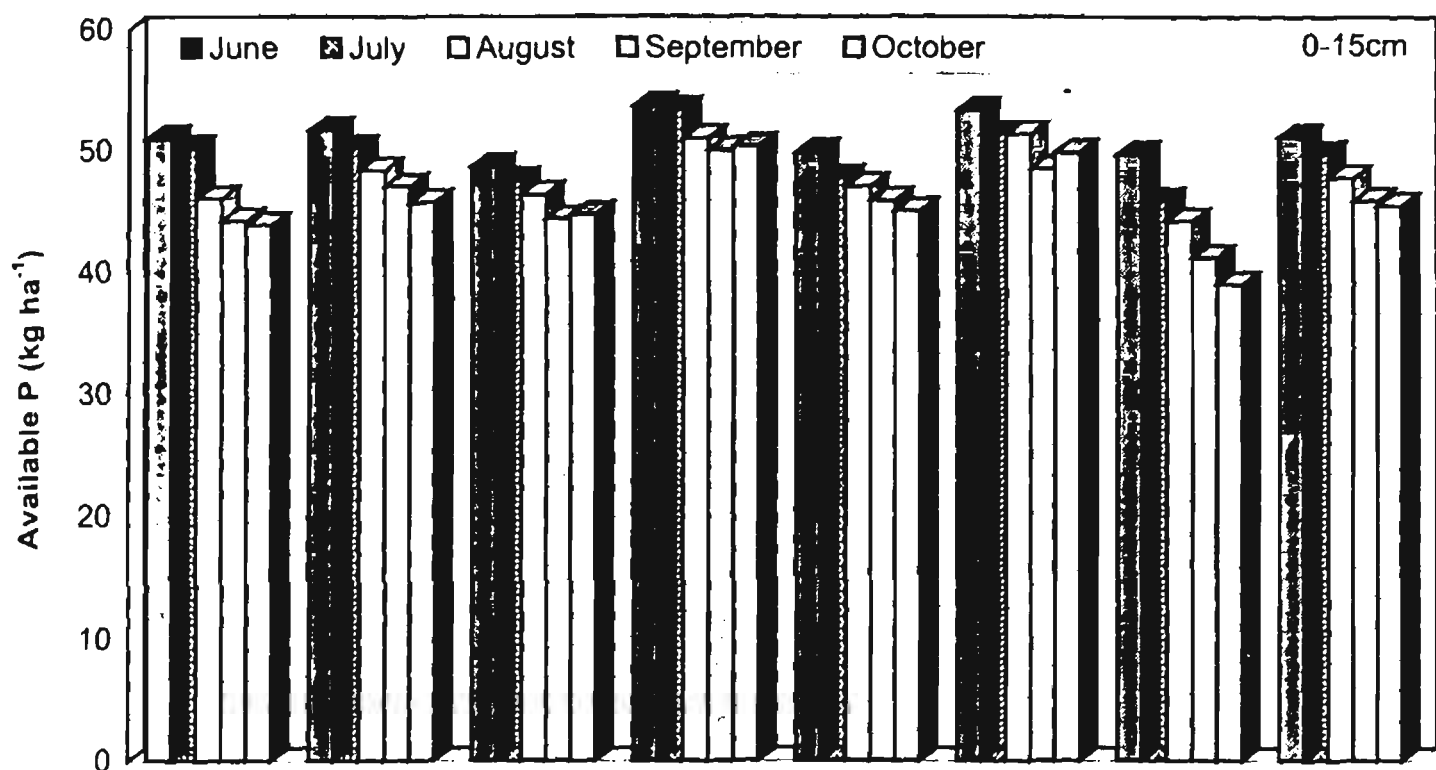


Fig. 13. Effect of tree-crop combinations on available P in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 1.11 and tree-crop combination x month x depth 2.93)

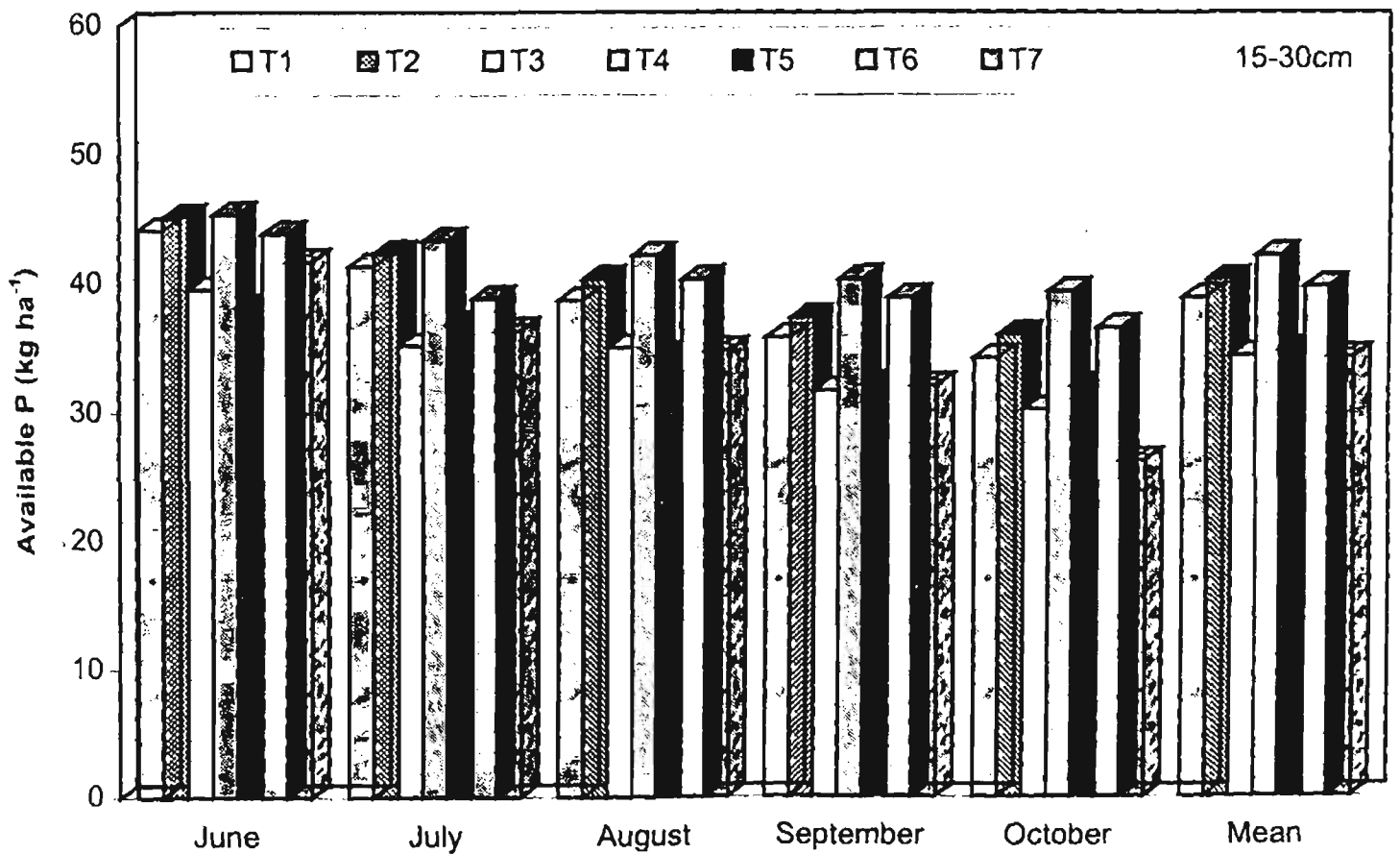
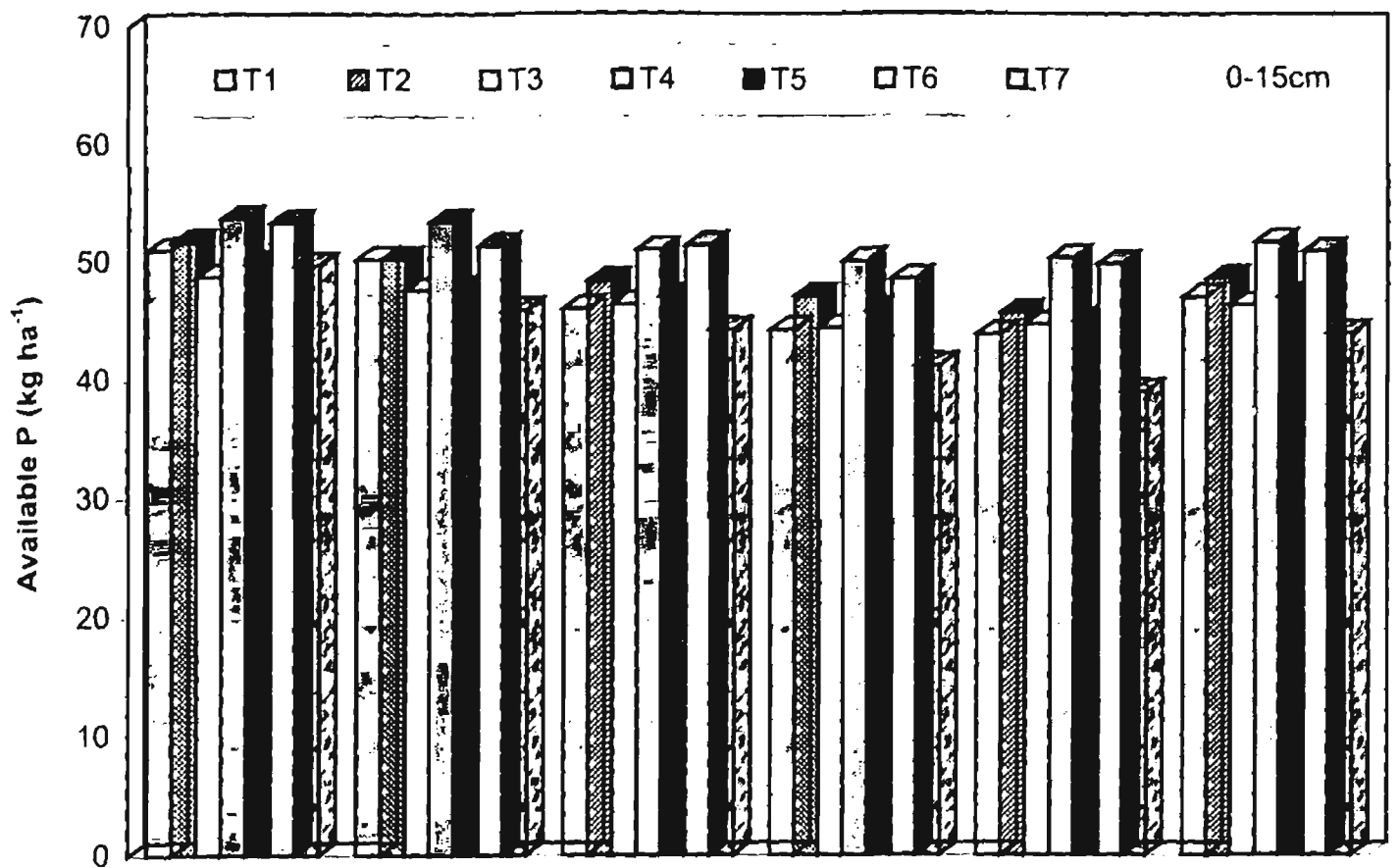


Fig. 14. Monthly variation in available P in 0-15 and 15-30 cm soil depth under different tree crop combinations. (CD(0.05) to compare the interaction T x D 1.30 and T x M x D 2.93)

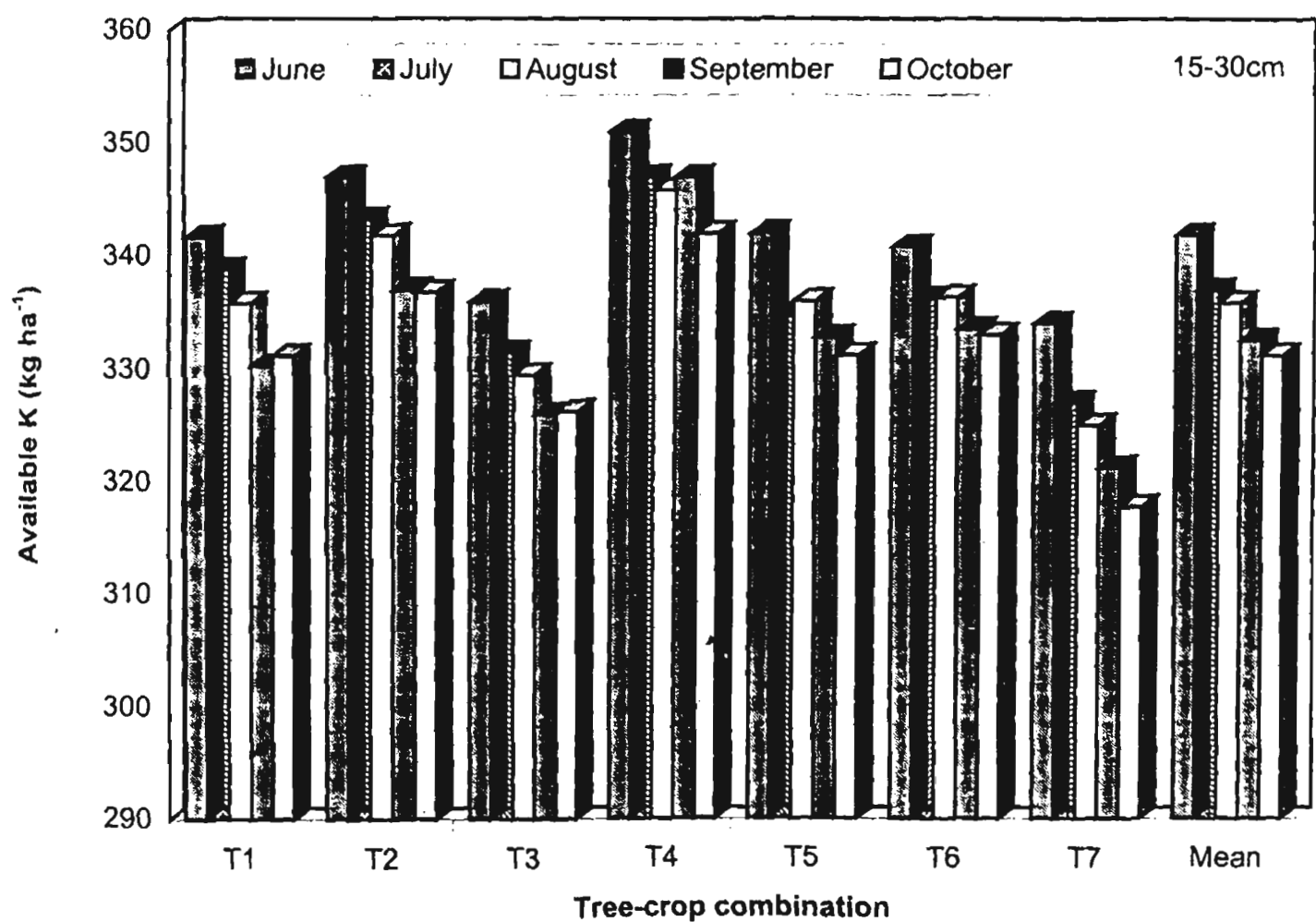
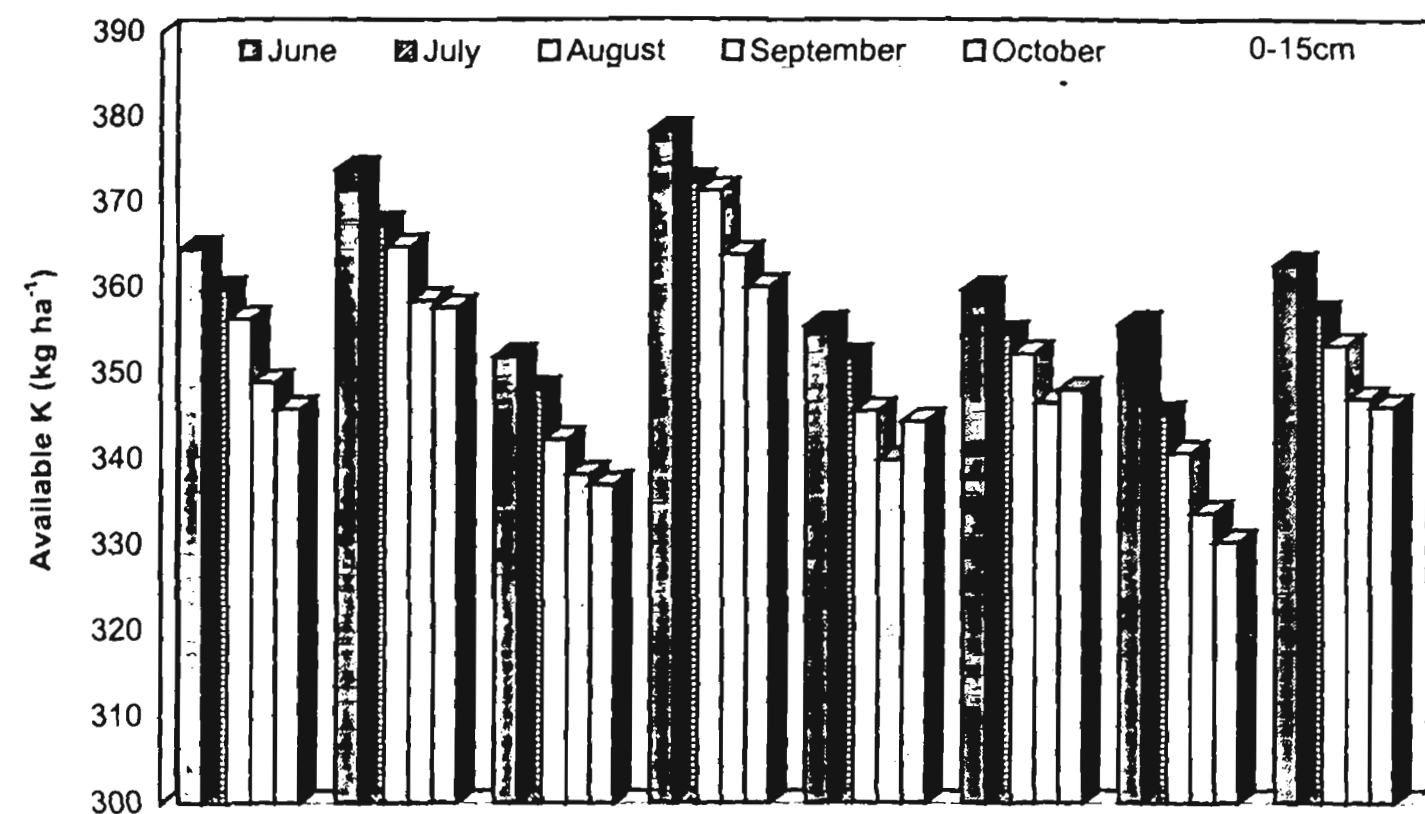


Fig. 15. Effect of Tree-crop combinations on available K in 0-15 and 15-30 cm soil depth during soybean crop season. {CD(0.05) to compare the interaction month x depth 2.27 and tree-crop combination x month x depth 6.00}

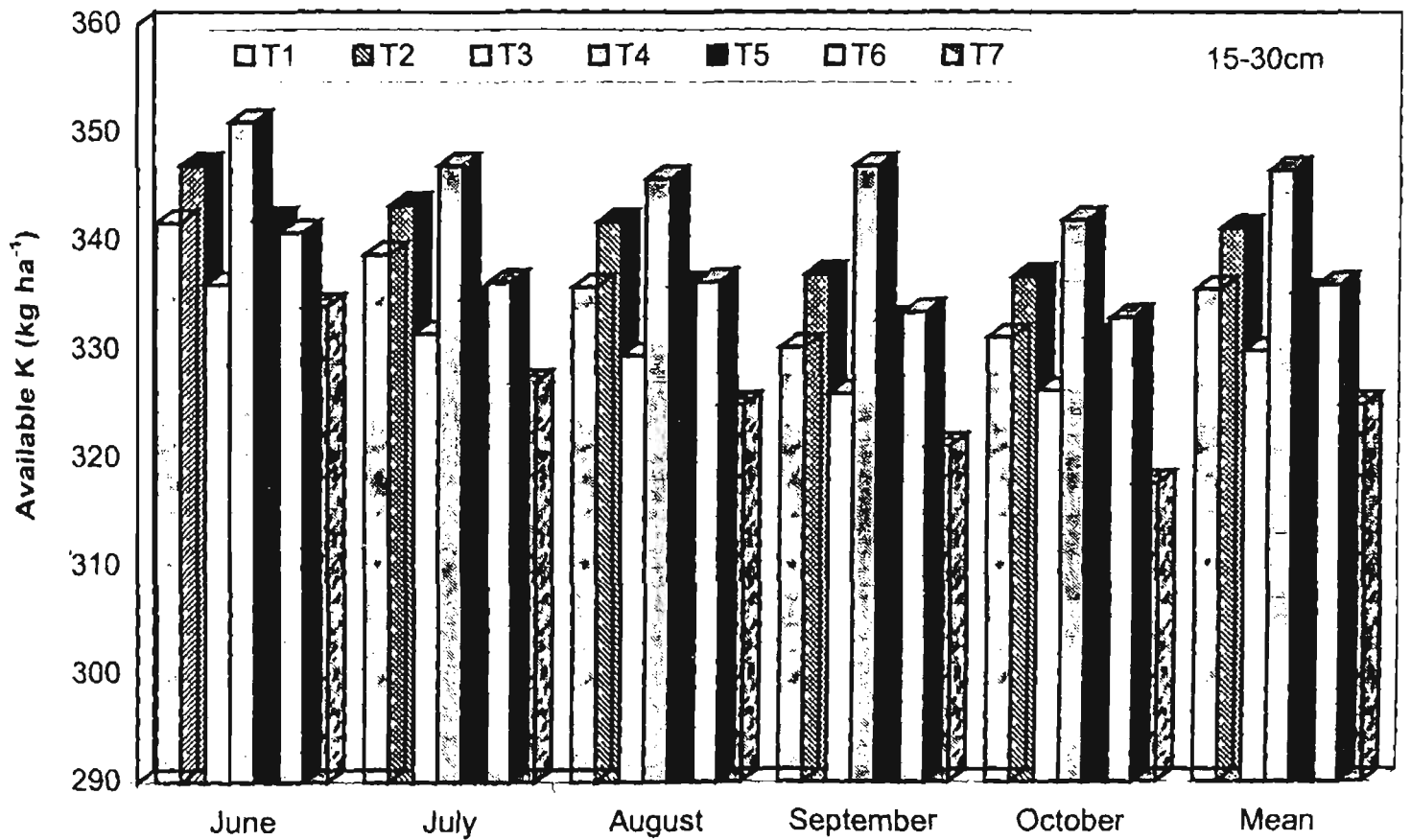
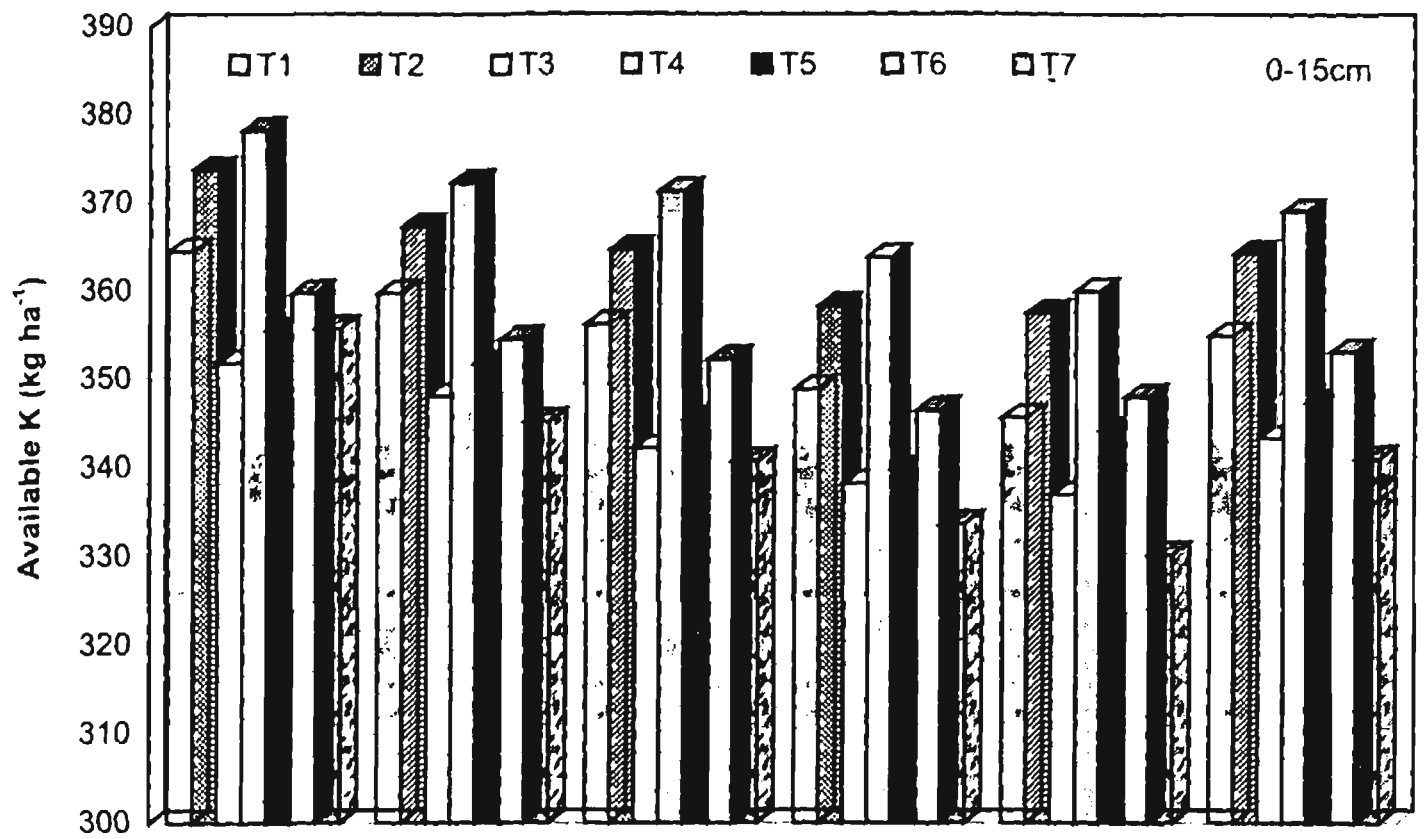


Fig. 16. Monthly variation in available K in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 2.69 and T x M x D 6.00}

and T₁ in October. Similarly, in sub-surface soil the K content was highest in T₄ followed by T₂, T₆, T₁, T₅, T₃ and lowest in T₇ (soybean alone). Available K was higher in surface soils than sub-surface one.

Exchangeable Ca (Kg ha⁻¹) : Exchangeable Ca under different tree-crop combination in surface and sub-surface soil showed a decreasing trend from June to October. However, in surface soil its content was observed to be a bit higher in October than September in T₁. In sub-surface soil Ca content was more in August and September than July in T₂. Similarly, its content was higher in October than September in T₇ (Fig. 17).

Monthwise analysis (Fig. 18) have shown that in surface soil Ca content was lowest in tree-crop combination T₇ (soybean alone) and highest in T₆ in all the months except June in which maximum value was observed in T₁. The values between maximum and minimum however, did not revealed a definite pattern. Similarly, in sub-surface soil its minimum value was observed in T₇ but no clear trend for maximum values was discernible. Exchangeable Ca was higher in sub-surface soils than surface soils.

Exchangeable Mg (Kg ha⁻¹) : Exchangeable Mg content of surface as well as sub-surface soils under different tree-crop combinations was maximum prior to the commencement of experiment (June) and thereafter, showed a decreasing trend till the termination of experiment (October) in each combination. However, in combination T₄ surface soils showed its content slightly higher during October than September (Fig. 19).

Monthwise variation in exchangeable Mg content of soils under different tree-crop combinations during a crop season (Fig. 20) have shown its maximum mean value in T₃ whereas, minimum in T₇ both in surface and sub-surface layers. The trend was almost similar during each month.

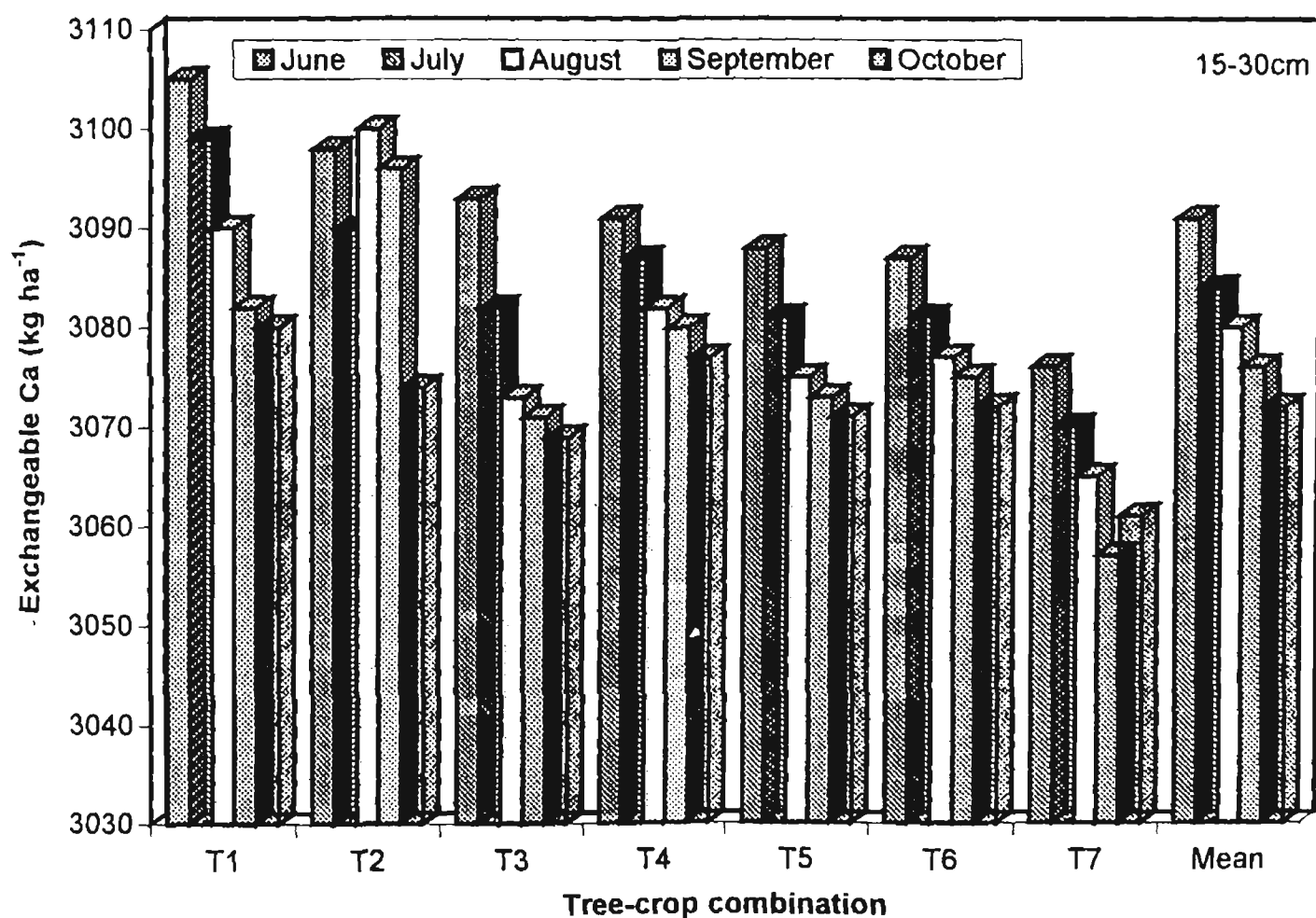
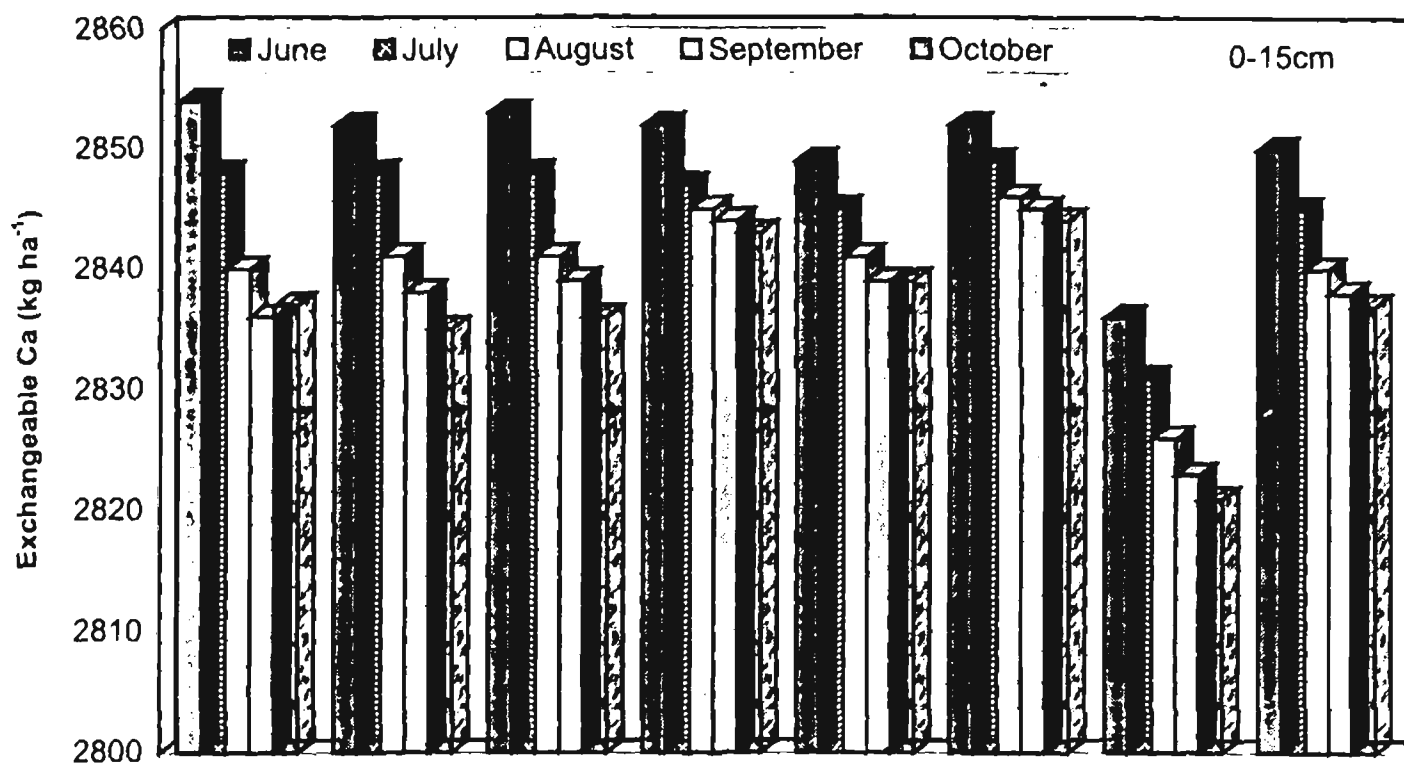


Fig. 17. Effect of tree-crop combinations on exchangeable Ca in 0-15 and 15-30 cm soil depth during soybean crop season. {CD(0.05) to compare the interaction month x depth 6.29 and tree-crop combination x month x depth 16.60}

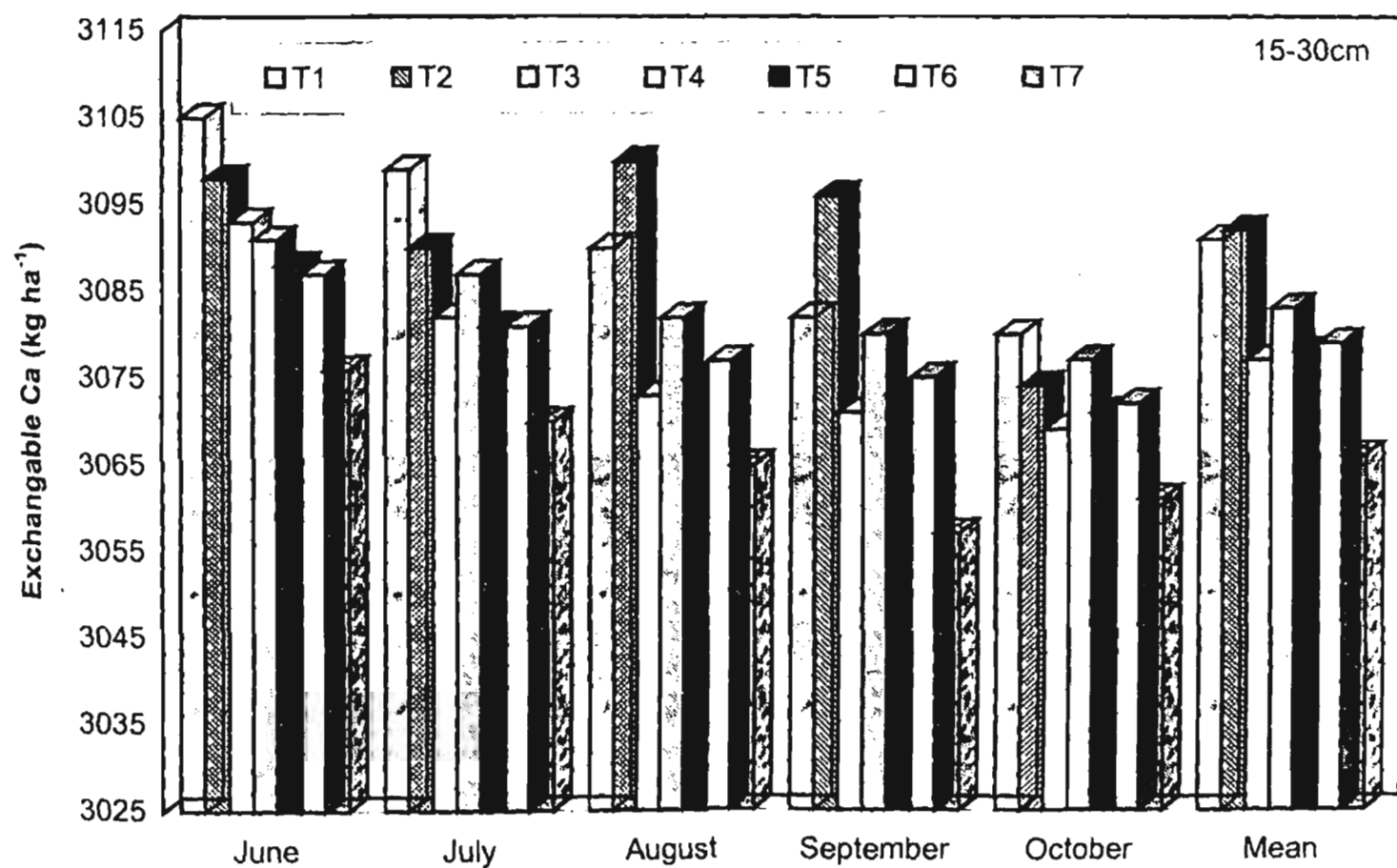
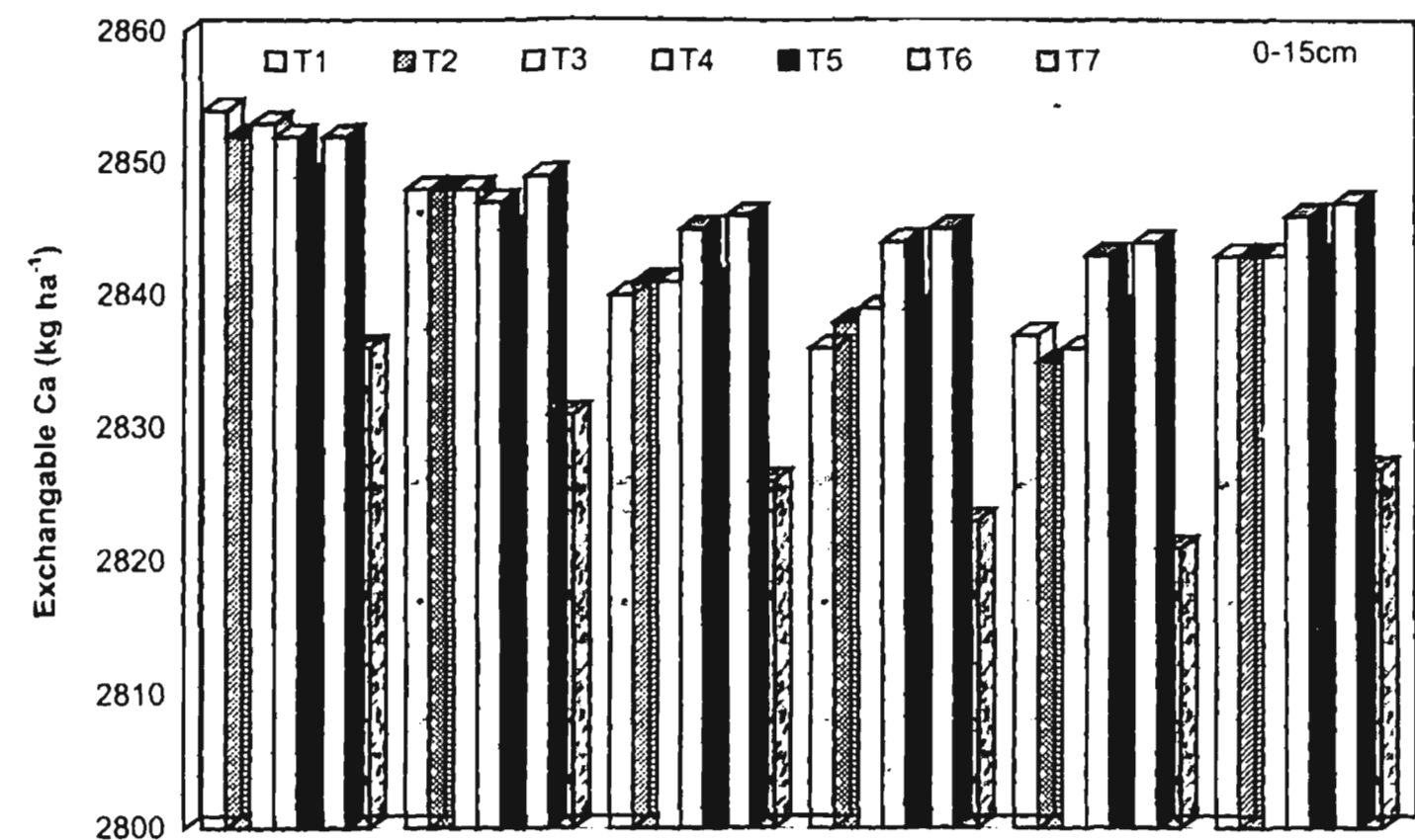
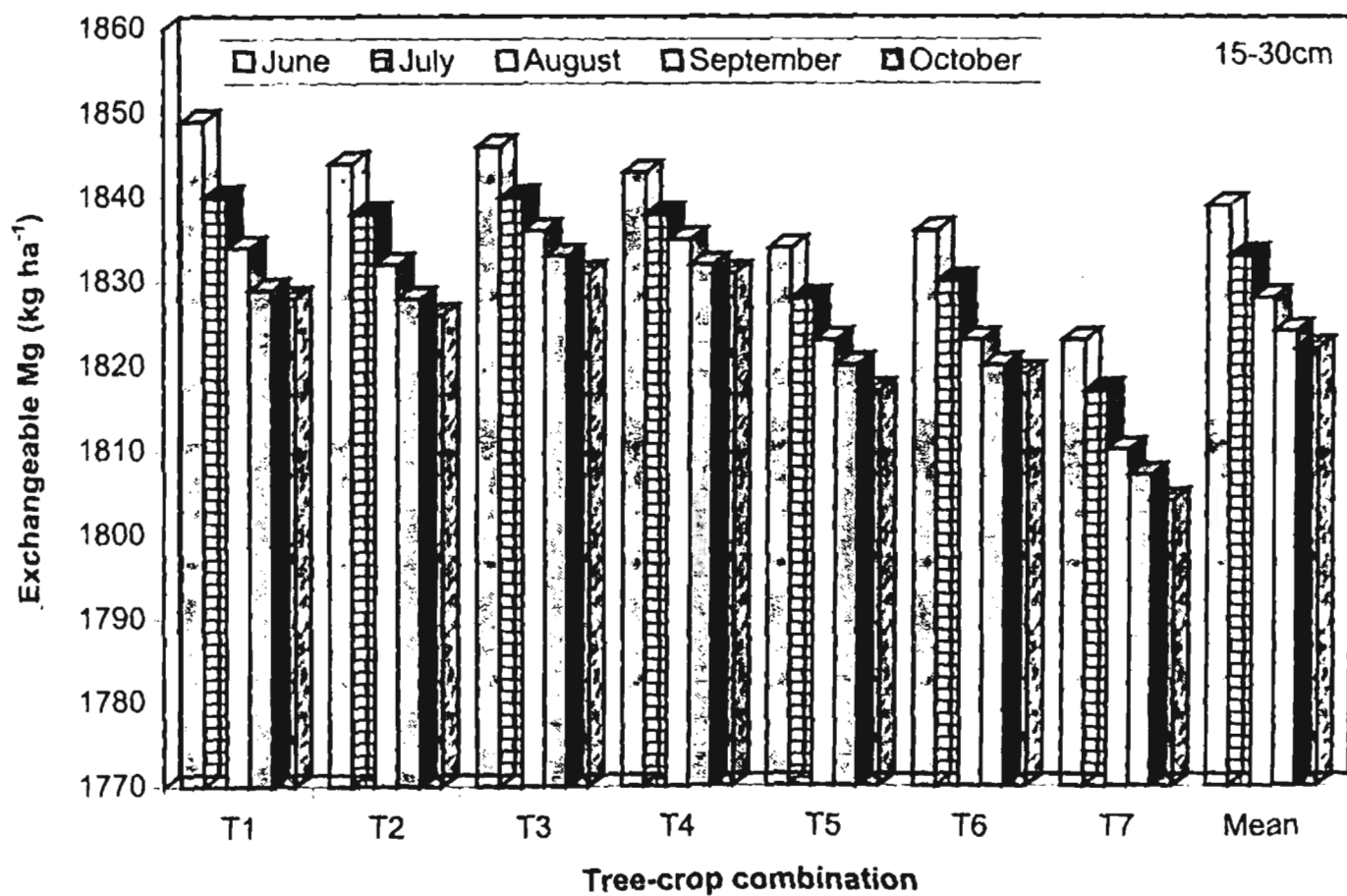
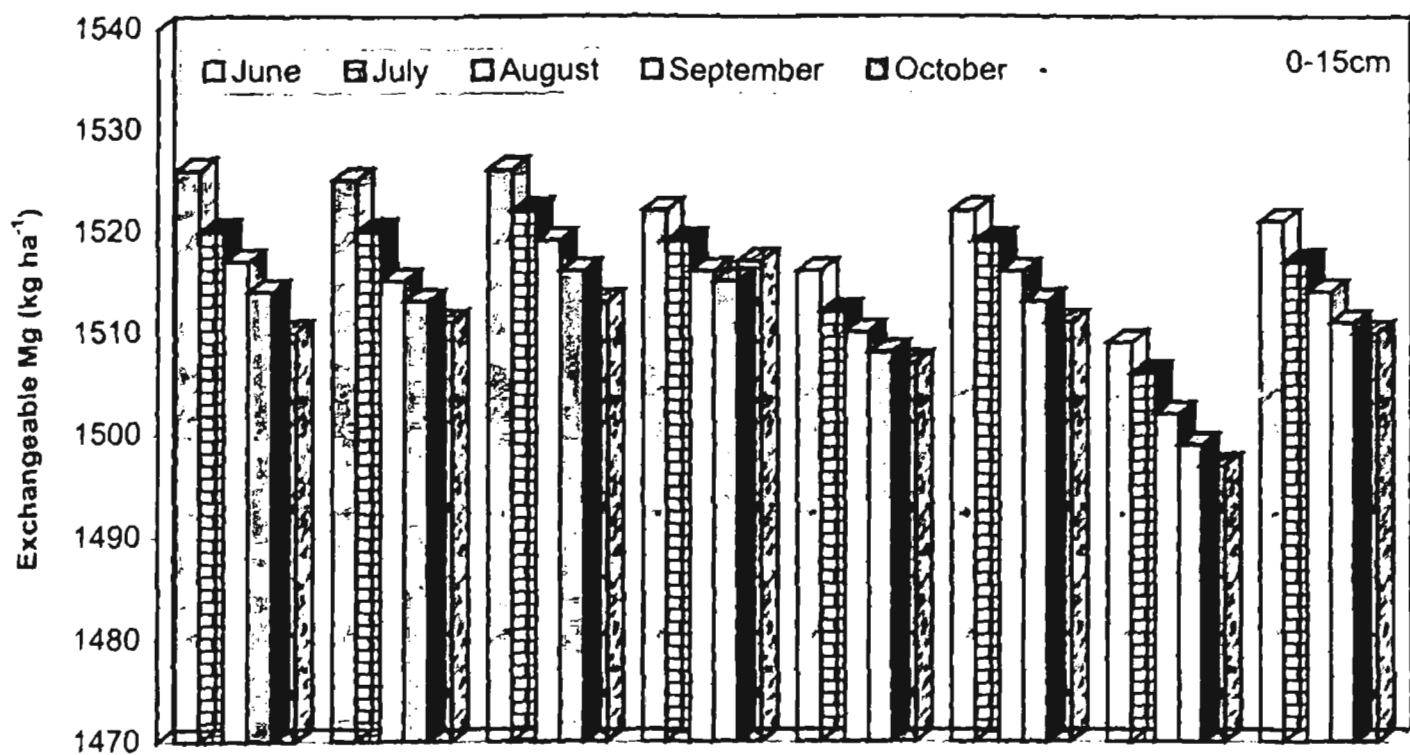


Fig. 18. Monthly variation in exchangeable Ca in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 7.43 and T x M x D 16.60}



8-19. Effect of tree-crop combinations on exchangeable Mg in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 2.85 and tree-crop combination x month x depth 7.51)

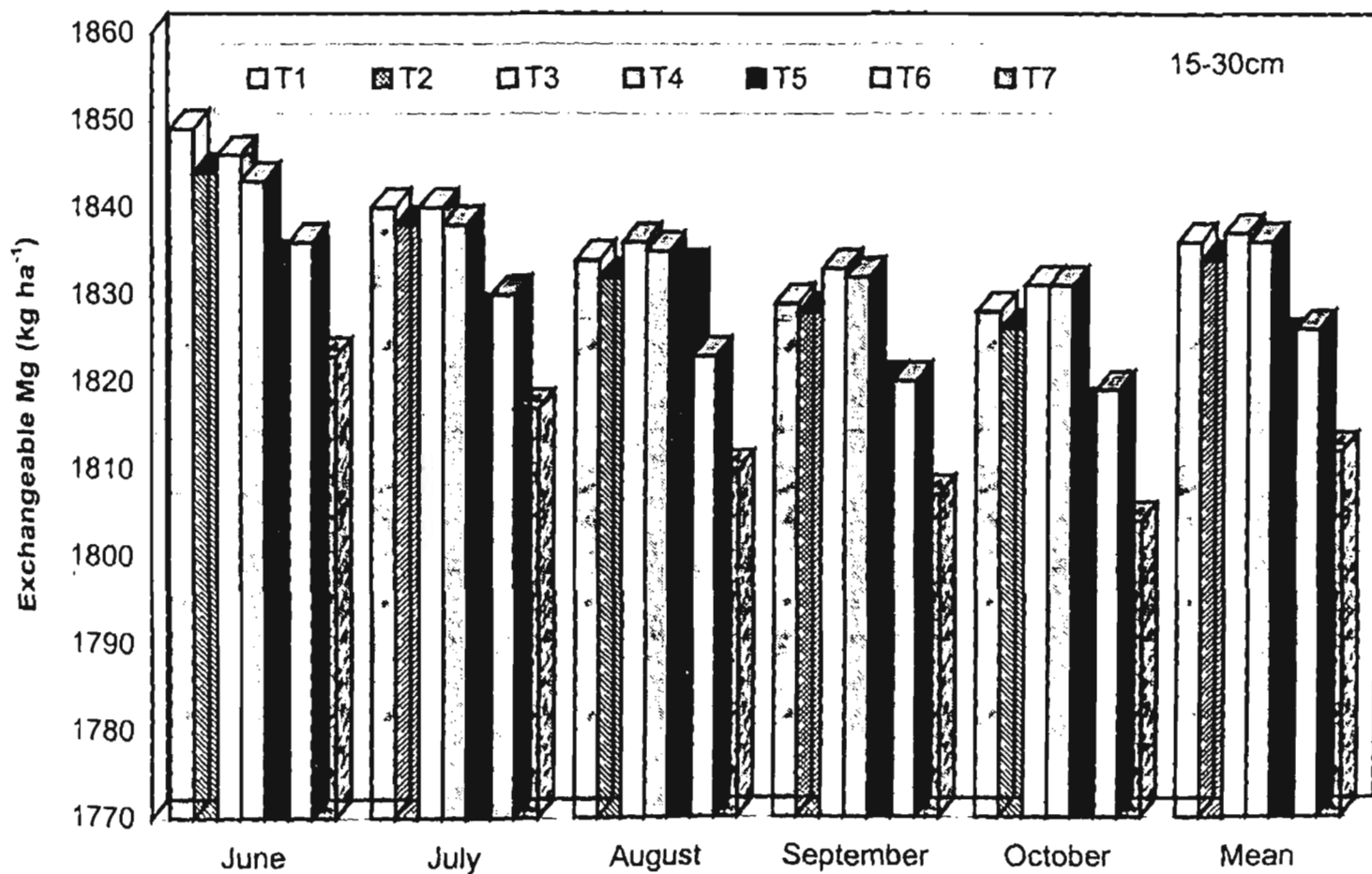
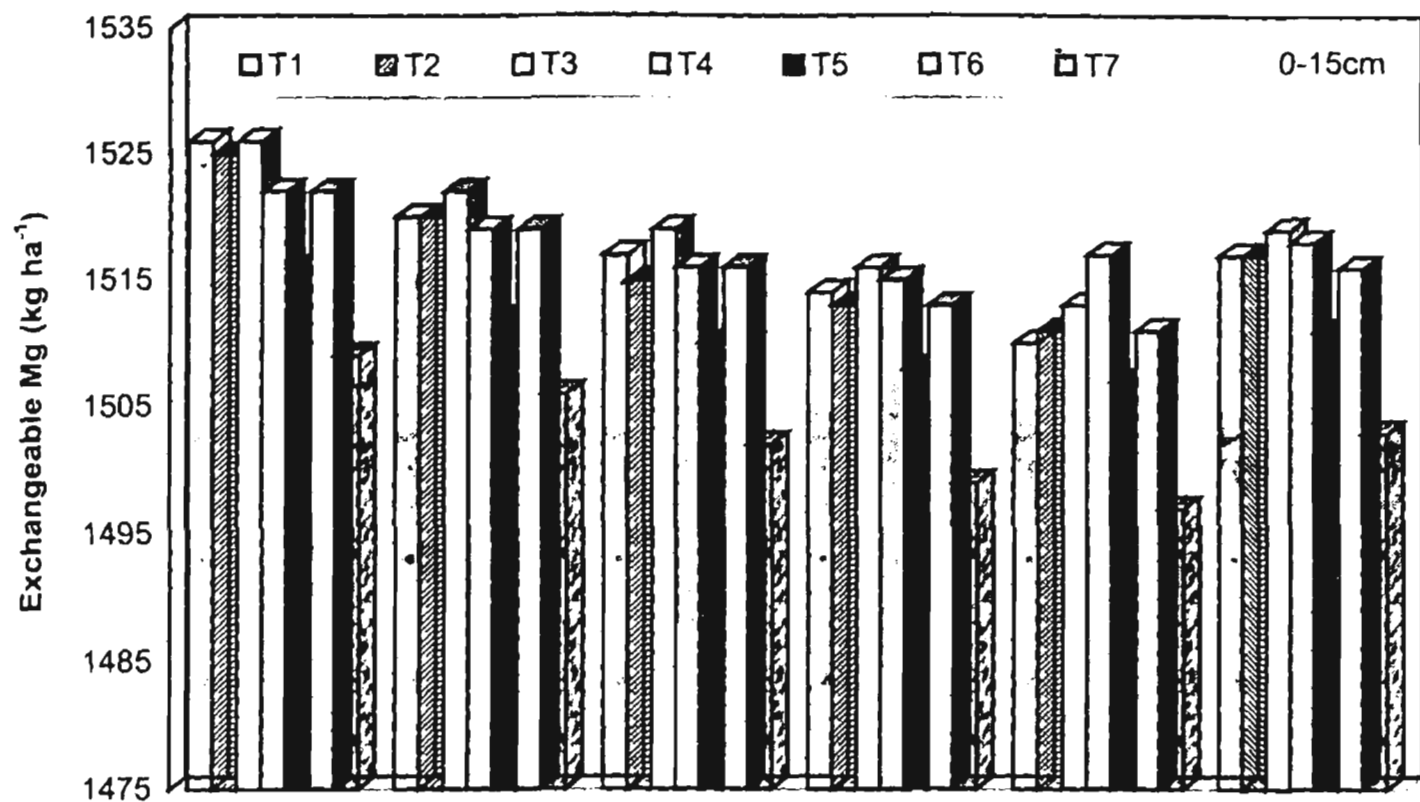


Fig. 20. Monthly variation in exchangeable Mg in 0-15 and 15-30 cm soil depth under different tree-crop combinations. (CD(0.05) to compare the interaction T x D 3.36 and T x M x D 7.51)

Exchangeable Mg was higher in sub-surface soils as compared to surface soils.

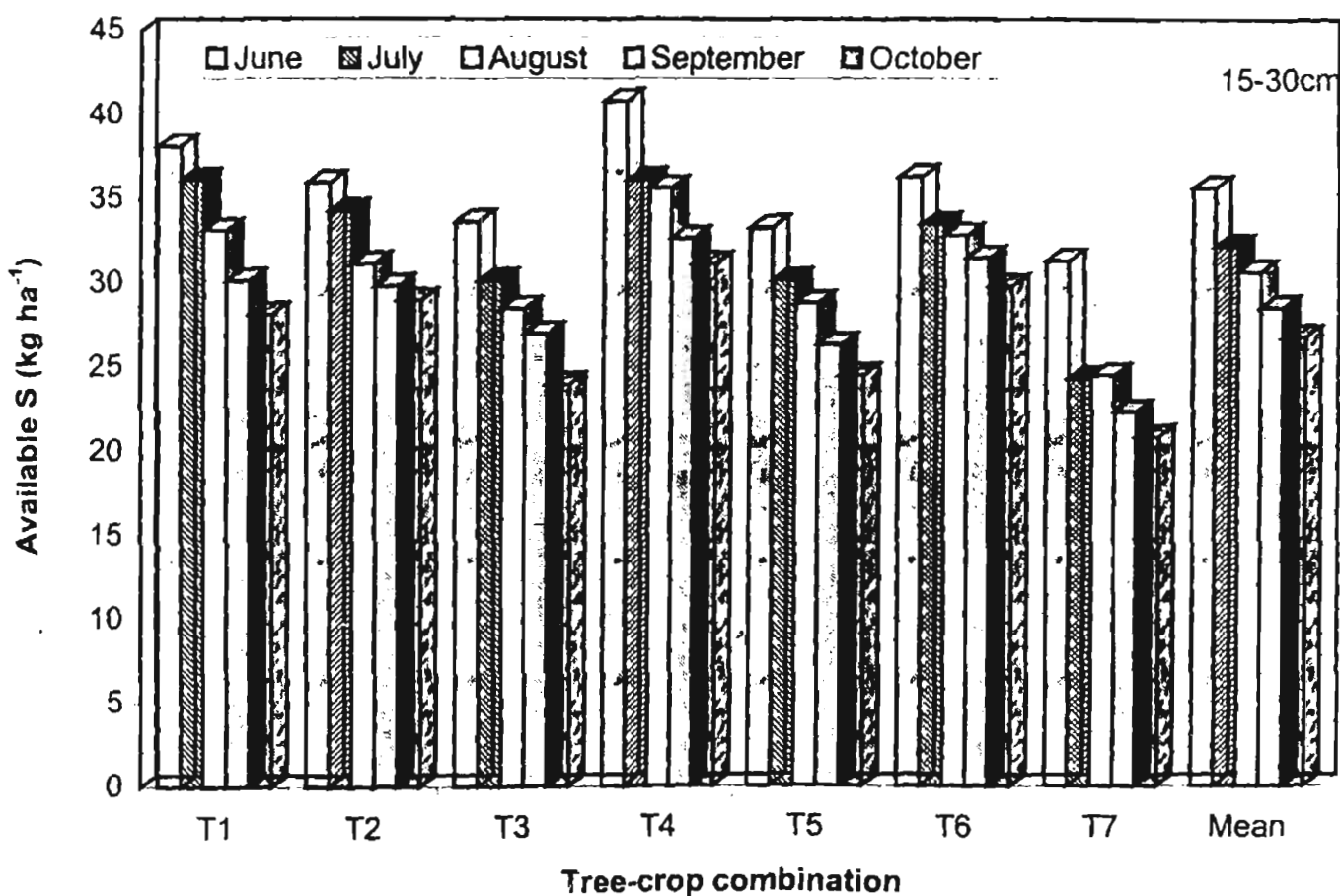
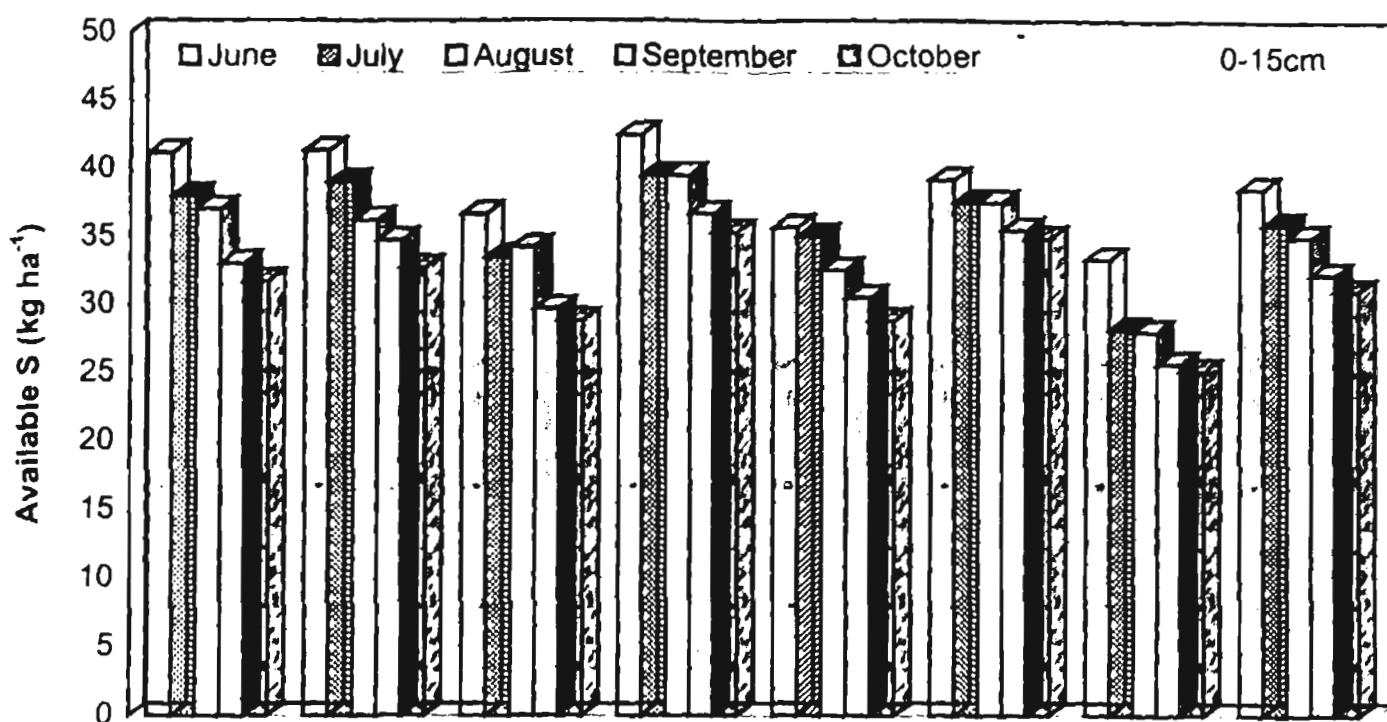
Available S (Kg ha^{-1}) : In each of the tree-crop combination, available S content of surface as well as sub-surface soil decreased with the advancement of soybean growth period showing maximum value in June and minimum in October (Fig. 21). However, in surface soils T_3 showed its higher content during August than July. Combinations T_4 and T_6 behaved in similar manner during July and August. In sub-surface soils a slightly higher value of S content was observed during August than July under T_7 .

The data presented in Fig. 22 revealed that in surface and sub-surface soil during different months available S content was lowest in sole soybean (T_7) and highest in T_4 . However, in sub-surface soils it exhibited similar values for T_4 and T_1 in July. The values between maximum and minimum did not follow a definite pattern. Available S was higher in surface soils than sub-surface soils.

4.4.2 Nutrient addition and removal through system components

The total amount of nutrients viz. N, P, K, Ca, Mg and S added through fertilizer, FYM and litter (Appendix- 17 and 18) vis-a-vis their amounts removed through tree-crop harvest (Appendix-19 to 22) was taken as input/addition and output/removal during a crop season. Addition (Table 7) and removal (Table 8) of nutrients have been calculated separately for each tree-crop combination.

Addition (kg ha^{-1}) : The amount of nutrients added (Table 7) to soybean was maximum in sole cropping (T_7) as compared to other tree-crop combinations (T_1 - T_6). Nutrient addition through plum, mulberry and pomegranate was highest in tree-crop combination T_4 , T_5 and T_6 respectively, and minimum in



21. Effect of tree-crop combinations on available S in 0-15 and 15-30 cm soil depth during soybean crop season. {CD(0.05) to compare the interaction month x depth 0.95 and tree-crop combination x month x depth 2.53}

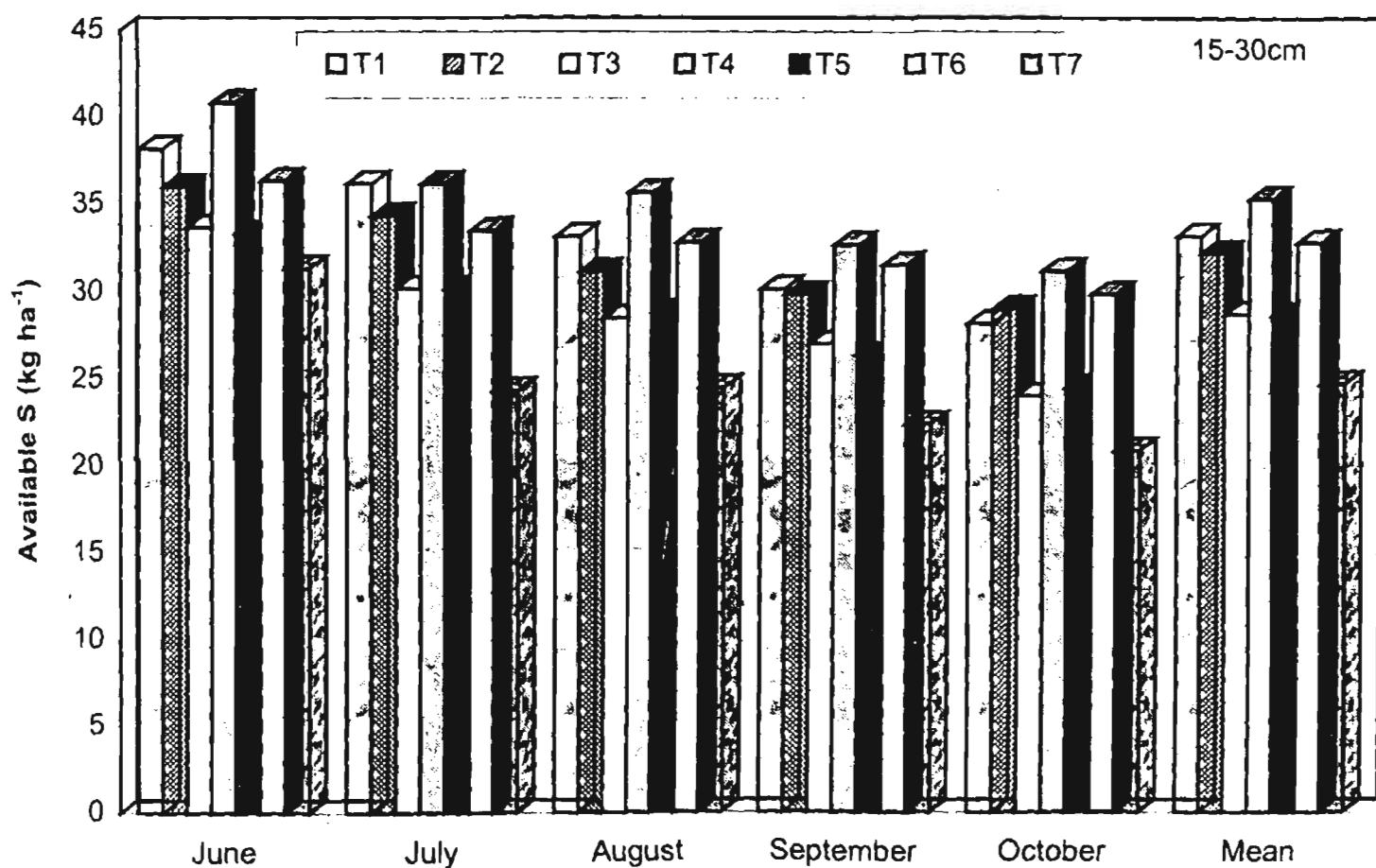
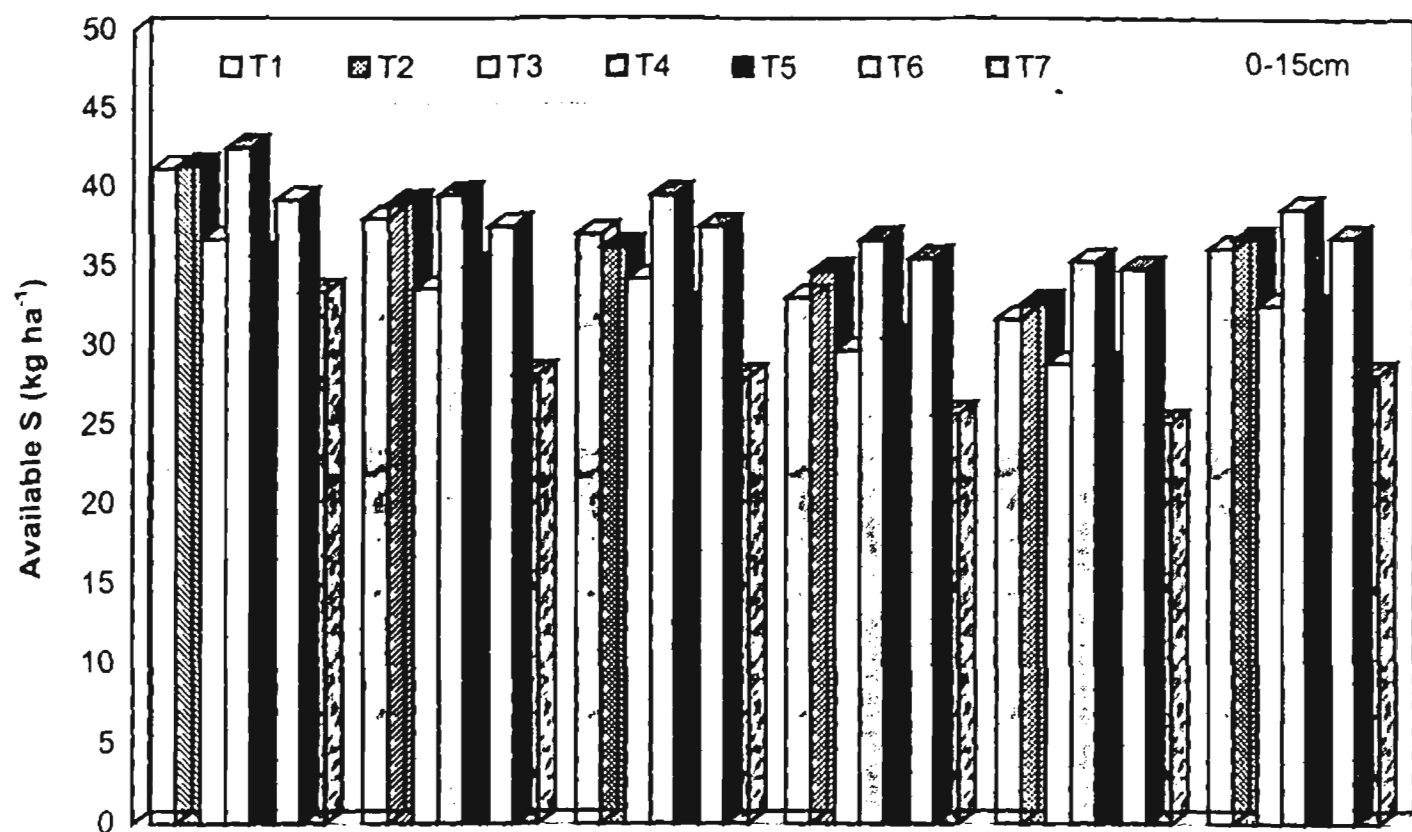


Fig. 22. Monthly variation in available S in 0-15 and 15-30 cm soil depth under different tree-crop combinations. {CD(0.05) to compare the interaction T x D 1.13 and T x M x D 2.53}

Table 7. Amount of nutrients added (kg ha⁻¹) to the soil under different tree-crop combinations

Tree-crop combinations	Components	Nutrients					
		N	P	K	Ca	Mg	S
T ₁	Soybean	8.00	24.00	24.00	37.96	1.00	14.59
	Plum	111.28	44.22	113.53	121.33	16.68	47.29
	Mulberry	0.68	0.10	0.58	1.44	0.20	0.16
	Pomegranate	2.02	0.25	1.62	2.33	0.48	0.21
	Total	121.97	68.56	139.73	163.06	18.36	62.25
T ₂	Soybean	8.00	24.00	24.00	37.96	1.00	14.59
	Plum	168.90	66.39	172.80	186.44	25.41	71.18
	Mulberry	1.26	0.19	1.07	2.70	0.36	0.30
	Pomegranate	-	-	-	-	-	-
	Total	178.16	90.57	197.87	227.10	26.77	86.07
T ₃	Soybean	8.00	24.00	24.00	37.96	1.00	14.59
	Plum	-	-	-	-	-	-
	Mulberry	1.76	0.25	1.48	3.62	0.51	0.39
	Pomegranate	4.27	0.60	3.31	4.92	0.98	0.48
	Total	14.03	24.85	28.79	46.50	2.49	15.46
T ₄	Soybean	8.0	24.00	24.00	37.96	1.00	14.59
	Plum	340.85	133.47	347.29	379.37	51.80	142.90
	Mulberry	-	-	-	-	-	-
	Pomegranate	-	-	-	-	-	-
	Total	348.85	157.47	371.29	417.33	52.80	157.49
T ₅	Soybean	8.00	24.00	24.00	37.96	1.00	14.59
	Plum	-	-	-	-	-	-
	Mulberry	4.16	0.61	3.60	8.64	1.34	1.03
	Pomegranate	-	-	-	-	-	-
	Total	12.16	24.61	27.60	46.60	2.34	15.62
T ₆	Soybean	8.00	24.00	24.00	37.96	1.00	14.59
	Plum	-	-	-	-	-	-
	Mulberry	-	-	-	-	-	-
	Pomegranate	10.48	1.44	8.15	12.24	2.57	1.33
	Total	18.48	25.44	32.15	50.20	3.57	15.92
T ₇	Soybean	10.00	30.00	30.00	47.55	1.25	18.23

Table 8. Nutrient removal (kg ha⁻¹) through harvestable biomass of different components

Tree-crop combinat -ions	Components	Nutrients					
		N	P	K	Ca	Mg	S
T ₁	Soybean	67.66	3.65	22.73	15.95	9.19	5.27
	Plum	15.30	3.46	12.77	16.14	1.99	0.76
	Mulberry	24.97	2.30	21.96	41.21	7.01	3.15
	Pomegranate	-	-	-	-	-	-
	Total	107.93	9.41	57.46	73.30	18.19	9.18
T ₂	Soybean	70.24	3.78	23.69	16.78	9.46	5.28
	Plum	25.13	6.16	20.56	25.77	3.33	1.64
	Mulberry	40.76	4.09	35.19	65.87	11.25	5.41
	Pomegranate	-	-	-	-	-	-
	Total	136.13	14.03	79.44	108.42	24.04	13.03
T ₃	Soybean	72.34	4.07	24.53	17.18	10.14	6.06
	Plum	-	-	-	-	-	-
	Mulberry	46.23	5.28	41.07	74.88	14.22	5.84
	Pomegranate	-	-	-	-	-	-
	Total	118.57	9.35	65.60	92.06	24.36	11.90
T ₄	Soybean	77.93	4.73	27.18	18.34	10.66	7.70
	Plum	54.46	12.75	44.93	56.84	8.07	3.05
	Mulberry	-	-	-	-	-	-
	Pomegranate	-	-	-	-	-	-
	Total	132.39	17.48	72.11	75.18	18.73	10.75
T ₅	Soybean	76.50	4.53	26.65	18.48	11.07	6.86
	Plum	-	-	-	-	-	-
	Mulberry	108.81	11.54	95.68	176.64	33.16	14.57
	Pomegranate	-	-	-	-	-	-
	Total	185.31	16.07	122.33	195.12	44.23	21.43
T ₆	Soybean	84.29	5.44	30.27	20.30	12.02	8.69
	Plum	-	-	-	-	-	-
	Mulberry	-	-	-	-	-	-
	Pomegranate	-	-	-	-	-	-
	Total	84.29	5.44	30.27	20.30	12.02	8.69
T ₇	Soybean	115.52	7.68	41.75	25.84	15.37	12.37

T₁. In general, tree-crop combination T₄ had highest amount of N, P, K, Ca, Mg and S addition with their respective value of 348.85, 157.47, 371.29, 417.33, 52.80 and 157.49. Minimum N (10.00) and Mg (1.25) addition was in T₇ ; P (24.61) and K (27.60) in T₅ ; Ca (46.50) and S (15.46) in T₃.

Removal (kg ha⁻¹) : The amount of nutrients removed (Table 8) by soybean was maximum in sole cropping (T₇) compared to other tree-crop combinations (T₁-T₆). Nutrient removed through harvested biomass of plum and mulberry was maximum in T₄ and T₅ respectively, and minimum in T₁. Total amount of nutrients removed by different components in each tree-crop combination revealed their least removal (N : 84.29, P : 5.44, K : 30.27, Ca : 20.30, Mg : 12.02 and S : 8.69) in T₆ and highest (N : 185.31, K : 122.33, Ca : 195.12, Mg : 44.23 and S : 21.43) in T₅. Maximum P (17.48) was removed through T₄. The remaining tree-crop combinations followed different order for different nutrients shown as below :

N = T₂ > T₄ > T₃, T₇ > T₁ ; Ca and S = T₂ > T₃ > T₄ > T₁ > T₇

P = T₅ > T₂ > T₁, T₃ > T₇ ; Mg = T₃ > T₂ > T₄ > T₁ > T₇

K = T₂ > T₄ > T₃, T₁ > T₇

4.4.3 Nutrient balance (kg ha⁻¹)

It is evident from the data (Table 9) that tree-crop combination T₅ have shown maximum(190.05) net gain of N followed by T₃ (120.74), T₇ (118.22), T₆ (84.51) and T₁ (6.36) whereas, T₄ depicted maximum (195.66) net loss following T₂ (23.13). In case of P a net loss ranging from 12.29 (T₅) to 143.39 (T₄) occurred. There was a net gain of 28.82 kg ha⁻¹ in K at T₃ combination whereas, in remaining combinations, net loss ranging from 307.88 at T₄ to 0.35 at T₇, resulted.

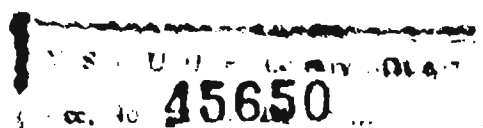


Table 9. NPK balance in soil due to different tree-crop combinations

Tree-crop combinations	Initial status	Amount added	Total amount (initial + added)	Cumulative removal (trees + crop)	Expected balance	Actual balance	Net gain or loss
Available N							
T ₁	388.30	121.97	510.27	107.93	402.34	408.70	+6.36
T ₂	391.70	178.16	569.86	136.13	433.73	410.60	-23.13
T ₃	382.80	14.03	396.83	118.57	278.26	399.00	+120.74
T ₄	393.20	348.85	742.05	132.39	609.66	414.00	-195.66
T ₅	384.10	12.16	396.26	185.31	210.95	401.00	+190.05
T ₆	387.50	18.48	405.98	84.29	321.69	406.20	+84.51
T ₇	379.00	10.00	389.00	115.52	273.48	391.70	+118.22
Available P							
T ₁	45.75	68.56	114.31	9.41	104.90	39.00	-65.90
T ₂	46.25	90.57	136.82	14.03	122.79	40.83	-81.96
T ₃	41.33	24.85	66.18	9.35	56.83	37.42	-19.41
T ₄	48.33	157.37	205.70	17.48	188.22	44.83	-143.39
T ₅	42.25	24.61	66.86	16.07	50.79	38.50	-12.29
T ₆	45.08	25.44	70.52	5.44	65.08	43.17	-21.91
T ₇	41.08	30.00	71.05	7.68	63.40	32.58	-30.82
Available K							
T ₁	349.20	139.72	488.92	57.46	431.46	338.40	-93.06
T ₂	355.30	197.15	552.45	79.44	473.01	347.20	-125.81
T ₃	339.70	28.78	368.48	65.60	302.88	331.70	+28.82
T ₄	359.70	371.29	730.99	72.11	658.88	351.00	-307.88
T ₅	343.20	27.60	370.80	122.33	248.47	337.70	-89.23
T ₆	345.30	32.15	377.45	30.27	347.18	340.50	-6.68
T ₇	336.10	30.00	366.10	41.75	324.35	324.00	-0.35

Ca and Mg content in soils showed net gains in T₅ and T₃ combinations but a net loss at T₄ following T₂, T₁, T₆ and T₇. S content showed a net loss being maximum (151.32) at T₄ followed by T₂ (79.13), T₁ (60.14), T₆ (10.40), T₇ (9.61), T₃ (8.97) and minimum (0.10) in T₅ (Table 10).

4.4.4 Soil moisture

Available soil moisture (%)

In order to explain the variations in available soil moisture due to different tree-crop combinations, moisture characteristics of the soil from experimental plot were studied at two different depths viz. 0-15 and 15-30cm using "Pressure Plate Membrane" apparatus. The data recorded in Fig. 23 have shown that per cent soil moisture measured at 0 and 0.3 bar was 36.95 and 22.52 per cent respectively in surface layer which decreased to 7.00 per cent at 15 bar pressure. In sub-surface layer, soil moisture content was less than surface layer. It was 34.10, 22.02 and 7.00 per cent at 0, 0.3 and 15 bar pressures, respectively. This indicates the limit of available soil moisture. In surface layer it ranges from 22.52 - 7.00 per cent and 22.02 - 7.00 per cent in sub-surface layer, which was almost similar in both layers.

The data presented in Fig. 24 and 25 indicated that soil moisture content was influenced significantly due to tree-crop combination x depth, month x depth and tree-crop combination x month x depth interactions.

Under all tree-crop combinations (T₁-T₇), in surface layer the soil moisture was maximum in August followed by September, July and minimum in October whereas, in sub-surface layer it was highest in September followed by August, July and minimum in October (Fig. 24).

Considering mean monthly variation in soil moisture content among various tree-crop combinations in surface as well as sub-surface layers

Table 10. Ca Mg S balance in soil due to different tree-crop combinations

Tree-crop combinations	Initial status	Amount added	Total amount (Initial + added)	Cumulative removal (trees + crop)	Expected balance	Actual balance	Net gain or loss
Exchangeable Ca							
T ₁	2979	163.06	3142.06	73.30	3068.76	2959	-109.76
T ₂	2975	227.10	3202.10	108.42	3093.68	2955	-138.68
T ₃	2973	46.50	3019.50	92.06	2927.44	2952	+24.56
T ₄	2971	417.33	3388.33	75.18	3313.15	2960	-353.15
T ₅	2968	46.60	3014.60	195.12	2819.48	2955	+135.52
T ₆	2970	50.20	3020.20	20.30	2999.90	2958	-41.90
T ₇	2956	47.55	3003.55	26.04	2977.51	2941	-36.51
Exchangeable Mg							
T ₁	1687	18.35	1705.35	18.19	1687.16	1669	-18.16
T ₂	1685	26.77	1711.77	24.04	1687.73	1668	-19.73
T ₃	1686	2.49	1687.99	24.36	1663.63	1672	+8.37
T ₄	1683	52.80	1735.80	18.73	1717.07	1674	-43.07
T ₅	1675	2.34	1677.34	44.23	1633.11	1662	+28.89
T ₆	1679	3.57	1682.57	12.02	1670.55	1665	-5.55
T ₇	1666	1.25	1667.25	15.57	1651.68	1650	-1.68
Available S							
T ₁	37.08	62.16	99.24	9.18	90.06	29.92	-60.14
T ₂	36.92	86.07	122.99	13.03	109.96	30.83	-79.13
T ₃	31.83	15.46	47.29	11.90	35.39	26.42	-8.97
T ₄	37.83	157.49	195.32	10.75	184.57	33.25	-151.32
T ₅	32.58	15.62	48.20	21.43	26.77	26.67	-0.10
T ₆	35.50	15.92	51.42	8.69	42.73	32.33	-10.40
T ₇	26.75	18.23	44.98	12.37	32.61	23.00	-9.61

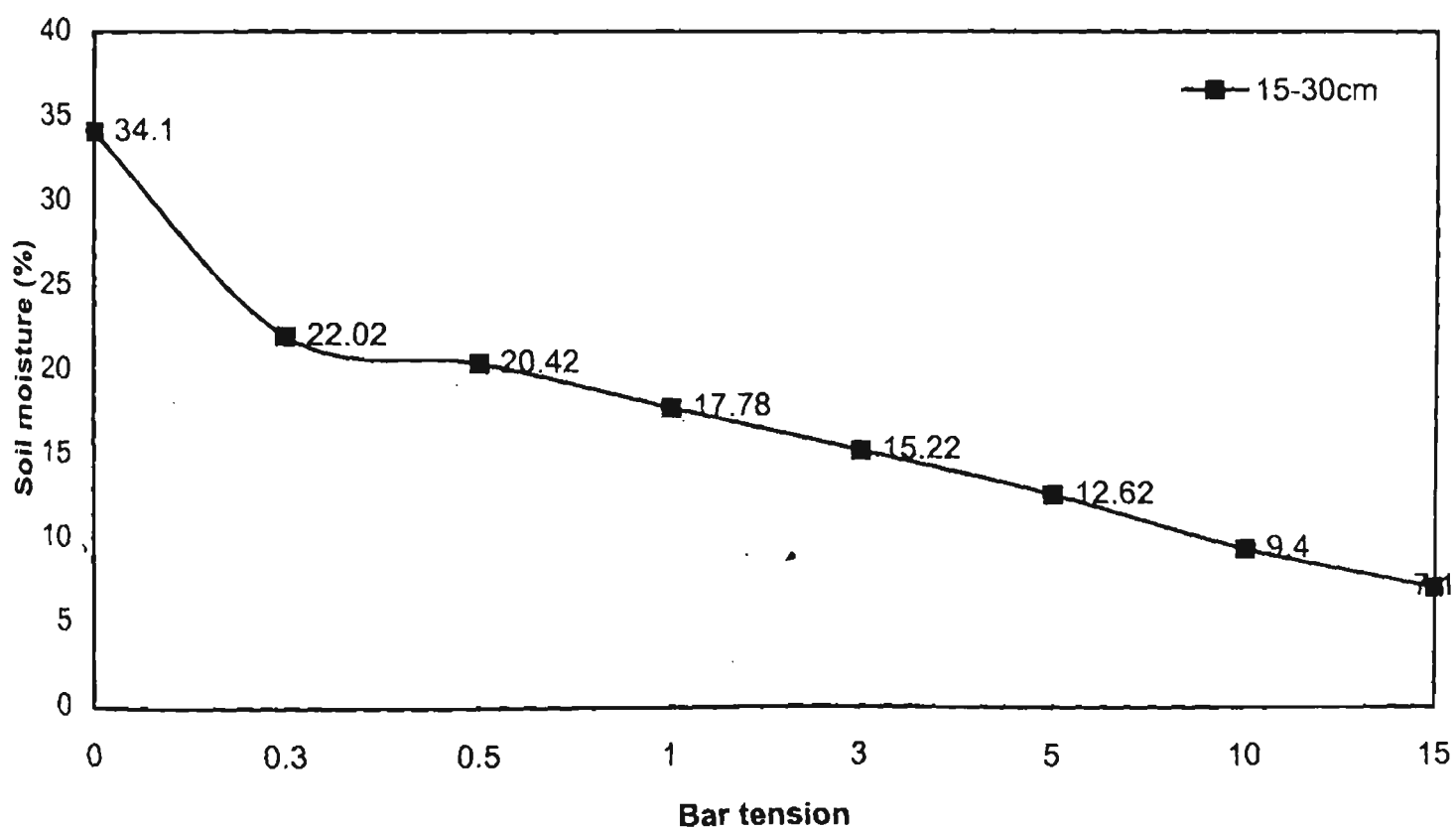
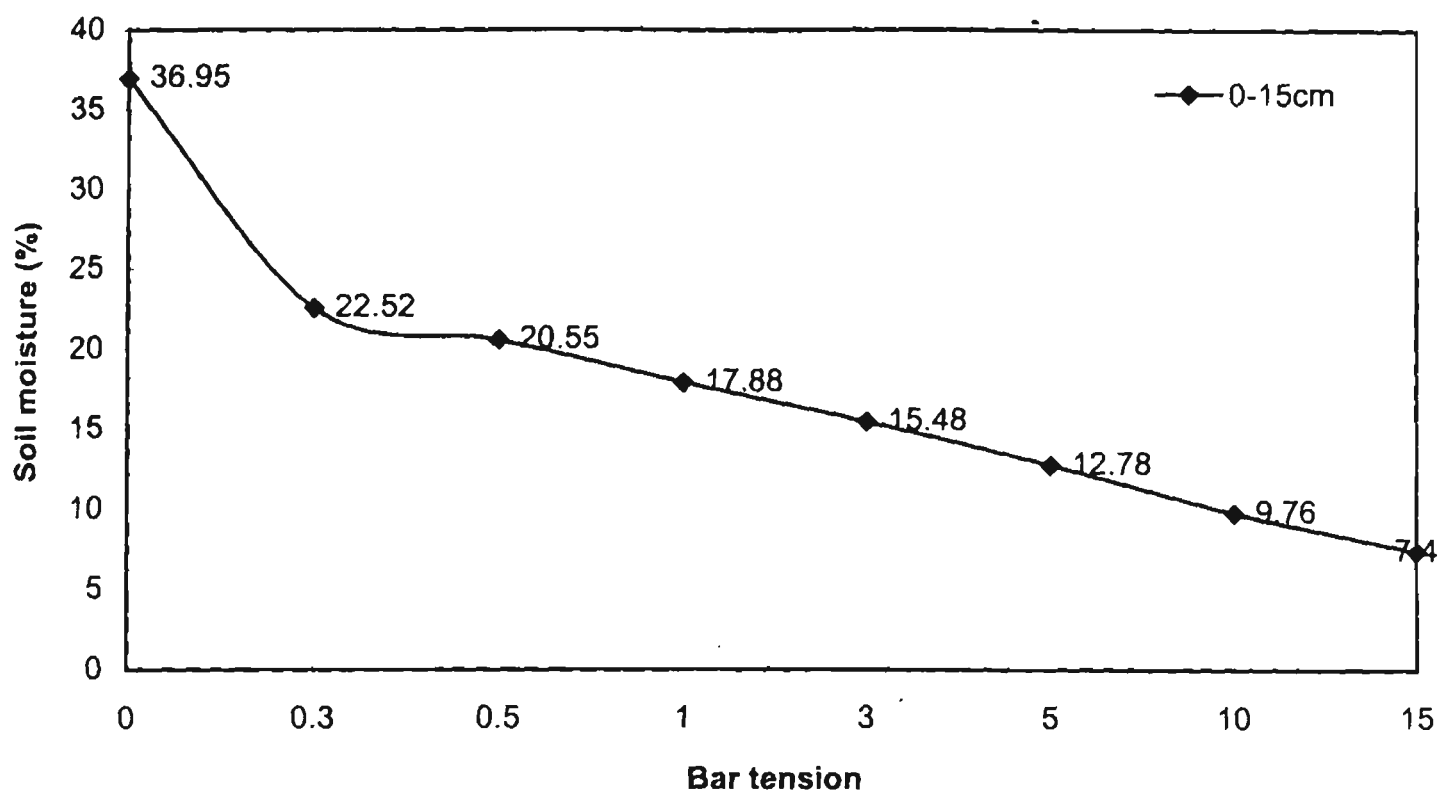


Fig. 23. Soil moisture characteristic curve of the study site

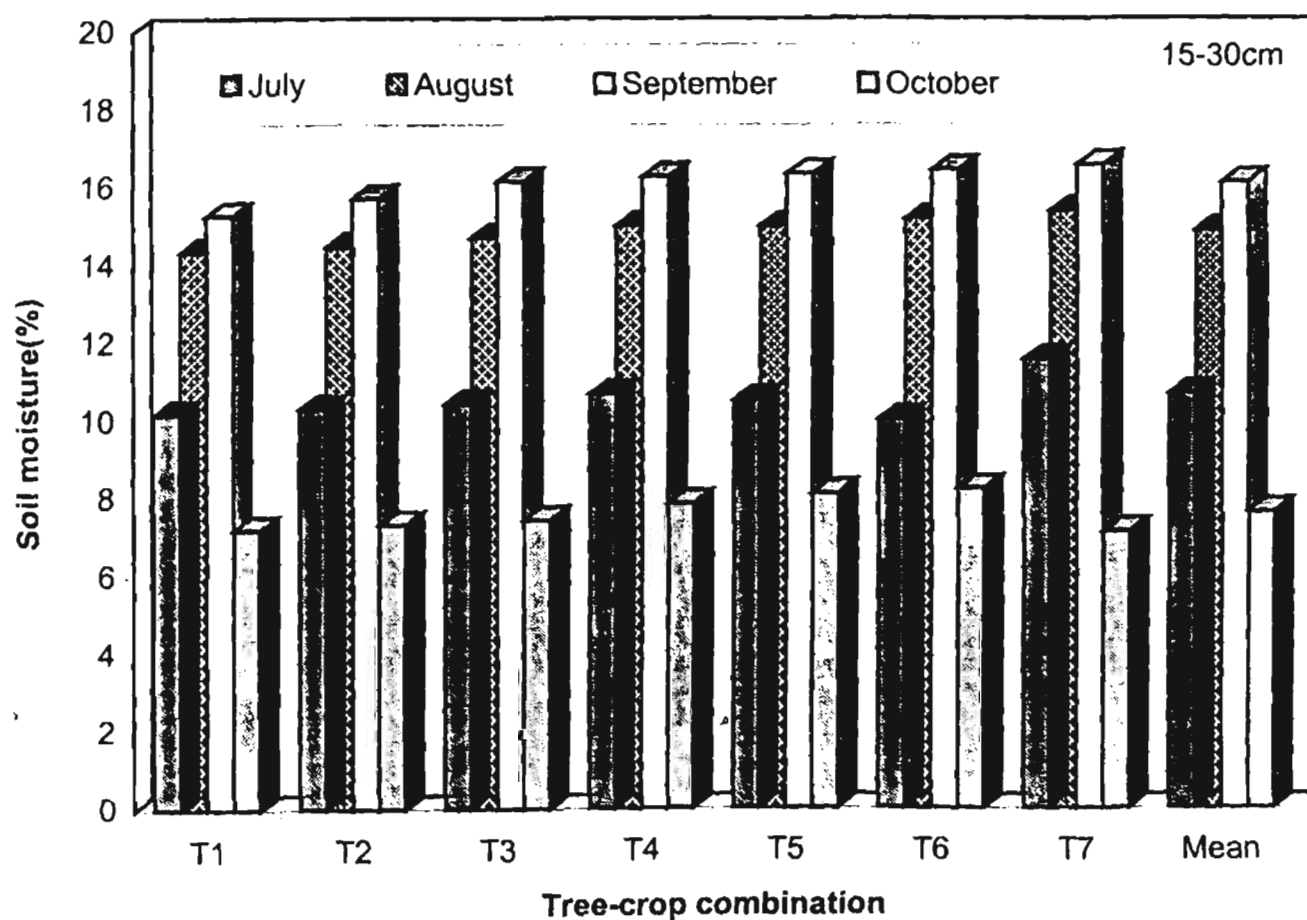
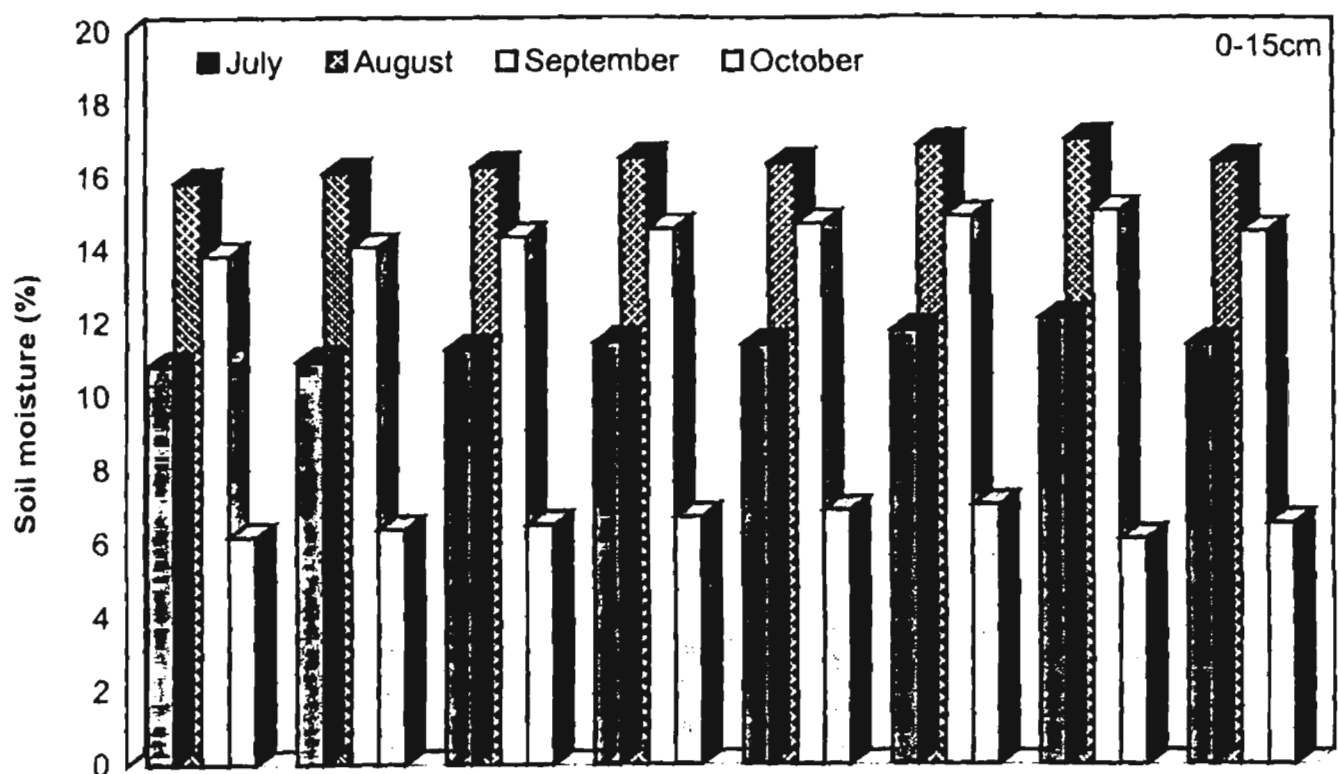


Fig. 24 Effect of tree-crop combinations on soil moisture content in 0-15 and 15-30 cm soil depth during soybean crop season. (CD(0.05) to compare the interaction month x depth 0.08 and tree-crop combination x month x depth 0.20)

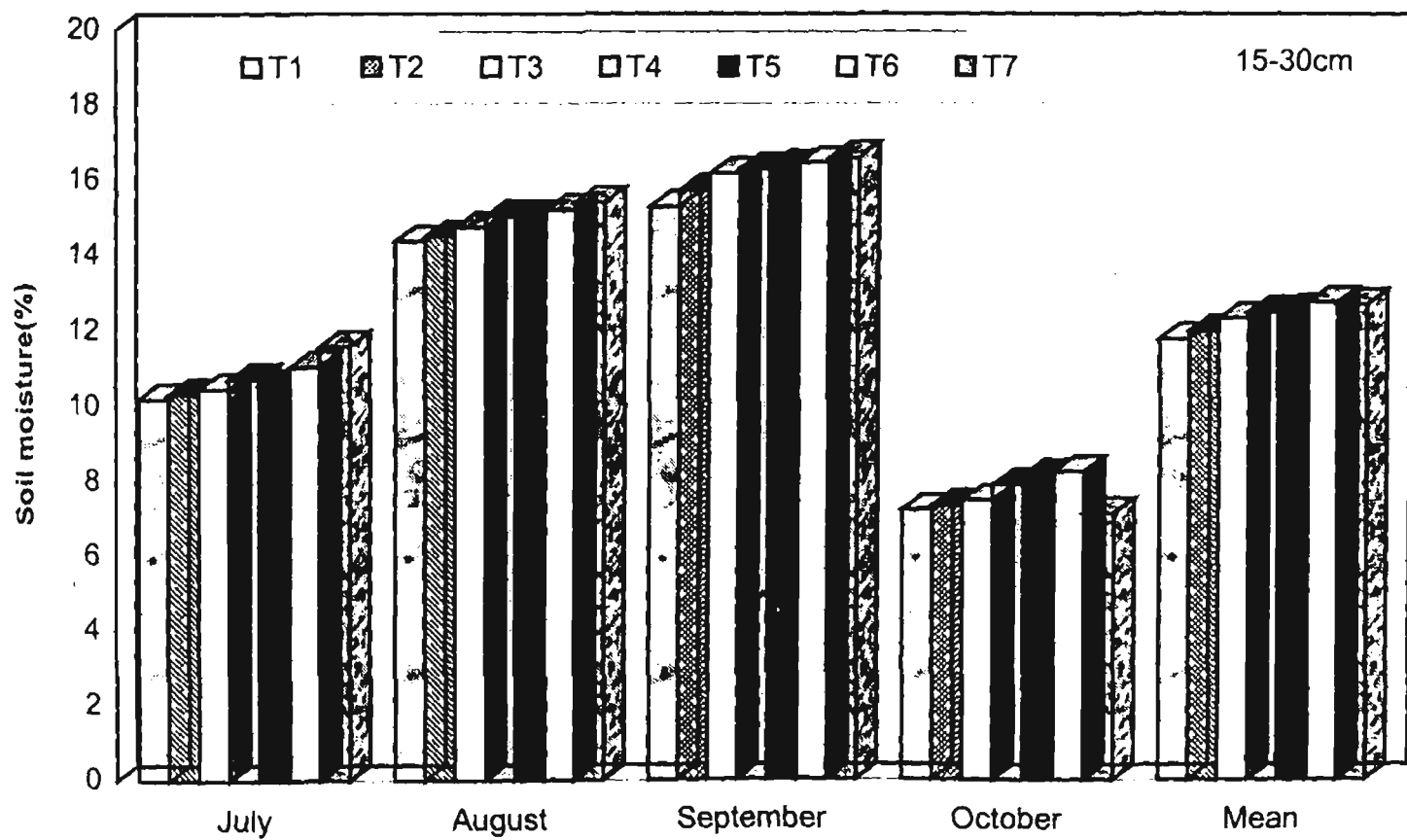
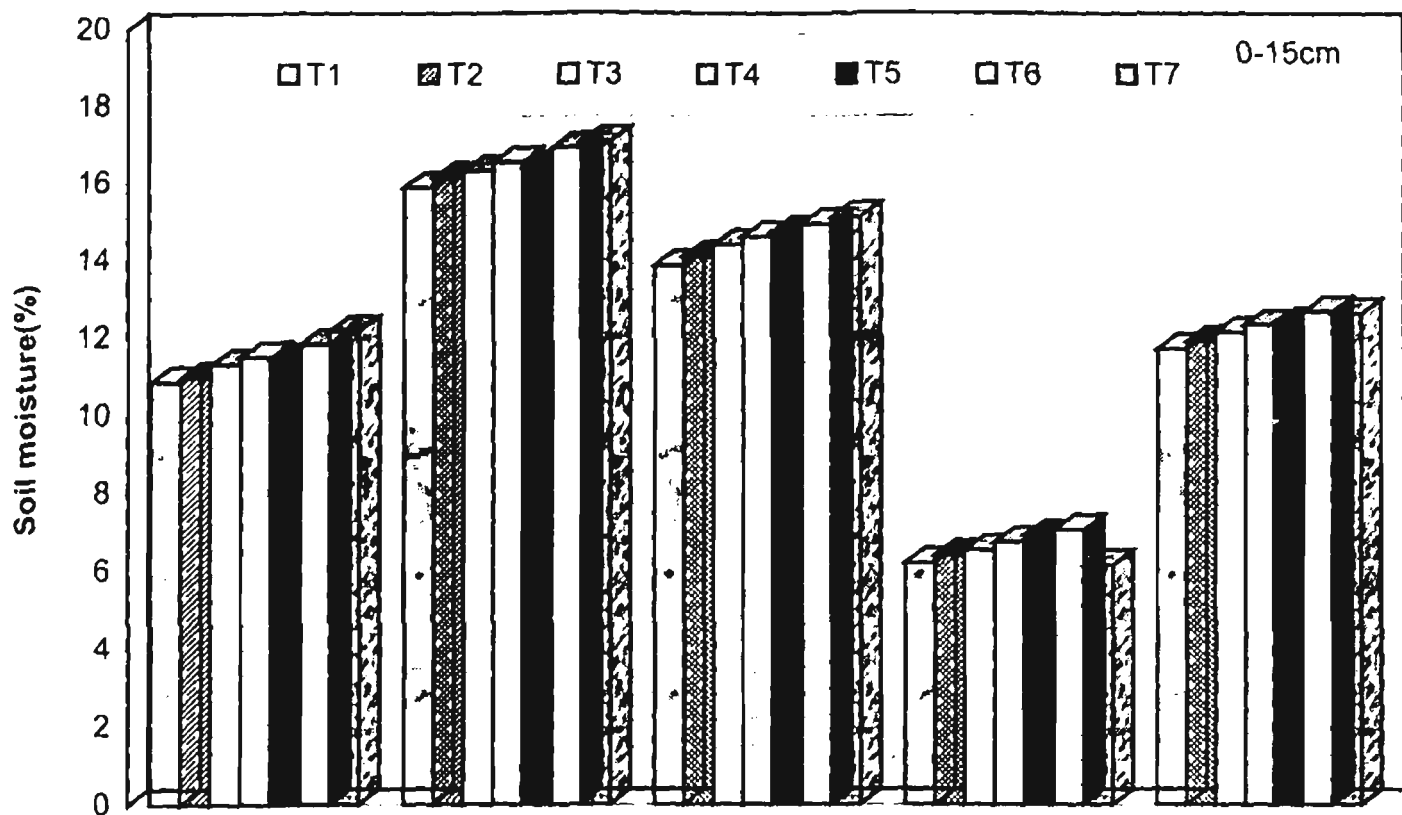


Fig. 25. Monthly variation in soil moisture content in 0-15 and 15-30 cm depth under different tree-crop combinations {CD(0.05) to compare the interaction T x D 0.10 and T x M x D 0.20}

(Fig. 25) its maximum value was in T_6 followed by T_7 , T_5 , T_4 , T_3 , T_2 and minimum at T_1 . However, monthwise variation under different tree-crop combinations have shown maximum soil moisture in T_7 and minimum in T_1 for all the sampling months except October when it was maximum in T_6 and minimum in T_7 .

4.5 Pre-dawn xylem water potential (-M Pa)

The observations for the pre-dawn xylem water potential were initiated in July for all the four components namely soybean, mulberry, plum and pomegranate of agrihortisilviculture system. It was recorded at monthly intervals till October i.e. harvesting of soybean crop. The data so obtained has been presented in Fig. 26. It is evident from the data that there was significant differences in xylem water potential within the components.

Soybean registered significantly higher (-0.08) xylem water potential in July and thereafter lowered to -0.17 in August, -0.18 in September and -0.39 in October. However, in August and September the values remain statistically at par with each other (Fig. 26).

In mulberry the xylem water potential also showed a decreasing trend from July to October. It was significantly higher (-0.19) in July than (-0.36) in August, (-0.72) in September and (-1.03) in October. The latter three months also depicted significantly different values from one another (Fig. 26).

Plum in the month of July had maximum (-0.19) xylem water potential which then decreased to -0.25 in August, -0.60 in September and -0.82 in October. However, in July and August, the xylem water potential behaved statistically alike (Fig. 26).

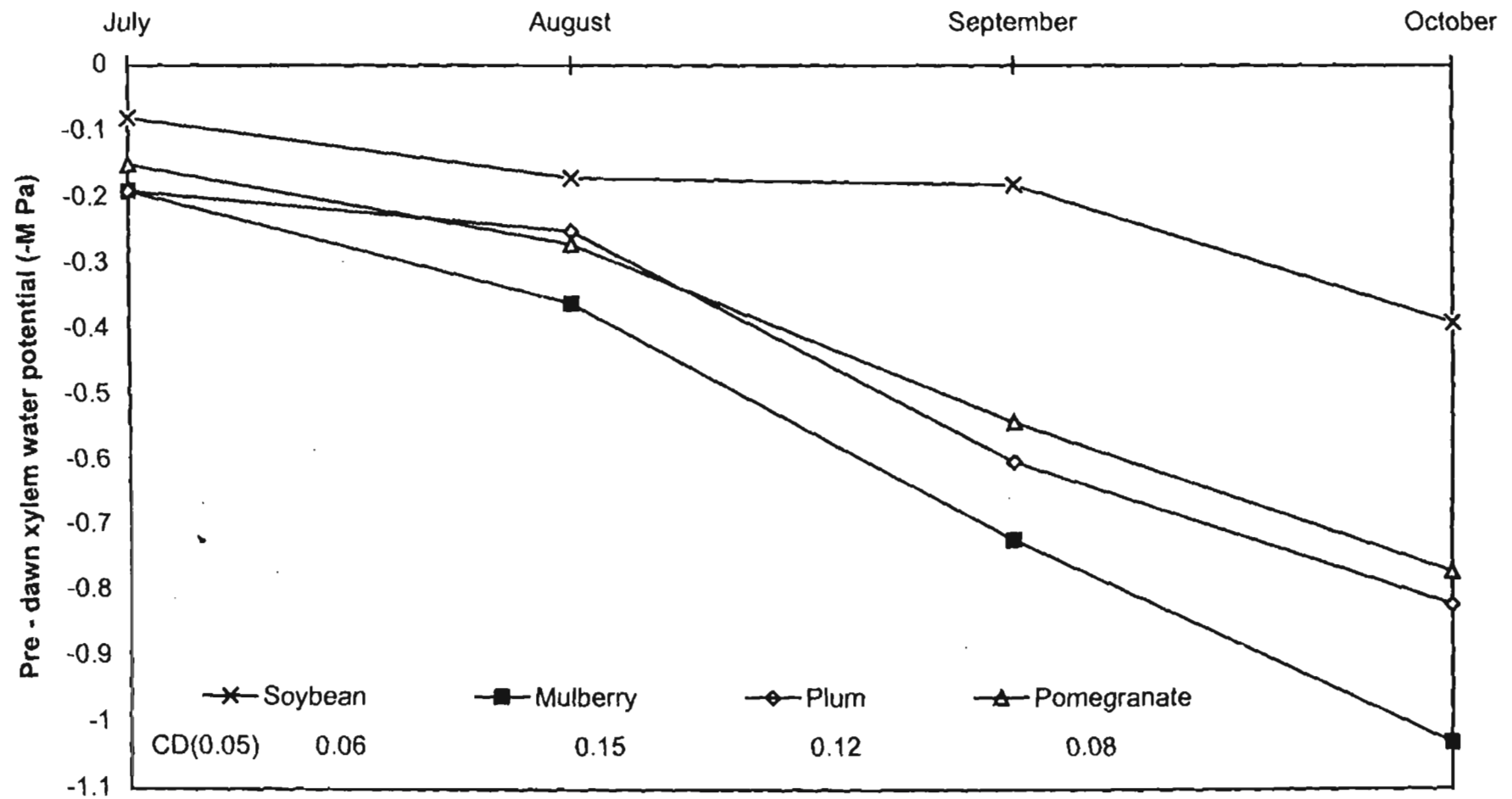


Fig. 26. Monthly variation in pre-dawn xylem water potential of soybean, mulberry, plum and pomegranate in agrihortisilviculture system.

In pomegranate, a decrease in xylem water potential was observed from July to October (Fig. 26). It was significant higher (-0.15) in July and then decreased to -0.27 in August, -0.54 in September and -0.77 in October. During July and August, the xylem water potential remained statistically at par with one another.

In general, all the four components recorded highest xylem water potential in July followed by August, September and lowest in October.

4.6 Relative light intensity (%)

Relative light intensity was recorded under mulberry, plum and pomegranate at monthly intervals starting from July till October. The data in the Fig. 27 shows monthly variation in relative light intensity among the three tree species which were statistically significant.

In July and August pomegranate had the maximum relative light intensity followed by plum and minimum under mulberry. Though pomegranate showed higher relative light intensity in September and October as well, however, mulberry showed higher values than plum during these months. In general, the relative light intensity was observed to show an increasing trend from July to October under all the three tree species except pomegranate which depicted lower value in August than July (Fig. 27).

4.7 Allelopathy

Allelopathic effect of mulberry, plum and pomegranate was studied on soybean grown for 30 days in pots. The soybean attributes studied viz. per cent germination, germination relative index (GRI), vigour index (VI), root length, shoot length and dry matter yield (DM Yield) were influenced significantly due to different treatments (Table 11).

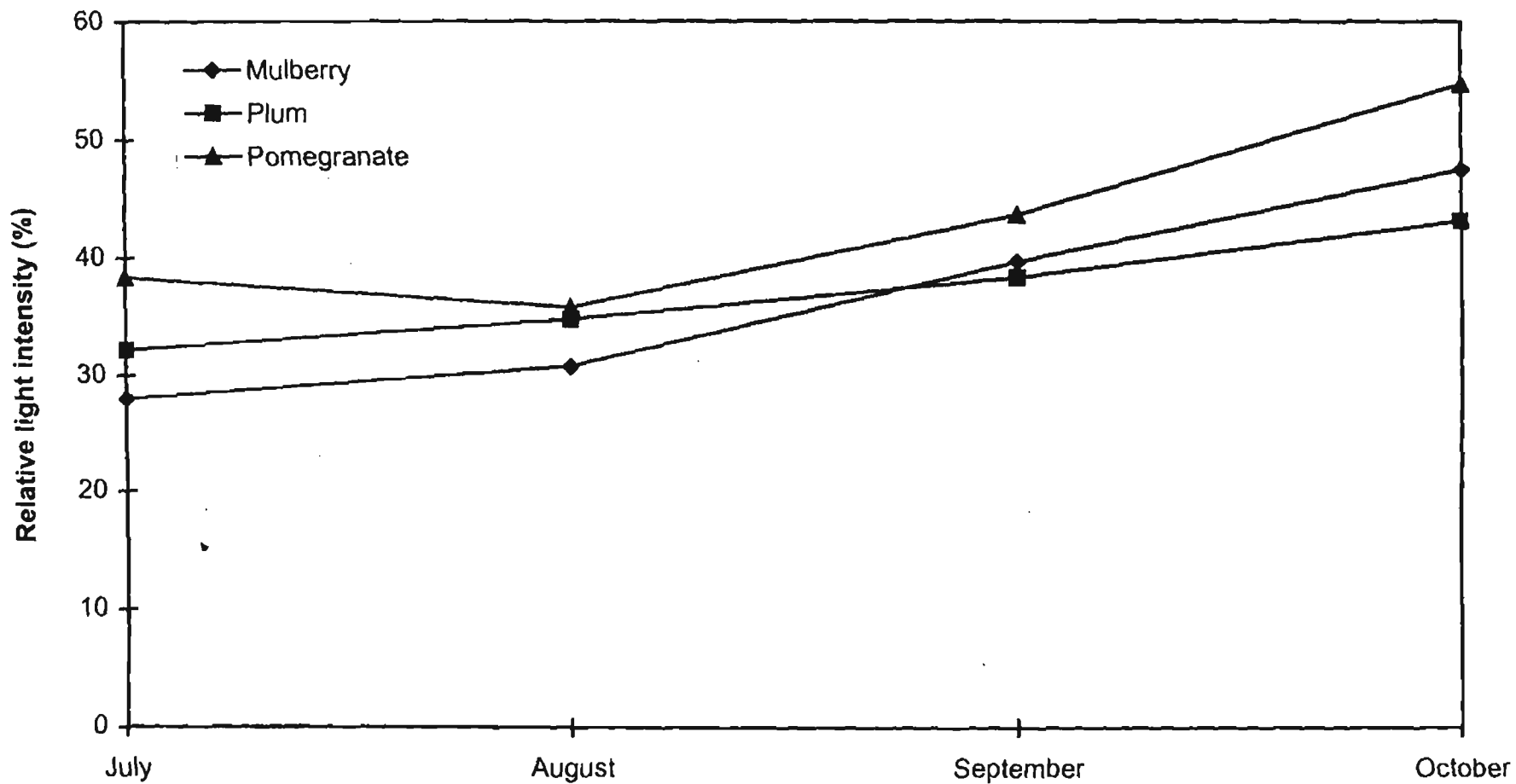


Fig. 27. Monthly variation in relative light intensity under mulberry, plum and pomegranate in agrihortisilviculture system { $CD_{(0.05)}$ to compare the interaction tree species x month 3.96}

Table 11. Allelopathic effect of mulberry, plum and pomegranate on germination, growth and dry matter yield of soybean

Treatments	Mulberry						Plum						Pomegranate					
	Germination (%)	Germination relative index	Vigour index	Root length (cm)	Shoot length (cm)	Dry matter yield (gm plant ⁻¹)	Germination (%)	Germination relative index	Vigour index	Root length (cm)	Shoot length (cm)	Dry matter yield (gm plant ⁻¹)	Germination (%)	Germination relative index	Vigour index	Root length (cm)	Shoot length (cm)	Dry matter yield (gm plant ⁻¹)
T ₁	66.66	41.48	3262	10.56	38.34	15.08	60.00	41.52	2680	9.20	35.42	12.10	53.33	39.05	2358	9.85	34.36	11.73
T ₂	60.00	42.66	2612	10.75	32.73	13.73	53.33	39.15	2170	8.80	31.90	11.74	53.33	33.51	2114	8.40	31.19	9.16
T ₃	53.33	38.20	2142	7.65	32.50	10.41	46.66	34.41	1645	8.02	27.15	9.45	46.66	31.89	1778	6.24	31.75	9.82
T ₄	53.33	33.15	1845	6.33	28.18	8.20	46.66	31.73	1592	6.48	27.60	8.05	40.00	27.80	1168	5.06	24.12	7.82
T ₅	66.66	47.33	3322	11.50	38.26	15.42	60.00	43.15	2872	10.25	37.55	13.78	60.00	42.16	2945	11.80	37.28	15.38
T ₆	66.66	45.75	2978	10.15	34.50	14.18	53.33	38.80	2399	9.85	35.10	12.24	66.66	40.48	3164	9.72	37.75	13.44
T ₇	60.00	46.12	2422	10.05	30.26	12.19	53.33	36.34	2140	8.54	31.54	9.75	53.33	36.33	2204	9.10	32.18	11.90
T ₈	60.00	41.90	2380	8.75	30.90	11.82	46.66	33.25	1618	6.34	28.32	9.10	53.33	36.20	2082	8.60	30.45	10.75
T ₉	66.66	49.28	3585	13.78	39.93	16.20	73.33	46.08	3545	12.56	35.78	13.74	73.33	48.06	3953	13.27	40.64	15.90
T ₁₀	73.33	48.32	3982	13.95	40.32	16.00	66.66	42.76	3178	10.45	37.15	13.85	73.33	48.40	3985	12.80	41.52	14.35
T ₁₁	66.66	46.78	3316	12.25	37.48	15.10	60.00	43.26	2763	10.80	35.25	11.98	66.66	45.20	3506	12.94	39.65	15.38
T ₁₂	66.66	46.20	3265	11.85	37.10	14.85	66.66	40.46	2870	9.80	33.18	11.25	66.66	43.32	3190	11.10	36.73	13.20
T ₁₃	73.33	51.40	4432	14.85	45.60	18.20	80.00	50.10	4406	14.20	40.88	15.73	80.00	50.75	4522	13.50	43.25	16.72
S.E.d.	2.27	1.69	257	0.64	1.06	1.54	1.95	2.86	237	0.77	1.33	0.97	2.11	1.60	306	0.68	1.77	1.14
CD _(0.05)	4.68	3.48	530	1.32	2.18	3.18	4.02	5.90	490	1.59	2.75	2.01	4.36	3.30	631	1.40	3.66	2.36

Mulberry : Per cent germination, germination relative index, vigour index, root length, shoot length and dry matter yield of soybean was maximum in control (T_{13}) as compared to various leaf leachate (T_1 - T_8) and mulch (T_9 - T_{12}) treatments (Table 11). Comparing treatments (T_1 - T_{12}), maximum inhibitory effect on these characters was observed in T_4 showing 53.33 per cent germination, 33.15 GRI, 1845 VI, 6.33 cm root length, 28.18 cm shoot length and 8.20 gm plant⁻¹ DM yield. However, minimum inhibitory effect for per cent germination (73.33), VI (3982), root length (13.95cm) and shoot length (40.32cm) was observed in T_{10} and for GRI (49.28) and DM yield (16.20) in T_9 .

Plum : Various leaf leachate (T_1 - T_8) and mulch (T_9 - T_{12}) treatments influenced germination, growth and yield attributes of soybean adversely as compared to control (T_{13}). Among different leaf leachate and mulch treatments (T_1 - T_{12}), treatment T_4 affected per cent germination, GRI, VI, root length and DM yield to the highest extent with their respective value of 46.66 per cent, 31.73, 1592, 6.48cm and 8.05 gm plant⁻¹ whereas, shoot length (27.15cm) was most negatively affected by T_3 . However, least adverse effect on per cent germination (73.33), GRI (46.08), VI (3545) and root length (12.56cm) was observed in T_9 whereas, for shoot length (37.15cm) and DM yield (13.85 gm plant⁻¹) in T_{10} (Table 11).

Pomegranate : The allelopathic effect of pomegranate leaf leachate (T_1 - T_8) and mulching (T_9 - T_{12}) treatments on soybean germination, growth and yield attributes followed the trend almost similar to that of mulberry and plum (Table 11). Among various leaf leachate and mulch treatments (T_1 - T_{12}), T_4 exercised its most adverse effect depicting 40 per cent germination, 27.80 GRI, 1168 VI, 5.06 cm root length, 24.12 cm shoot length and 7.82 gm plant⁻¹

DM yield. Minimum negative influence for root length and DM yield was noticed in T₉ with their respective value of 13.27cm and 15.90 gm plant⁻¹ whereas, T₁₀ affected GRI (48.40), VI (3985) and shoot length (41.52cm) to the minimum but T₉ and T₁₀ both depicted similar per cent germination (73.33).

4.8 Total Biomass and Economic Returns

Total biomass (q ha⁻¹)

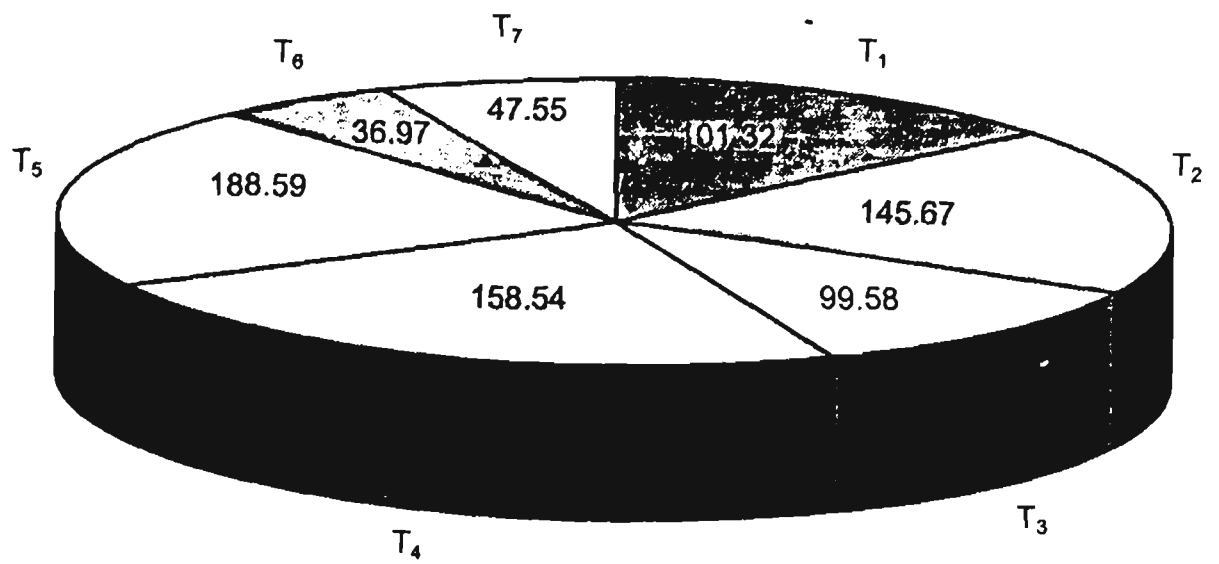
The total harvested biomass viz. grain and straw of soybean; branch wood and leaf of mulberry; and fruit and pruned wood of plum obtained from each tree-crop combination have been presented in Fig.28. The data clearly indicates that tree-crop combination T₅ produced maximum (188.59) biomass followed by T₄ (158.54), T₂ (145.67), T₁ (101.32), T₃ (99.58), T₇ (47.55) and the minimum in T₆ (36.97).

Total costs (Rs. ha⁻¹)

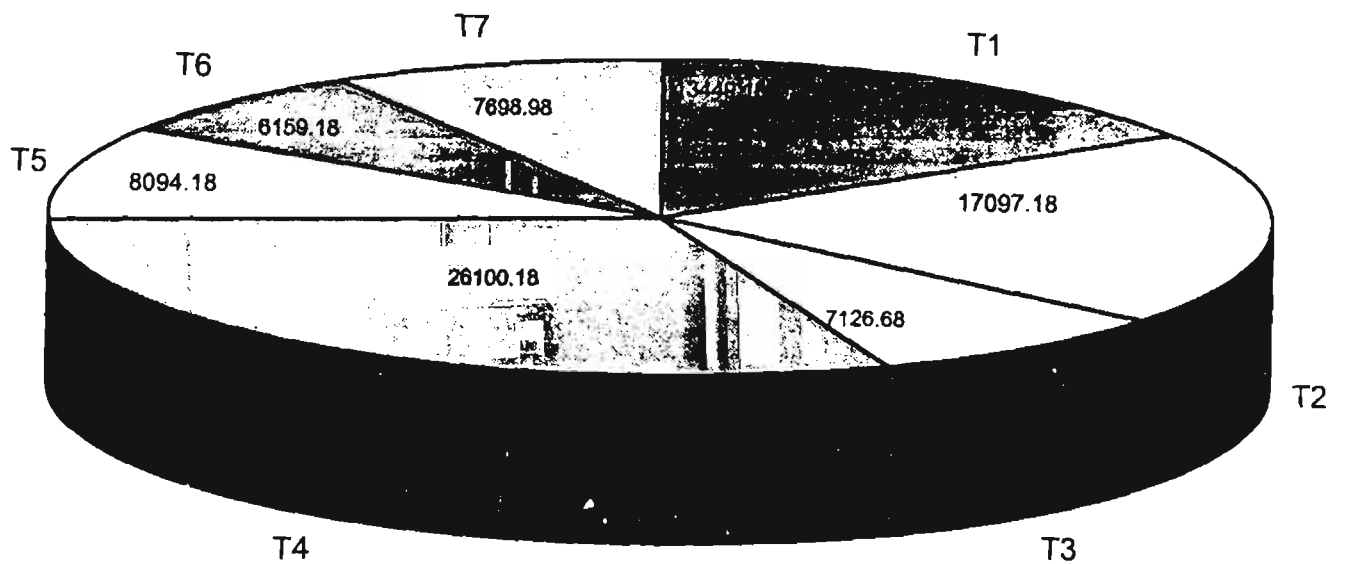
The total costs incurred in each tree-crop combination have been presented in Fig. 28. Tree-crop combination T₄ was highest cost intensive (26100.18) followed by T₂ (17097.18), T₁ (13449.18), T₅ (80.94.18), T₇ (7698.98), T₃ (7126.68) and T₆ the minimum (6159.18).

Gross returns (Rs. ha⁻¹)

The gross returns (Fig. 29) obtained from different tree-crop combination followed the trend similar to total costs however, T₃ furnished higher gross returns than T₇.

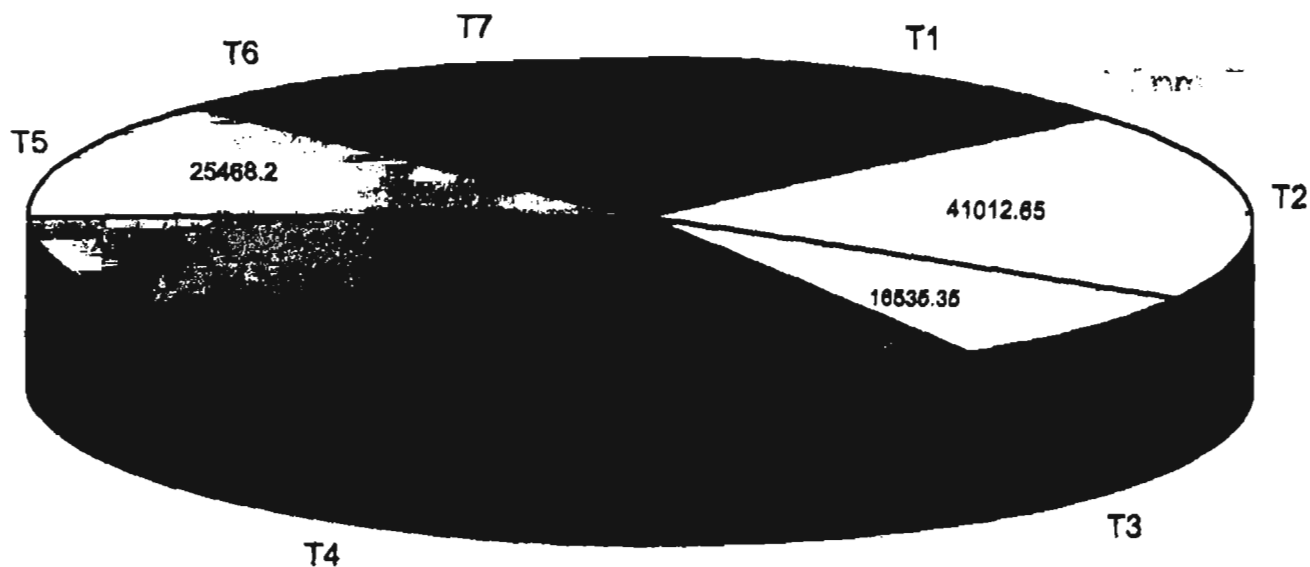


Total biomass (q ha⁻¹)

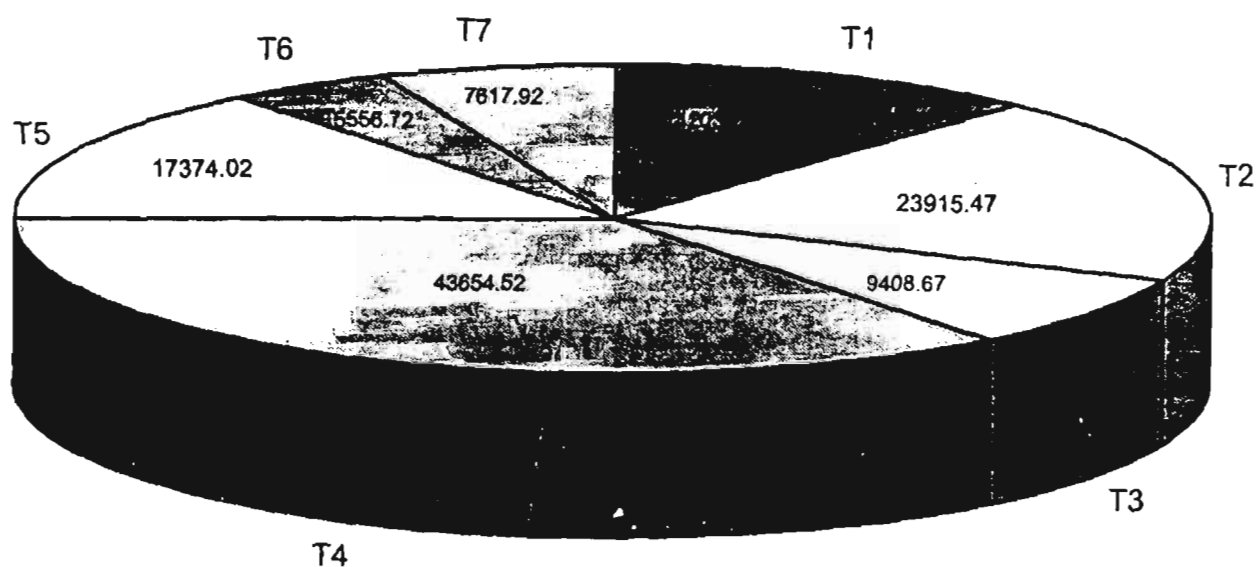


Total costs (Rs.ha⁻¹)

Fig. 28. Total biomass and total costs due to different tree-crop combinations



Gross returns (Rs. ha⁻¹)



Net returns (Rs. ha⁻¹)

Fig. 29. Gross and net returns due to different tree-crop combinations

Net returns (Rs. ha⁻¹)

The net returns (Fig. 29) were highest (43654.52) from T₄ followed by T₂ (23915.47), T₅ (17374.02), T₁ (14203.22), T₃ (9408.67), T₇ (7617.92) and least from T₆ (5556.72).

CHAPTER - 5

DISCUSSION

The results obtained from the present investigations have been discussed in this chapter, establishing a cause and effect relationship wherever necessary or feasible, in the light of available literature, under the following heads.

5.1 Plant growth and yield

5.1.1 Soybean

5.1.2 Mulberry, Plum and Pomegranate

5.2 Plant nutrient concentration

5.2.1 Soybean

5.2.2 Mulberry, Plum and Pomegranate

5.3 Litter studies

5.3.1 Litter production and nutrient concentration - mulberry, plum and pomegranate.

5.3.2 Litter decomposition - mulberry, plum and pomegranate

5.4 Soil characteristics

5.4.1 Chemical properties

5.4.2 Nutrient addition and removal through system components.

5.4.3 Nutrient balance

5.4.4. Soil moisture

5.5 Pre-dawn xylem water potential - soybean, mulberry, plum and pomegranate.

5.6 Relative light intensity under mulberry, plum and pomegranate

5.7 Allelopathic effect of mulberry, plum and pomegranate on soybean

5.8 Total biomass and economic returns

5.1 Plant growth and yield

5.1.1 Soybean

The growth parameters namely plant height and number of plants m^{-2} were influenced significantly by different tree-crop combinations (Table 2). T_7 gave higher values for both the attributes nevertheless the values were statistically at par with those obtained in T_6 . The combination T_1 gave the minimum values. This is equally true for yield attributes also. The comparison between T_4 and T_5 i.e. association with plum and mulberry, respectively have shown that mulberry influences the number of plants and other yield attributes of soybean adversely than plum.

The above tree-crop influences on the soybean growth and yield attributes can be due to the following reasons. First, plants in T_7 were grown in sole crop system i.e. a situation with nil competition with respect to tree association. Additionally, the soybean plants growing in association with trees may also have experienced allelopathic influences as was evident from the present studies (Table 11) that the growth and yield attributes of soybean were negatively influenced by tree leaf leachate and mulch treatments in comparison to control.

In tree-crop combination T_6 the associated fruit species was pomegranate. Its height was less and crown spread small and sparse (Table 3) which may not have hindered the growth of soybean plants to a larger extent. The higher soil moisture (Fig. 24 and 25) and relative light intensity (Fig. 27) under pomegranate compared with plum and mulberry observed during the present studies also support the above results. The more negative influence of mulberry compared to plum on soybean may have occurred due to higher

competition for nutrient elements by mulberry (Fig.1) and also for light (Fig.27) during July-August.

The minimum values for different growth and yield attributes at T_1 may be attributed to the reason that this combination involves more number of trees of fodder and fruit species together compared to all other combinations, which means that soybean plants were growing in a situation of high competition for light, moisture and nutrients. This was evident from the lower concentration of nutrient elements in the plants growing in T_1 (Fig.1).

The results are in line with the findings of Rao and Coe (1992), who reported higher competition and suppressed crop yield with tree species ranking high in terms of height, diameter and crown spread. Alley cropping induces competition for water (Singh *et al.*, 1989; Corlett *et al.*, 1989) or water and nutrients both (Rao *et al.*, 1990; Ong, *et al.* 1991b) between the trees and crops which severely reduce the crop yield. Huck *et al.* (1986) observed significant reduction in total shoot weight and seed weight with respect to water stress in soybean. Reduced growth and yield of soybean due to shade was observed by Wahna and Miller (1978), Eriksen and Whitney (1984). Growth and yield decrease in soybean grown with mulberry as compared to monocropping were also reported by Dinissa (1993), Kumar (1996) and Kaushal (1998).

5.1.2 Mulberry, plum and pomegranate

Mulberry growth attributes (Table 3) namely height, diameter and crown spread at sowing as well as at harvesting of soybean were higher in T_5 . Directionally the crown spread was more towards South and West at sowing and, East and West at harvesting. In case of plum, the crown spread was more towards East and West at sowing as well as at harvesting however, height and diameter were more in T_4 among the combinations it was present. Pomegranate height and diameter were more in T_6 however, crown spread at sowing and

harvesting was more towards West and South though the values for East and South were statistically at par at harvesting.

The more height and diameter of all the three tree species in their respective combinations as discussed above was due to the presence of single tree in these combinations compared to all other in which there are present. The more crown towards East and West may have developed because crown competition between the trees was in North and South since the trees have been planted in rows extending from North to South.

The leaf and branch biomass yield of mulberry (Table 4) whereas, pruned wood and fruit yield of plum (Table 5) followed the trend similar to their height, diameter and crown development.

It was inferred from the above findings that higher growth and yield in combinations having one tree may be due to less competition for light, water and nutrients and hence better utilization of resources.

5.2 Plant nutrient concentration

The concentration of N, P, K, Ca, Mg and S in soybean grain and straw was significantly influenced by different tree-crop combinations (Fig. 1). It was deduced from the data that although sole cropping (T₇) plants had highest values of nutrient concentration yet among the various tree-crop combinations (T₁-T₆) maximum nutrient concentration was observed in T₆ followed by T₄, T₅, T₃, T₂ and T₁. The higher nutrient concentration in T₆ (Pomegranate - Soybean) may be due to less competition for nutrients in this association as height, diameter and crown spread of pomegranate trees (Table 3) were considerably less than other two species. Higher soil moisture in this combination (Fig.24 and 25) may also have resulted in better nutrient availability to the soybean crop. Similarly, more nutrient concentration in association with plum (T₄) than mulberry (T₅) can be explained to the fact that plum trees have

been supplied with additional amount of fertilizers and manures every year whereas, the mulberry trees were grown without their application.

5.2.2 Mulberry, plum and pomegranate

The nutrient concentration of harvested biomass viz. branch wood and leaves of mulberry (Fig. 2) and pruned wood and fruits of plum (Fig. 3) have shown their respective higher values in combinations having single tree viz. T₅ (one mulberry) and T₄ (one plum). Lesser nutrient concentrations for both mulberry as well as plum was observed in T₁ having maximum of three trees : one each of mulberry, plum and pomegranate. This can be ascribed to less competition for nutrients in T₄ and T₅ in comparison to T₁. Additionally, higher soil moisture (Fig. 24 and 25) in T₄ and T₅ might have enhanced the nutrient availability.

Monthly variation (Fig.4) in foliar nutrient concentration of mulberry, plum and pomegranate were statistically significant. N, P, K and S decreased whereas, Ca and Mg increased with the advancement of growth season from July to October. However, Mg concentration in pomegranate was higher in September and in plum it depicted higher value in August. The observed trend can be attributed to the fact that young foliage often have high concentration of N, P and K. As the foliage matures, their concentration often decrease due to accumulation of carbohydrates and cellulose, while Mg and particularly Ca concentration usually increase with leaf age because of secondary thickening, including calcium pectate deposition in cell walls, and from increasing storage of calcium oxalate in cell vacuoles (Chapin, 1980). Similar results have also been reported by Verma and Mishra (1989) for Robinia and Grewia; Kaushal (1998) for Almond, Grewia and Morus.

5.3 Litter studies

5.3.1 Litter production and nutrient concentration

Litter produced by mulberry, plum and pomegranate under different tree-crop combinations have shown significant results (Table 6). Litter production was more in T₅ for mulberry; T₄ for plum and T₆ for pomegranate which can be ascribed to the presence of more number (800) of tree ha⁻¹ as compared to other combinations (Table 1). Plum produced more litter than pomegranate obviously owing to its large size and crown development (Table 3). Mulberry produced the litter in least quantity. This was due to the removal of foliage for fodder. Nutrient concentration in mulberry, plum and pomegranate litter produced under different tree-crop combinations was statistically significant (Fig. 5). N, P, K, Ca, Mg and S concentration in litter increased with the decrease in number of trees per treatment which may be due to less competition for soil water and nutrients.

5.3.2 Litter decomposition

The litter decomposition rate of mulberry, plum and pomegranate was statistically significant (Fig. 6). At the beginning i.e. in July, the decomposition rate was rapid which declined significantly in August irrespective of tree species. It again attained a peak in September and then slowed down in October. Puri *et al.* (1992) also reported higher litter decomposition of leucaena during the high rainfall period. Greater decomposition in the rainy season is perhaps due to pronounced microbial activity under favourable temperature and moisture conditions and accentuated leaching due to rainfall (Pandey and Singh, 1982). The higher weight loss in initial periods (Vossbrink *et al.*, 1979) occurs due to leaching of soluble materials that may happen in the presence or absence of microflora and fauna. Specieswise, the decomposition rate followed the order plum > pomegranate > mulberry (Fig. 6). Madge (1965) also reported that the leaf discs of different species disappeared at different rates. Ovington (1961)

observed complete litter decay of temperate deciduous forest species in 6-9 months. Tanner (1981) reported that decomposition of freshly fallen litter of 15 species to vary between 27.0 to 79.6 per cent year⁻¹.

5.4 Soil characteristics

5.4.1 Chemical properties

The pH was maximum in T₇ (sole soybean) as compared to other tree-crop combination (T₁-T₆). However, T₁ (Plum-Mulberry-Pomegranate-Soybean) showed minimum values (Fig. 7). The reduction in pH under tree based treatments (T₁-T₆) can be ascribed to the substantial addition of organic matter in the form of litter to the soils under trees (Table 6) and due to tree root activities. Nakayama (1969) reported reduced soil pH under vegetative cover because the respiring roots raise the CO₂ concentration in soil atmosphere, which on dissolution in water produces carbonic acid (HCO₃). Least soil pH values under T₁ may be due to more number of trees in this treatment and hence more root activities. Lower pH in July, August and September than June and October may be due to more rains at the time of sampling which might have resulted in rapid leaching of base forming cations. High pH in sub-surface layer (15-30cm) than surface layer (0-15cm) may also be attributed to leaching of base forming cations from surface layer to sub-surface layer during the period of high rains.

The organic carbon, available N, P, K, S, exchangeable Ca and Mg (Fig. 9-22) were lower in sole soybean (T₇) compared to other tree-crop combinations (T₁-T₆). Among various tree based treatments (T₁-T₆), higher values for organic carbon N, P, K and S were observed in T₄ (Plum-Soybean) and lesser in T₃ (Pomegranate - Mulberry - Soybean) for N, P and K. Per cent organic carbon and S however, were less in T₅ (Mulberry-Soybean). For Mg T₃

gave the higher value which was almost equal to T₄ and T₅ the least. Trends in the Ca contents of soils was not well defined. The results thus, indicate that mulberry and pomegranate impoverished the soil nutrients more than plum. Lower nutrient content in soils under sole crop over the tree-crop combinations indicates that soybean plants growing as sole crop have utilized soil nutrients more efficiently and in larger amounts. This is also evident from the higher plant nutrient content of soybean in T₇ over T₁ - T₆ (Fig. 1). Additionally, trees may not have utilized the nutrients from soybean crop zone since these were planted on bunds thus, forming smallest tree-crop interface area.

Higher soil nutrient status under agroforestry (T₁ - T₆) than monoculture (T₇) may also be associated with efficient nutrient cycling by the tree species (Nair, 1984); canopy capture of precipitation inputs (Kellman, 1979); root turnover (Yamoah *et al.*, 1986) increased mineralization (Rhoades, 1995) and other means (reduced soil erosion, reduced leaching of nutrients and uptake from deep soil layer) of below ground improvement (Rao *et al.*, 1998). High soil nutrient status under trees than in open areas have also been reported by Atta-Krah *et al.*, 1985; Yamoah, *et al.*, 1986a; Kater *et al.*, 1992).

Higher soil nutrient status under T₄ (Plum-soybean) compared with other combinations may be due to fertilizer and FYM addition to plum trees (Appendix-18); more number (800) of plum trees ha⁻¹ (Table 1) resulting in higher litter addition (Table 6), rapid litter decomposition (Fig.6) and thus, higher nutrient turnover (Appendix-18). However, low soil nutrient status under T₅ (Mulberry-Soybean) and T₃ (Pomegranate - Mulberry - Soybean) may be attributed to the non-supply of fertilizers to the trees; lesser litter addition (Table 6) and decomposition rate (Fig. 6) and higher removal of nutrients through mulberry branch wood and leaf (Appendix-20 to 22).

Monthly variation in soil fertility status revealed that organic carbon, P, K, Ca, Mg and S content decreased with the advancement of growth season from June to October. The resultant declining trend of nutrients may be due to their more utilization by the trees and crop. Although N content in soils increased with the increase in crop growth period yet it was minimal from June - August and thereafter it was significant and rapid. This can be ascribed to the reason that due to non-nitrophilic crop its utilization was lesser than to its availability because of mineralization coupled with the nitrogen fixation by soybean (Burns and Hardy, 1975; Singh and Kashyap, 1983; Yadav and Kumar, 1998). The increase in N content of soils and decrease in other nutrients after harvesting of leguminous crops have also been reported by Thind *et al.* (1979); Mishra *et al.* (1985); Maiti *et al.* (1993) and Kaushal (1998).

Depth of soil revealed higher organic carbon, N, P, K and S in the surface (0-15 cm) layer than sub-surface (15-30cm) layer. It may have occurred partly due to surface application of fertilizers and partly due to nutrient cycling from sub-soil to surface soil. The Ca and Mg were higher in sub-surface layer compared to surface layer, which is evident from the fact that basic cations are more liable for leaching in soils.

5.4.2 Nutrient addition and removal

Addition of N, P, Ca, Mg and S (Table 7) was higher in T₄, T₂ and T₁ compared with T₃, T₅, T₆ and T₇. This was due to the presence of plum as a fruit component in T₄, T₂ and T₁ combinations which was supplied with fertilizers and manures (Appendix-18) in addition to its higher litter production (Table 6) and rapid litter decomposition rate (Fig. 6).

Removal of N, P, K, Ca, Mg and S (Table 8) through the harvested biomass of different components was least in T₆ and highest in T₅ except P, which was removed in maximum quantity in T₄. The lowest quantity of

nutrient removal in T₆ was due to lowest total harvested biomass (Fig. 28) because of the presence of pomegranate which was not in its bearing stage. The higher nutrient removal in T₅ was due to the higher total harvested yield (Fig. 28) especially the branches and leaves of mulberry which removed a sizeable quantity of nutrients (Appendix-21 and 22).

5.4.3 Nutrient balance

All the nutrient elements studied viz. N, P, K (Table 9), Ca, Mg and S (Table 10) have shown maximum net loss in T₄ which was due to the reason that expected balance in the soil was higher than the actual balance. The higher expected balance is due to higher amount of nutrients added to their initial values resulting in higher total amount but the cumulative removal was not in the proportion of addition. Lower actual balance in the soil may have occurred due to the reason that only a part of added nutrients were utilizable rather recoverable in the soil system.

All the tree-crop combination (T₁-T₇) depleted the soil P and S reserves. However, N, Ca and Mg revealed higher net gain in T₅ whereas, K in T₃. The higher net gain of N, P, Ca, and Mg was due to less expected balance than actual balance. The lower expected balance was due to less amount of nutrients added thus exhibiting less total amount but the cumulative removal is comparatively higher than the addition. The higher actual balance in soil can be attributed to the reason that it did not differ appreciably to its initial amount.

5.4.4 Soil moisture

Soil moisture was influenced significantly by various tree-crop combinations (Fig. 24 and 25). It was higher when soybean was grown alone (T₇) followed by its association with pomegranate (T₆), mulberry (T₅) and plum (T₄). The lower soil moisture under trees as compared to open control may be

due to higher evaporative demand of tree species (Connor, 1983). Among the tree association, lesser soil moisture under plum and mulberry from July-October can be ascribed to the fact that during this period these trees were in their active growth phase coupled with heavy canopy load (phytomass) and may, therefore, have extracted larger volume of soil water. The results are in line with the findings of Singh *et al.*, (1989); Corlett *et al.* (1989); Rao *et al.* (1990), Ong *et al.* (1991b); Khybri *et al.* (1992) and, Srivastava and Rao (1993) who reported less soil moisture in agroforestry combinations as compared to sole cropping.

Monthly variation in soil moisture during the soybean crop season under each combinations (Fig. 24) revealed its higher content in the month of August and September followed by July and October. This may be due to higher rainfall at the time of moisture measurements in August and September, and lesser rains in July and October.

Among the two soil layers, more soil moisture was in surface layer during July and August and lesser in September and October this may be due to peak period of rainy season in July and August and drier period in September and October.

5.5 Pre-dawn xylem water potential

Xylem water potential of soybean, plum, mulberry and pomegranate have shown a decreasing trend with the advancement of season from July to October. This can be ascribed to the variation in availability of soil moisture in addition to internal physiological capabilities of different components to regulate internal water content.

5.6 Relative light intensity

The per cent relative light intensity below the mulberry, plum and pomegranate canopies increased from July to October except for pomegranate which evinced lower value in August than July. Such an increase

was obvious as the growth season advanced towards maturity the trees started shedding leaves in greater quantity resulting in sparse canopy.

Among the tree species, the relative light intensity was maximum below pomegranate than plum and mulberry. Plum showed more relative light intensity in July and August than mulberry whereas, a reverse trend was observed in September and October. The higher relative light intensity under pomegranate as compared to plum and mulberry may be due to less foliage and crown spread of pomegranate (Table 3). Jaswal *et al.* (1993), Dinssa (1993) and Kumar (1996) with different tree species reported almost similar results.

5.7 Allelopathy

Allelopathic effect of mulberry, plum and pomegranate leaf leachate and mulch on per cent germination, germination relative index, vigour index, root length, shoot length and dry matter yield of soybean was significant (Table 11). In general, all the three tree species influenced the above plant growth and yield parameters negatively to their maximum with 40 per cent leaf leachate obtained after Hollis *et al.*, 1982 and minimum with 5 gm foliage pot⁻¹ as surface mulch. This can be ascribed to release of more phytotoxic natural products from 40 per cent leaf leachate and corresponding less through 5 gm foliage mulch. The toxicity effect varied from species to species, being higher for pomegranate in treatments T₁-T₄ and for plum in treatments T₅-T₁₂. Melkania (1984) also observed the different response of leachates of woody species on agricultural crops and concluded that leachates from *Celtis australis* were phytotoxic to *Glycine soja*. Bhatt and Todaria (1990); Srinivasan *et al.* (1990) and Bhardwaj (1993) also observed decrease in germination, growth and yield parameters of soybean with leaf leachates of different species. Waks (1969) noticed inhibition of growth of barley due to some toxins of *Robinia pseudoacacia*. Rice (1979) and, Singh and Bawa (1982) found

reduced germination and biomass of herbaceous plants due to allelopathic influence of woody species.

5.8 Total biomass and economic returns

Total biomass : The total harvested biomass yield (Fig. 28) was maximum in T₅ (Mulberry-Soybean) followed by T₄ (Plum-Soybean), T₂ (Plum-Mulberry-Soybean), T₁ (Plum-Mulberry-Pomegranate-Soybean), T₃ (Pomegranate-Mulberry-Soybean), T₇ (Soybean) and T₆ (Pomegranate - Soybean). Highest biomass yield in T₅ was due to more number (800) of mulberry trees ha⁻¹ (Table 1) which contributed substantial quantity of branch wood and leaf (Table 4). Similarly 800 plum tree ha⁻¹ (Table 1) in T₄ account for higher biomass through pruned wood and fruit (Table 5). Minimum biomass yield in T₆ which is even less than the T₇ has been attributed to the fact that former having less (0.8ha) area under soybean cultivation than the latter (1.0 ha). Secondly, the presence of pomegranate in T₆ have depressed crop yield (Table 2). Finally, pomegranate trees were not in bearing stage during the study period and hence did not gave yield.

Total costs : Total costs incurred were highest in T₄ followed by T₂, T₁, T₅, T₇, T₃ and T₆ (Fig. 28). The above trend appeared due to the presence of plum and its relative number in different tree-crop combinations (T₄ : 800, T₂ : 400, T₁ : 267). Plum incurred more costs owing to its exacting nature. It was supplied with FYM, fertilizers and also involved additional costs on management practices such as basin preparation, pruning and application of plant protection chemicals (Appendix-31). Whereas, combinations having pomegranate and/or mulberry were less cost intensive as these species do not require intensive management practices.

Gross returns : Gross returns (Fig. 29) were maximum from T₄ followed by T₂, T₁, T₅, T₃, T₇ and T₆. The observed trend was due to corresponding harvested biomass (Fig. 28) and price of the product (Appendix-32) of these tree-crop combinations. It is concluded that treatments having plum as a fruit component furnished higher gross returns over the others.

Net returns : The net returns (Fig. 29) showed the following order : T₄ > T₂ > T₅ > T₁ > T₃ > T₇ > T₆. It is deduced from the above results that treatments having more plum trees (T₄ : 800 trees ha⁻¹, T₂ : 400 trees ha⁻¹) furnished higher net returns because of high priced fruit (Appendix-32) and higher biomass (Fig. 28). High net returns from T₅ (800 mulberry trees ha⁻¹) was due to less costs (Appendix-31) and highest biomass (Fig. 28) obtained from this treatment. Least net returns from T₆ (pomegranate-soybean) which is even less than T₇ (soybean) was due to less net cropped area (0.8 ha) in T₆ than T₇ (1.0 ha) and hence less grain and straw yield (Table 2). Moreover, the pomegranate trees are not in bearing stage so nil biomass and returns from it.

The incorporation of trees with field crops will increase the overall productivity and the marginal fall in crop production will be compensated by the financial returns from sale of tree products (Chaturvedi, 1991). Similarly, the overall economics favour tree-crop combination rather than the sole cultivation of a field crop or a simple plantation of a tree species (Mittal and Singh, 1989; Harsh and Tewari, 1993; Kumar, 1996; Yadav and Kumar, 1998).

CHAPTER - 6

SUMMARY AND CONCLUSIONS

“Tree-crop interaction studies in agroforestry system - productivity, moisture and nutrient dynamics” were carried out at experimental farm of the Department of Silviculture and Agroforestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan (H.P.) during the Kharif season, 1997 and 1998. The experiment was laid in randomized block design using seven tree-crop combinations viz. Plum-Mulberry-Pomegranate-Soybean (T_1), Plum-Mulberry-Soybean (T_2), Pomegranate-Mulberry-Soybean (T_3), Plum - Soybean (T_4), Mulberry-Soybean (T_5), Pomegranate-Soybean (T_6) and sole soybean (T_7). Each combination was replicated thrice. Tree leaf litter production, its decomposition rate and allelopathic effect on soybean crop were also studied separately.

Soybean growth, yield and nutrient concentrations

Association of mulberry, plum and pomegranate using above tree-crop combinations negatively influenced the soybean growth and yield attributes as compared with the sole crop. The negative influence was statistically significant. Soybean growth and yield response in general, among the tree-crop combinations was in the order of $T_6 > T_4 > T_5 > T_3 > T_2 > T_1$. The macronutrient concentration in soybean grain and straw was higher in T_7 than all other tree-crop combinations which showed following order : $T_6 > T_4 > T_5 > T_3 > T_2 > T_1$.

Tree growth, yield and nutrient concentration

Height, diameter and crown spread of mulberry, plum and pomegranate as well as biomass yield measured i.e. branch wood and leaves of mulberry as well as pruned wood and fruits of plum vis-a-vis their litter

production, macronutrient concentration in litter, leaves, branch wood, pruned wood and fruits were respectively higher in tree-crop combination having only one tree species association (T_4 : Plum-Soybean; T_5 : Mulberry-Soybean; T_6 : Pomegranate-Soybean) resulting in maximum number of trees ha^{-1} of the same species.

Monthly variation in foliar nutrient concentration of mulberry, plum and pomegranate revealed that N, P, K and S concentration decreased whereas, Ca and Mg increased with the advancement of growth season from July to October. However, Mg concentration in pomegranate was higher in September and in plum its value was more in August.

Litter decomposition

The leaf litter decomposition rate of mulberry, plum and pomegranate was rapid at the beginning of the experiment in July then declined in August, again attained a peak in September and finally slow down in October.

Soil chemical changes

Soil chemical changes have shown that soil pH was highest under T_7 (sole soybean) and lowest under T_1 (Plum-Mulberry-Pomegranate-Soybean) as compared with other tree-crop combinations (T_2 - T_6). Monthly variation in soil pH revealed its lower values in July, August and September than June and October. Depthwise, higher soil pH value was observed in sub-surface (15-30cm) layer than surface (0-15cm) layer. Macronutrient elements content in soils viz. available N, P, K, S ; exchangeable Ca, Mg and organic carbon was lower under sole soybean (T_7) than other tree-crop combinations (T_1 - T_6). Among various tree-based treatments, T_4 (Plum-Soybean) showed higher OC, N, P, K and S whereas, T_3 (Pomegranate-Mulberry-Soybean)

revealed lower values for N, P and K while T₅ (Mulberry-Soybean) for organic carbon and sulphur. Soil Mg was observed higher in T₃ which is almost equal to T₄ and least in T₅. However, Ca content of soil did not reveal well defined trend. Monthly variation in soil nutrients indicated that organic carbon, P, K, Ca, Mg and S content decreased whereas, N have shown an upward trend with the advancement of season from June to October. Depthwise organic carbon, N, P, K and S status of soils was higher in the surface (0-15cm) layer compared to sub-surface (15-30cm) layer. The Ca and Mg however, have shown a reverse trend being higher in sub-surface layer than surface layer.

Addition and removal of nutrients

Addition of macronutrients was high in tree-crop combination involving plum as one of the component (T₄, T₂, T₁). However, removal except P was high in tree-crop combination having mulberry (T₅). In soil N, Ca and Mg showed higher net gain in T₅ whereas K in T₃. P and S reserves of soils was observed to be depleted by all the tree-crop combinations (T₁-T₇) however, net loss for all the macronutrients was higher in T₄.

Soil moisture, xylem water potential and relative light intensity

The soil moisture was high when soybean was grown alone (T₇) followed by its association with pomegranate (T₆), mulberry (T₅), plum (T₄), pomegranate-mulberry (T₃), plum-mulberry (T₂) and plum-mulberry-pomegranate (T₁). Monthly variation in soil moisture during the crop growth season revealed its higher content in August and September followed by July and October. Depthwise more soil moisture was observed in surface layer in July and August whereas, its values were higher in sub-surface layer in September and October. Pre-dawn xylem water potential of soybean, mulberry, plum and pomegranate has shown a decreasing trend with the advancement of

season depicting maximum xylem water potential in July and minimum in October.

Relative light intensity below mulberry, plum and pomegranate canopies revealed an increasing trend from July to October except for pomegranate which depicted lower value in August than July. Throughout the growth season from July to October it was high below pomegranate than plum and mulberry. However, plum depicted more relative light intensity in July and August than mulberry whereas, a reverse trend was observed in September and October.

Allelopathy

Allelopathic effect of mulberry, plum and pomegranate on per cent germination, germination relative index, vigour index, root length, shoot length and dry matter yield of soybean grown for 30 days in pots containing field soils, was significant due to different leaf leachate and mulch treatments. The maximum adverse effect was caused by 40 per cent leaf leachate (after Hollis *et al.*, 1982) and minimum by 5gm foliage mulched at the soil surface. Relatively, plum had more adverse effect in treatments T₅-T₁₂ whereas, phytotoxic effect of pomegranate was more pronounced in T₁-T₄.

Total biomass and economic returns

The total biomass yield in different tree-crop combination followed the order : T₅ (Mulberry-Soybean) > T₄ (Plum-Soybean) > T₂ (Plum-Mulberry-Soybean) > T₁ (Plum-Mulberry-Pomegranate-Soybean) > T₃ (Pomegranate-Mulberry-Soybean) > T₇ (Soybean alone) > T₆ (Pomegranate-Soybean).

The total costs incurred were higher for tree-crop combinations involving plum as one of the component with soybean ($T_4 > T_2 > T_1$) than mulberry and/or pomegranate and sole cropping ($T_5 > T_7 > T_3 > T_6$). The gross as well as net returns followed the trend similar to that of total costs however, T_3 revealed higher gross and net returns than T_7 , and T_5 showed more net returns than T_1 .

CONCLUSIONS

Comparing the tree-crop interactions while integrating plum and pomegranate as fruit trees and mulberry as fodder tree with soybean as food crop in agrihortisilviculture system the following inferences can be made.

Soybean performance was significantly higher in sole cropping than under agrihortisilviculture system. The growth and yield attributes of soybean vis-a-vis its macronutrients concentration have shown an increase with the decrease in number of trees per treatment. Mulberry depressed these characters more than plum whereas, pomegranate the least.

Mulberry, plum and pomegranate have shown their respective maximum growth, biomass yield, litter production and macronutrient concentration in the harvested biomass as well as in litter in tree-crop combination having single tree species. Plum leaf litter decomposed rapidly followed by pomegranate and mulberry.

The restorative effect of plum on soil fertility was higher in comparison to pomegranate and mulberry. Soybean grown as pure crop tended to deplete higher amount of nutrients than in association with either fodder or fruit trees. The surface (0-15cm) layer was more fertile having higher amount of OC, N, P, K and S whereas, Ca and Mg have shown abundance in sub-surface (15-30cm). The N content in soils has shown accumulating effect with the

advancement of season from June to October whereas, other macronutrient elements alongwith organic carbon showed depletion. The depletion however, was higher from sub-surface zone which is also the nutrient sorption zone of soybean.

Nutrient addition through FYM, fertilizer and litter was higher in combinations involving plum as one of the component with soybean (T_4 , T_2 , T_1) and the total nutrients added followed the order : $Ca > K > N > P > S > Mg$. The order of added nutrients in combinations having mulberry and/or pomegranate as associated components (T_3 , T_5 , T_6) was : $Ca > K > P > N > S > Mg$ whereas, in sole soybean crop (T_7) it was : $Ca > P = K > S > N > Mg$. Nutrient removal through harvested biomass was higher for Mulberry-Soybean combination (T_5). However, all the tree-crop combinations (T_1 - T_7) exhibited following nutrient removal order : $Ca > N > K > Mg > S > P$.

Total addition of the nutrient elements into the system and their removal through harvested biomass from the system resulted in higher net gain of N, Ca and Mg in T_5 combination and K in T_3 . The process resulted in net loss of P and S in each combinations (T_1 - T_7). Irrespective of treatments, the net gain followed the order : $N > Ca > Mg > K$ whereas, net loss : $Ca > K > N > S > P > Mg$.

Soil moisture content depicted that mulberry and plum compete more strongly with soybean whereas, pomegranate the least. Pre-dawn xylem water potential indicated lesser internal plant water status in mulberry followed by plum and pomegranate. Mulberry cast more shade during July and August resulting in more competition for light with soybean in comparison to plum whereas, pomegranate cast least shade on soybean throughout the season. The degree of allelopathic effect of tree species on soybean grown in pots followed the order : plum > pomegranate > mulberry if

leaf leachate (after Tukey and Mecklenberg, 1964) and mulch treatments are taken into account.

The tree-crop combination Mulberry-Soybean (T_5) gave higher biomass yield whereas, Pomegranate-Soybean (T_6) the least. Total costs, gross returns and net returns were higher from combinations involving plum as one of the component with soybean ($T_4 > T_2 > T_1$) while least from pomegranate - soybean (T_6).

Based on economic and biophysical criteria of scoring for designing economically viable, sustainable, more productive and diversified land use system, the different tree-crop combinations comprising specific functional units are found suitable/promising in the following order of preference:

A. If net returns dominates over product diversification

Plum - Soybean > Plum - Mulberry - Soybean > Mulberry - Soybean > Plum - Mulberry - Pomegranate - Soybean > Pomegranate - Mulberry - Soybean > Soybean > Pomegranate - Soybean.

B. If product diversification dominates over net returns

Plum - Mulberry - Pomegranate - Soybean > Plum - Mulberry - Soybean > Pomegranate - Mulberry - Soybean > Plum - Soybean > Mulberry - Soybean > Pomegranate - Soybean > Soybean.

C. Overall preference (Net returns, total costs, total biomass, product diversification and soil nutrients)

Plum-Soybean = Plum - Mulberry - Soybean > Plum - Mulberry - Pomegranate - Soybean > Mulberry - Soybean > Pomegranate - Mulberry - Soybean > Pomegranate - Soybean > Soybean.

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APPENDICES

APPENDIX - 1

Meteorological data for the experimental site during the period of field studies

Months	Temperature (°C)		Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
	Maximum	Minimum			
1997					
June	29.4	19.0	104.2	64.0	4.4
July	29.2	21.3	69.4	78.0	4.0
August	26.7	20.2	425.0	84.0	3.8
September	27.3	18.1	43.6	75.0	3.4
October	22.5	10.3	45.6	71.0	2.6
1998					
June	31.5	17.9	185.1	57.5	5.3
July	29.3	20.3	206.4	80.0	3.4
August	28.2	20.2	100.8	79.0	3.1
September	27.3	17.8	193.7	81.0	2.8
October	26.3	12.5	264.0	69.0	2.6

Source : Meteorological section , Department of Soil Science and Water Management, Dr. Y.S., Parmar University of Horticulture and Forestry Nauni, Solan (HP)

Appendix - 2

Growth and Yield attributes of soybean as influenced by tree-crop combinations

Tree- crop combinations	1997								1998							
	Growth		Yield						Growth		Yield					
	Plant height (cm)	No. of plants (m ⁻²)	No. of pods (plant ⁻¹)	Grain (gm m ⁻²)	Grain** (q)	Straw (gm m ⁻²)	Straw** (q)	Harvest index** (%)	Plant height (cm)	No. of plants (m ⁻²)	No. of pods (plant ⁻¹)	Grain (gm m ⁻²)	Grain** (q)	Straw (gm m ⁻²)	Straw** (q)	Harvest index** (%)
T ₁	54.67	13.00	30.00	116.00	9.28	288.70	23.10	28.66	52.33	12.00	27.33	109.30	8.75	286.6	22.93	27.61
T ₂	56.00	12.33	29.33	119.70	9.57	295.00	23.60	23.86	57.90	13.67	28.67	112.70	9.01	291.7	23.33	27.83
T ₃	57.33	14.67	32.00	122.30	9.78	297.70	23.31	29.13	56.00	14.33	29.33	116.30	9.31	298.0	23.84	28.31
T ₄	60.00	15.10	32.00	130.70	10.45	312.70	25.10	29.47	59.00	16.33	32.67	122.70	9.81	307.7	24.61	28.51
T ₅	59.00	16.00	32.60	128.70	10.29	310.70	24.85	29.28	62.18	15.00	30.67	121.00	9.68	304.3	24.35	28.44
T ₆	64.25	17.33	34.33	140.30	11.23	323.30	25.87	30.26	63.67	18.33	32.00	133.00	10.64	327.3	26.19	28.89
T ₇	63.00	18.00	35.33	145.70	11.66 (14.57)*	332.70	26.62 (32.93)*	30.46 (30.67)*	65.33	17.33	34.00	140.70	11.26 (14.07)*	335.3	26.82 (33.53)*	29.57 (29.55)*
S.Ed.	0.79	0.98	0.82	1.75	0.14	4.25	0.45	0.13	1.61	1.45	1.22	1.93	0.16	4.83	0.41	0.14
CD _(0.05)	1.72	2.13	1.79	3.82	0.30	9.26	0.98	0.28	3.51	3.15	2.65	4.20	0.35	10.53	0.89	0.30

* Values on the basis of net cropped area of agrihortisilviculture system (0.80 ha.)

** Values in the parentheses are on the basis of net cropped area of sole cropping (1 ha.)

Appendix – 3

Height, diameter and crown spread of mulberry, plum and pomegranate during the soybean crop season (1997)

Tree-crop combin- ations	At sowing of Soybean							At harvesting of Soybean						
	Height (m)	Diameter (cm)	Crown spread (m)					Height (m)	Diameter (cm)	Crown spread (m)				
			East	West	North	South	Mean			East	West	North	South	Mean
Mulberry														
T ₁	3.20	10.55	1.15	0.95	1.20	1.18	1.12	3.52	10.95	1.45	1.22	1.25	1.40	1.36
T ₂	4.48	12.20	1.10	1.05	1.12	1.32	1.15	4.85	12.60	1.52	1.38	1.32	1.55	1.44
T ₃	4.35	15.30	1.22	1.70	1.42	1.28	1.41	4.60	15.65	1.55	1.95	1.82	1.62	1.74
T ₄	4.75	15.42	1.65	1.68	1.65	1.52	1.63	5.10	15.58	1.98	2.10	2.00	1.90	2.00
Mean			1.28	1.35	1.35	1.33				1.63	1.66	1.62	1.62	
T*	S.E.d C'D _{0.05} 0.07 0.16		S.E.d C'D _{0.05} 0.10 0.21					S.E.d C'D _{0.05} 0.13 0.28		S.E.d C'D _{0.05} 0.08 0.18				
D**			0.06 NS							0.04 NS				
T x D			0.22 NS							0.17 NS				
Plum														
T ₁	3.90	9.90	1.10	1.40	0.90	1.42	1.21	4.32	10.05	1.75	1.60	1.15	1.55	1.51
T ₂	4.95	10.65	1.35	2.05	0.98	1.38	1.44	5.22	10.98	2.05	2.55	1.10	1.65	1.84
T ₃	4.72	12.30	1.90	1.98	1.12	1.58	1.65	5.45	12.85	2.20	2.52	1.38	1.92	2.01
Mean			1.45	1.81	1.00	1.46				2.00	2.22	1.21	1.71	
T*	S.E.d C'D _{0.05} 0.13 0.32		S.E.d C'D _{0.05} 0.09 0.20					S.E.d C'D _{0.05} 0.09 0.19		S.E.d C'D _{0.05} 0.12 0.26				
D**			0.06 0.14							0.08 0.18				
T x D			0.21 0.45							0.27 0.58				
Pomegr- anate														
T ₁	2.80	6.95	1.12	1.45	0.95	1.15	1.17	3.10	7.10	1.42	1.65	1.25	1.30	1.41
T ₂	2.72	6.20	1.15	1.32	1.10	1.50	1.27	2.90	6.60	1.38	1.85	1.35	1.65	1.56
T ₃	2.95	7.85	1.35	1.70	1.32	1.45	1.46	3.08	8.05	1.70	2.15	1.60	1.75	1.80
Mean			1.21	1.49	1.12	1.37				1.50	1.88	1.40	1.57	
T*	S.E.d C'D _{0.05} 0.01 NS		S.E.d C'D _{0.05} 0.07 0.16					S.E.d C'D _{0.05} 0.15 NS		S.E.d C'D _{0.05} 0.06 0.12				
D**			0.05 0.10							0.05 0.10				
T x D			0.14 0.30							0.13 0.28				

* Tree-crop combination

** Direction

Appendix – 4

Height, diameter and crown spread of mulberry, plum and pomegranate during the soybean crop season (1998)

Tree-crop	At sowing of Soybean							At harvesting of Soybean						
combinations	Height (m)	Diameter (cm)	Crown spread (m)					Height (m)	Diameter (cm)	Crown spread (m)				
			East	West	North	South	Mean			East	West	North	South	Mean
Mulberry														
T ₁	3.93	11.30	0.95	1.10	0.85	0.90	0.95	4.90	11.90	1.25	1.30	1.05	1.10	1.18
T ₂	4.23	12.75	1.28	1.15	0.80	1.12	1.09	4.96	13.00	2.00	1.45	1.20	1.35	1.50
T ₃	4.87	15.80	1.25	1.98	1.20	1.65	1.52	4.95	15.90	2.20	2.30	1.40	1.70	1.90
T ₄	4.70	15.75	1.85	1.95	1.90	1.67	1.84	5.28	16.25	2.18	2.20	2.05	1.80	2.06
Mean			1.33	1.55	1.19	1.34				1.91	1.81	1.43	1.49	
	S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)					S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)				
T*	0.11	0.25	0.53	1.16				0.06	0.12	0.74	1.62			
D**					0.08	0.18						0.12	0.26	
T x D					0.06	0.14						0.09	0.19	
					0.28	0.62						0.36	0.78	
Plum														
T ₁	4.10	10.30	1.55	1.15	1.20	1.50	1.35	4.93	10.35	1.75	1.25	1.45	1.60	1.51
T ₂	5.46	11.25	1.80	1.50	1.05	1.75	1.53	5.83	11.40	2.00	1.55	1.80	1.82	1.79
T ₄	5.35	13.50	2.15	2.18	1.07	1.90	1.83	5.80	13.80	2.40	2.26	1.82	2.50	2.25
Mean			1.83	1.61	1.11	1.72				2.05	1.69	1.69	1.97	
	S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)					S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)				
T*	0.08	0.18	0.39	0.85				0.04	0.08	0.45	0.98			
D**					0.06	0.12						0.17	0.38	
T x D					0.04	0.09						0.07	0.16	
					0.17	0.38						0.35	0.76	
Pomegr- anate														
T ₁	3.25	7.60	1.10	1.15	1.00	1.50	1.19	3.50	7.90	1.15	1.25	1.05	1.60	1.26
T ₂	2.50	7.00	1.65	1.25	1.30	1.20	1.35	2.70	7.35	1.90	1.40	1.50	1.55	1.59
T ₄	3.85	8.60	1.55	1.75	1.20	1.80	1.58	3.95	8.85	1.75	1.85	1.55	1.84	1.75
Mean			1.43	1.38	1.17	1.50				1.60	1.50	1.37	1.66	
	S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)					S.Ed CD _(0.05)	S.Ed CD _(0.05)	S.Ed CD _(0.05)				
T*	0.20	0.44	0.21	0.45				0.17	0.36	0.24	0.52			
D**					0.08	0.18						0.06	0.13	
T x D					0.05	0.10						0.04	0.08	
					0.15	0.32						0.17	0.36	

* Tree-crop combination

** Direction

Appendix – 5

Effect of tree-crop combinations on nutrient concentration (%) in soybean grain and straw

Tree-crop Combina- tions	1997												1998											
	Grain						Straw						Grain						Straw					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T ₁	4.63	0.22	1.24	0.33	0.17	0.23	1.13	0.07	0.50	0.55	0.33	0.14	4.64	0.23	1.24	0.34	0.19	0.23	1.12	0.07	0.50	0.57	0.33	0.14
T ₂	4.68	0.24	1.26	0.33	0.17	0.26	1.15	0.07	0.51	0.57	0.32	0.16	4.65	0.23	1.23	0.36	0.20	0.25	1.14	0.07	0.52	0.59	0.33	0.15
T ₃	4.68	0.25	1.28	0.33	0.18	0.26	1.17	0.07	0.53	0.57	0.34	0.16	4.67	0.24	1.26	0.35	0.20	0.26	1.16	0.08	0.51	0.60	0.36	0.15
T ₄	4.77	0.27	1.29	0.35	0.17	0.29	1.22	0.08	0.56	0.59	0.35	0.18	4.71	0.26	1.32	0.36	0.21	0.29	1.19	0.08	0.57	0.60	0.36	0.20
T ₅	4.71	0.27	1.30	0.34	0.19	0.28	1.21	0.08	0.56	0.60	0.37	0.17	4.69	0.25	1.27	0.38	0.21	0.28	1.20	0.08	0.56	0.61	0.37	0.16
T ₆	4.75	0.29	1.32	0.36	0.19	0.31	1.25	0.09	0.60	0.63	0.38	0.20	4.73	0.28	1.33	0.38	0.22	0.32	1.24	0.09	0.61	0.62	0.38	0.20
T ₇	4.95	0.30	1.42	0.38	0.20	0.34	1.31	0.10	0.65	0.61	0.38	0.22	4.96	0.30	1.44	0.39	0.22	0.35	1.38	0.11	0.63	0.62	0.38	0.23
S.Ed	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.03	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01
CD _(0.05)	0.06	0.03	0.05	0.03	NS	0.03	0.03	NS	0.04	0.05	0.04	0.03	0.05	0.03	0.04	NS	NS	0.03	0.04	0.02	0.02	NS	0.03	0.02

Appendix - 6

Nutrient concentration (%) in mulberry branch wood and leaf at their harvestable period

Tree-crop Combinat -ions	Branch wood						Leaf					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
1997												
T ₁	0.71	0.08	0.60	1.12	0.15	0.06	2.04	0.12	1.86	3.55	0.77	0.35
T ₂	0.75	0.10	0.64	1.14	0.16	0.07	2.05	0.12	1.86	3.57	0.78	0.38
T ₃	0.77	0.11	0.68	1.15	0.19	0.07	2.06	0.15	1.86	3.61	0.81	0.37
T ₅	0.78	0.11	0.66	1.18	0.18	0.08	2.09	0.14	1.87	3.60	0.83	0.38
S.Ed.	0.014	0.014	0.018	0.014	0.014	0.009	0.014	0.009	0.009	0.009	0.005	0.009
CD _(0.05)	0.03	NS	0.04	0.03	0.03	NS	0.03	0.02	NS	0.02	0.01	0.02
1998												
T ₁	0.72	0.08	0.63	1.16	0.16	0.08	2.02	0.12	1.83	3.62	0.79	0.36
T ₂	0.74	0.08	0.62	1.15	0.16	0.09	2.03	0.13	1.84	3.64	0.81	0.36
T ₃	0.75	0.10	0.66	1.17	0.18	0.07	2.07	0.13	1.85	3.68	0.82	0.37
T ₅	0.76	0.09	0.67	1.19	0.20	0.08	2.07	0.13	1.84	3.68	0.82	0.37
S.Ed.	0.023	0.014	0.023	0.023	0.009	0.009	0.009	0.005	0.014	0.009	0.018	0.009
CD _(0.05)	NS	NS	NS	NS	0.02	NS	0.02	NS	NS	0.02	NS	NS

Appendix - 7

Nutrient concentration in plum pruned wood (%) and fruit (mg/100g fresh wt.) at their respective harvestable period

Tree-crop	Pruned wood						Fruit					
Combinat -ions	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
1997												
T ₁	0.90	0.22	0.80	0.98	0.10	0.04	168.10	14.10	106.55	124.15	24.40	3.40
T ₂	0.93	0.25	0.79	0.99	0.10	0.06	173.15	16.50	106.09	127.95	28.80	3.80
T ₄	0.92	0.25	0.82	1.01	0.12	0.05	172.28	17.25	102.65	128.60	26.20	4.10
S.Ed	0.018	0.014	0.018	0.023	0.014	0.014	1.42	1.12	0.96	1.59	1.20	0.53
CD _(0.05)	NS	NS	NS	NS	NS	NS	3.10	2.45	2.10	3.46	2.62	NS
1998												
T ₁	0.85	0.24	0.76	1.01	0.12	0.05	170.12	16.28	108.18	125.80	26.12	4.15
T ₂	0.86	0.26	0.79	1.00	0.11	0.07	174.20	16.72	107.82	126.38	29.45	4.08
T ₄	0.88	0.25	0.80	1.04	0.14	0.06	175.45	18.51	106.10	129.25	29.42	4.32
S.Ed.	0.018	0.014	0.014	0.018	0.009	0.018	1.19	1.23	0.90	1.14	1.24	0.38
CD _(0.05)	NS	NS	0.03	NS	0.02	NS	2.60	NS	1.96	2.49	2.70	NS

Appendix - 8

Nutrient concentration (%) in mulberry, plum and pomegranate litter under different tree-crop combinations

Tree-crop Combinations	1997						1998					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Mulberry												
T ₁	1.15	0.17	0.98	2.42	0.33	0.26	1.14	0.14	0.97	2.48	0.33	0.28
T ₂	1.18	0.19	0.97	2.46	0.34	0.29	1.16	0.15	1.02	2.56	0.33	0.26
T ₃	1.20	0.20	1.01	2.49	0.36	0.28	1.25	0.15	1.04	2.54	0.35	0.27
T ₄	1.24	0.20	1.06	2.58	0.39	0.30	1.27	0.17	1.11	2.64	0.42	0.32
S.Ed.	0.014	0.018	0.023	0.028	0.014	0.009	0.023	0.009	0.032	0.041	0.009	0.009
CD(0.05)	0.03	NS	0.05	0.06	0.03	0.02	0.05	0.02	0.07	0.09	0.02	0.02
Plum												
T ₁	1.28	0.13	1.16	2.85	0.29	0.11	1.26	0.11	1.14	2.60	0.25	0.10
T ₂	1.30	0.11	1.18	2.89	0.28	0.14	1.31	0.12	1.19	2.63	0.26	0.10
T ₄	1.35	0.014	1.25	2.98	0.32	0.16	1.32	0.15	1.22	2.68	0.28	0.12
S.Ed.	0.018	0.005	0.028	0.041	0.023	0.009	0.014	0.009	0.023	0.023	0.018	0.014
CD(0.05)	0.04	0.01	0.06	0.09	NS	0.02	0.03	0.02	0.05	0.05	NS	NS
Pomegranate												
T ₁	1.19	0.14	0.98	1.37	0.29	0.13	1.21	0.15	0.94	1.40	0.28	0.12
T ₃	1.22	0.16	1.00	1.41	0.30	0.16	1.27	0.19	0.93	1.46	0.27	0.12
T ₆	1.30	0.16	1.04	1.48	0.33	0.18	1.31	0.20	0.99	1.57	0.31	0.15
S.Ed.	0.028	0.014	0.009	0.023	0.009	0.014	0.023	0.014	0.014	0.037	0.023	0.009
CD(0.05)	0.06	NS	0.02	0.05	0.02	0.03	0.05	0.03	0.03	0.08	NS	0.02

Appendix – 9

Effect of tree-crop combinations on pH in 0-15 and 15-30cm soil depth during soybean crop season

Tree-Crop Combina- -tion	1997												1998											
	Soil depth (cm)												Soil depth (cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	6.40	6.00	6.03	6.10	6.20	6.15	6.83	6.60	6.70	6.73	6.80	6.73	6.33	6.13	6.07	6.13	6.23	6.18	6.73	6.47	6.27	6.30	6.53	6.46
T ₂	6.63	6.47	6.27	6.33	6.46	6.43	7.03	6.70	6.63	6.67	6.60	6.73	6.53	6.30	6.13	6.27	6.43	6.33	7.00	6.60	6.53	6.57	6.77	6.69
T ₃	6.60	6.37	6.30	6.43	6.50	6.44	6.93	6.63	6.60	6.57	6.67	6.68	6.50	6.20	6.13	6.20	6.30	6.27	6.73	6.40	6.47	6.57	6.63	6.56
T ₄	6.73	6.60	6.60	6.53	6.63	6.62	7.10	6.73	6.87	6.83	6.90	6.89	6.63	6.40	6.37	6.30	6.47	6.43	6.90	6.70	6.53	6.60	6.77	6.70
T ₅	6.80	6.57	6.63	6.63	6.70	6.67	7.07	6.73	6.83	6.80	6.90	6.87	6.87	6.60	6.63	6.43	6.57	6.62	6.97	6.77	6.63	6.87	6.87	6.82
T ₆	6.60	6.40	6.20	6.23	6.47	6.38	6.97	6.63	6.63	6.60	6.53	6.67	6.50	6.23	6.10	6.23	6.40	6.29	7.00	6.60	6.47	6.43	6.81	6.66
T ₇	7.00	6.73	6.53	6.83	6.90	6.80	7.40	7.07	6.97	7.17	7.17	7.15	6.90	6.80	6.70	6.80	6.87	6.81	7.57	7.40	7.27	7.33	7.47	7.41
Mean	6.68	6.45	6.37	6.44	6.55		7.05	7.73	6.75	6.77	6.80		6.61	6.38	6.31	6.34	6.47		6.99	6.71	6.60	6.67	6.84	

T x D	S.Ed.	CD _(0.05)	S.Ed.	CD _(0.05)
M x D	0.083	0.16	0.084	0.17
T X M X D	0.70	0.14	0.072	0.14
	0.186	0.37	0.190	0.38

Appendix – 10

Effect of tree-crop combinations on per cent organic carbon in 0 - 15 and 15 - 30 cm soil depth during soybean crop season

Tree-crop Combina- -ations	1997												1998											
	Soil depth (cm)												Soil depth (cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	1.08	1.12	1.07	1.02	0.99	1.06	0.89	0.95	0.86	0.81	0.77	0.86	1.07	1.10	1.05	1.01	0.99	1.05	0.87	0.92	0.85	0.77	0.74	0.83
T ₂	1.07	1.08	1.05	1.03	1.02	1.05	0.89	0.93	0.86	0.82	0.80	0.86	1.04	1.05	1.01	0.99	0.98	1.01	0.86	0.89	0.82	0.78	0.75	0.82
T ₃	1.00	1.03	0.97	0.95	0.94	0.98	0.83	0.87	0.84	0.77	0.74	0.81	0.98	1.00	0.96	0.93	0.90	0.95	0.80	0.84	0.79	0.70	0.68	0.76
T ₄	1.10	1.11	1.07	1.04	1.03	1.07	0.92	0.96	0.90	0.86	0.84	0.90	1.08	1.11	1.06	1.04	1.04	1.06	0.89	0.90	0.87	0.84	0.82	0.86
T ₅	1.01	1.02	0.97	0.94	0.94	0.98	0.85	0.87	0.79	0.76	0.75	0.80	0.95	0.97	0.93	0.91	0.89	0.93	0.81	0.84	0.77	0.73	0.70	0.77
T ₆	1.05	1.07	1.04	1.02	1.02	1.04	0.88	0.91	0.87	0.84	0.82	0.86	1.04	1.06	1.03	1.00	0.99	1.02	0.89	0.90	0.86	0.84	0.81	0.86
T ₇	0.89	0.90	0.86	0.84	0.84	0.87	0.80	0.80	0.77	0.75	0.74	0.77	0.84	0.86	0.82	0.81	0.82	0.83	0.78	0.79	0.78	0.76	0.74	0.77
Mean	1.03	1.05	1.00	0.98	0.97		0.86	0.90	0.84	0.80	0.78		1.00	1.02	0.98	0.95	0.94		0.84	0.87	0.82	0.77	0.75	

T x D	S.Ed.	CD _(0.05)	S.Ed.	CD _(0.05)
M x D	0.009	0.02	0.009	0.02
T X M X D	0.007	0.01	0.007	0.01
	0.020	0.04	0.019	0.04

Appendix – 11

Effect of tree-crop combination on available N (Kg ha⁻¹) in 0 -15 and 15 - 30 cm soil depth during soybean crop season

Tree-crop combination	1997												1998											
	Soil depth (cm)												Soil depth (cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	395.70	398.70	404.00	410.30	416.30	405.00	387.70	392.70	396.30	402.70	405.70	397.00	386.70	390.30	400.30	409.30	411.00	399.50	383.30	386.00	391.30	400.70	401.70	392.60
T ₂	400.70	405.00	409.30	420.00	422.00	411.40	390.00	392.70	397.00	403.00	407.70	398.10	389.70	397.30	400.30	409.00	412.00	401.70	386.30	388.30	393.70	399.00	400.70	393.60
T ₃	393.00	395.70	398.70	408.00	409.00	400.90	380.00	384.00	387.70	395.00	396.30	388.60	381.70	384.30	388.30	393.70	400.70	389.70	376.70	379.70	384.00	388.30	390.00	383.70
T ₄	402.70	408.30	414.30	421.70	424.30	414.30	393.70	396.30	400.70	405.70	409.00	401.10	391.00	399.30	402.30	410.30	416.30	403.90	385.30	390.70	397.70	401.30	406.30	396.30
T ₅	392.00	397.70	401.00	405.70	408.70	401.00	384.30	387.30	390.70	394.30	398.70	391.10	381.70	385.00	388.70	395.00	400.70	390.20	378.30	382.70	387.30	394.00	396.00	387.70
T ₆	395.00	398.00	400.00	407.30	410.70	402.20	387.00	389.00	390.30	405.00	407.70	395.90	384.70	390.30	393.70	399.30	408.00	395.20	383.30	385.70	390.70	393.70	398.30	390.30
T ₇	387.70	389.00	391.30	396.30	398.70	392.60	377.70	380.70	382.30	386.30	387.70	382.90	377.30	380.70	382.00	387.70	395.00	384.50	373.30	379.30	381.00	384.00	385.70	380.70
Mean	395.20	398.90	402.70	409.90	412.80		385.80	389.00	392.10	398.90	401.80		384.70	389.60	393.70	400.60	406.20		381.00	384.60	389.40	394.40	397.80	

T x D M x D T X M X D	S.Ed.	CD _(0.05)	S.Ed.	CD _(0.05)
	1.57	3.10	1.49	2.95
	1.32	2.61	1.26	2.49
	3.50	6.92	3.32	6.56

Appendix – 12

Effect of tree-crop combinations on available P (Kg ha⁻¹) in 0-15 and 15-30 cm soil depth during soybean crop season

Tree-crop Combinations	1997												1998											
	Soil depth(cm)												Soil depth(cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	50.33	52.00	45.67	44.67	44.33	47.40	43.33	42.00	38.00	35.67	34.33	38.73	51.67	48.33	46.33	43.67	43.33	46.67	45.00	40.33	39.33	36.00	34.00	38.93
T ₂	52.33	51.67	48.33	47.00	45.67	49.00	45.33	43.00	40.33	37.67	35.00	40.27	51.00	48.67	48.33	47.00	45.67	48.13	45.00	41.67	40.33	37.00	37.00	40.20
T ₃	51.00	48.00	48.00	46.00	45.00	47.60	41.33	36.00	35.00	32.33	30.00	34.93	46.33	47.00	44.67	42.67	44.33	45.00	37.67	34.33	35.00	31.00	30.33	33.67
T ₄	55.67	55.33	53.00	51.67	52.00	53.33	47.00	45.00	43.00	41.00	40.33	43.27	51.67	51.33	49.00	48.33	48.67	49.80	43.67	41.67	41.33	39.67	38.33	40.93
T ₅	50.67	49.00	48.00	47.67	46.67	48.40	39.00	37.67	35.00	33.00	32.33	35.40	49.00	46.33	46.00	44.00	43.33	45.73	37.33	36.00	34.00	31.33	31.67	34.07
T ₆	54.67	52.00	52.33	48.67	50.00	51.33	44.00	39.67	40.33	39.67	36.67	40.07	52.33	50.67	50.33	48.33	49.67	50.27	43.67	38.00	40.00	38.00	36.33	39.27
T ₇	50.67	46.33	45.33	41.67	38.33	44.47	45.33	37.33	38.67	36.32	27.33	37.00	48.67	45.33	43.00	40.67	39.67	43.47	38.00	35.33	31.00	27.67	25.00	31.40
Mean	52.19	50.62	48.67	46.76	46.00		43.62	40.14	38.62	36.52	33.71		50.10	48.24	46.81	44.95	44.95		41.48	38.19	37.33	34.38	33.24	
T x D	S.Ed.						CD _(0.05)						S.Ed.						CD _(0.05)					
M x D	0.94						1.86						0.91						1.80					
T X M X D	2.11						4.17						2.03						4.01					

Appendix – 13

Effect of tree-crop combinations on available K (kg ha⁻¹) in 0-15 and 15-30 cm soil depth during soybean crop season

Tree – crop combinations	1997												1998											
	Soil depth(cm)												Soil depth(cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	365.30	361.00	358.00	348.70	349.00	356.48	341.00	339.30	336.70	330.00	332.00	335.80	363.70	358.30	354.30	349.00	342.30	353.50	342.30	338.30	335.00	330.70	330.30	335.30
T ₂	377.00	371.30	367.70	360.30	361.00	367.50	348.30	344.30	343.70	339.30	338.30	342.80	370.70	363.30	361.70	356.30	354.00	361.10	345.70	342.30	340.00	334.70	335.30	339.60
T ₃	354.30	349.30	344.30	338.70	337.70	344.90	335.00	332.00	329.00	325.30	327.30	329.70	349.30	346.70	340.00	337.70	336.30	342.00	337.00	331.00	330.00	326.00	325.30	330.00
T ₄	378.30	376.70	373.70	365.70	367.00	372.30	352.00	350.00	346.00	342.00	348.00	347.70	378.00	368.00	369.00	362.00	353.00	366.00	350.00	344.00	345.00	352.00	336.00	345.40
T ₅	357.30	353.70	347.30	341.70	345.70	349.10	344.30	336.30	337.70	332.70	333.30	336.90	353.70	349.70	343.70	338.00	343.00	345.60	339.00	333.00	334.00	333.00	329.00	333.80
T ₆	358.30	355.30	350.30	345.30	347.30	351.30	342.00	338.00	337.30	335.00	333.70	337.20	361.00	353.70	354.00	347.00	348.70	353.00	339.70	334.30	335.30	332.00	332.30	334.70
T ₇	355.70	346.70	343.70	335.70	332.30	342.80	335.00	329.00	327.70	322.70	320.00	326.90	355.70	343.70	337.70	331.70	328.30	339.40	333.00	325.00	323.00	319.70	315.30	323.20
Mean	363.80	359.10	355.00	348.00	348.60		342.50	338.40	337.00	332.40	333.20		361.70	354.80	351.50	346.00	343.70		341.00	335.40	334.70	332.70	329.10	

	S.Ed.	CD _(0.05)	S.Ed.	CD _(0.05)
T x D	1.71	3.35	1.61	3.18
M x D	1.44	2.85	1.36	2.69
T X M X D	3.81	7.53	3.59	7.10

Appendix – 14

Effect of tree-crop combinations on exchangeable Ca (kg ha^{-1}) in 0-15 and 15-30 cm soil depth during soybean crop season

Tree - crop combinations	1997												1998											
	Soil depth(cm)												Soil depth(cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	2861	2853	2843	2837	2843	2847	3110	3106	3097	3083	3082	3096	2846	2842	2837	2835	2832	2839	3100	3092	3084	3080	3078	3087
T ₂	2857	2854	2848	2845	2840	2849	3102	3063	3090	3087	3080	3085	2846	2842	2834	2831	2830	2837	3094	3117	3109	3105	3068	3099
T ₃	2856	2850	2843	2840	2838	2845	3097	3082	3072	3069	3071	3078	2850	2846	2840	2839	2834	2842	3088	3081	3074	3072	3067	3077
T ₄	2853	2850	2849	2848	2846	2849	3093	3089	3084	3083	3080	3086	2851	2844	2842	2840	2841	2844	3088	3084	3080	3076	3074	3081
T ₅	2850	2845	2841	2839	2838	2843	3089	3081	3077	3074	3071	3078	2847	2844	2841	2839	2839	2842	3087	3081	3074	3073	3071	3077
T ₆	2854	2850	2847	2845	2845	2849	3091	3083	3079	3075	3073	3080	2850	2848	2846	2844	2843	2846	3084	3078	3074	3076	3071	3077
T ₇	2841	2835	2830	2825	2823	2831	3083	3078	3072	3069	3067	3074	2831	2827	2822	2820	2819	2824	3070	3063	3059	3045	3054	3058
Mean	2853	2848	2843	2840	2839		3095	3083	3082	3077	3075		2846	2842	2838	2834	2834		3087	3085	3079	3075	3069	
T x D	S.Ed.						CD _(0.05)						S.Ed.						CD _(0.05)					
M x D	3.65						7.22						5.59						11.05					
T X M X D	3.08						6.09						4.73						9.35					
	8.16						16.13						12.50						24.72					

Appendix – 15

Effect of tree-crop combinations on exchangeable Mg in 0-15 and 15-30 cm soil depth during soybean crop season

Tree-crop combinations	1997												1998											
	Soil depth(cm)												Soil depth(cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	1528	1521	1517	1514	1510	1518	1853	1842	1834	1827	1828	1837	1523	1519	1516	1513	1511	1516	1845	1839	1834	1830	1828	1835
T ₂	1529	1526	1522	1520	1519	1523	1849	1843	1840	1836	1833	1840	1521	1514	1509	1506	1502	1510	1840	1832	1823	1821	1818	1827
T ₃	1525	1523	1520	1518	1515	1520	1846	1842	1839	1837	1834	1839	1527	1522	1518	1514	1511	1518	1846	1838	1834	1830	1829	1835
T ₄	1524	1522	1519	1517	1522	1521	1846	1842	1840	1838	1836	1840	1521	1517	1514	1513	1513	1516	1840	1834	1830	1827	1826	1832
T ₅	1517	1513	1510	1509	1509	1512	1836	1829	1825	1822	1820	1826	1516	1511	1510	1507	1506	1510	1833	1827	1822	1818	1814	1823
T ₆	1522	1519	1515	1512	1510	1516	1837	1832	1821	1818	1817	1825	1523	1519	1517	1514	1512	1517	1834	1828	1824	1822	1820	1826
T ₇	1513	1510	1506	1501	1499	1506	1826	1820	1812	1809	1806	1815	1505	1503	1499	1496	1494	1499	1820	1815	1808	1805	1802	1810
Mean	1523	1519	1516	1513	1512		1842	1836	1830	1827	1825		1519	1515	1512	1509	1507		1837	1830	1825	1822	1820	
T x D	S.Ed.						CD _(0.05)						S.Ed.						CD _(0.05)					
M x D	2.33						4.61						2.18						4.31					
T X M X D	1.97						3.89						1.84						3.64					
	5.21						10.30						4.87						9.63					

Appendix – 16

Effect of tree-crop combinations on available S (kg ha⁻¹) in 0-15 and 15-30 cm soil depth during soybean crop season

Tree-crop combinations	1997												1998											
	Soil depth(cm)												Soil depth(cm)											
	0-15						15-30						0-15						15-30					
	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean	June	July	Aug.	Sept.	Oct.	Mean
T ₁	41.67	39.33	37.00	32.67	33.00	36.73	40.00	38.00	33.33	31.33	30.00	34.53	40.67	36.67	37.00	33.33	30.33	35.60	36.33	34.33	33.00	29.00	26.33	31.80
T ₂	43.00	42.00	36.33	34.33	32.33	37.60	37.00	36.33	31.67	30.67	30.00	33.13	39.67	36.00	36.00	35.00	33.00	35.93	35.67	32.67	30.67	29.00	28.00	31.20
T ₃	38.33	34.00	36.33	29.67	28.00	33.27	33.67	30.00	30.00	25.33	24.33	28.67	35.00	33.00	32.00	29.67	29.67	31.87	33.67	30.33	27.00	28.67	23.67	28.67
T ₄	44.00	40.67	40.00	37.33	36.33	39.67	43.67	38.67	37.33	34.00	32.33	37.20	41.00	38.33	39.00	36.00	34.33	37.73	38.00	33.67	34.00	31.33	30.00	33.40
T ₅	37.33	36.00	33.00	31.67	30.67	33.73	34.67	32.00	30.00	28.00	26.00	30.13	34.00	34.00	32.00	29.33	27.00	31.27	32.00	28.33	27.67	24.67	23.00	27.13
T ₆	40.00	38.00	38.00	36.00	34.67	37.33	36.67	34.33	34.00	32.33	32.00	33.87	38.33	37.00	37.00	35.00	35.00	36.47	36.00	32.67	31.67	30.67	27.67	31.73
T ₇	35.67	30.00	30.00	27.33	26.67	29.93	35.00	27.00	28.00	25.00	23.00	27.60	31.00	28.33	26.00	24.00	23.67	26.60	27.67	21.67	21.00	19.67	18.67	21.73
Mean	40.00	37.14	35.81	32.71	31.67		37.14	33.86	32.05	29.52	28.24		37.10	34.76	34.14	31.76	30.43		34.19	30.52	29.29	27.57	25.33	
T x D	S.Ed. 0.77						CD _(0.05) 1.52						S.Ed. 0.75						CD _(0.05) 1.48					
M x D	0.65						1.29						0.63						1.25					
T X M X D	1.73						3.42						1.67						3.30					

Appendix – 17

Amount of nutrient added (kg ha⁻¹) by mulberry, plum and pomegranate litter under different tree-crop combinations

Tree-crop	1997						1998						Pooled					
Combinations	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Mulberry																		
T ₁	0.73	0.11	0.62	1.54	0.21	0.17	0.62	0.08	0.53	1.34	0.18	0.15	0.68	0.10	0.58	1.44	0.20	0.16
T ₂	1.22	0.20	1.00	2.55	0.35	0.30	1.29	0.17	1.13	2.85	0.37	0.29	1.26	0.19	1.07	2.70	0.36	0.30
T ₃	1.60	0.27	1.35	3.33	0.48	0.37	1.92	0.23	1.60	3.90	0.54	0.41	1.76	0.25	1.48	3.62	0.51	0.39
T ₅	3.91	0.63	3.34	8.13	1.23	0.95	4.40	0.59	3.85	9.14	1.45	1.11	4.16	0.61	3.60	8.64	1.34	1.03
S.Ed.	0.11	0.03	0.09	0.25	0.04	0.03	0.08	0.02	0.12	0.36	0.03	0.04	0.07	0.02	0.06	0.21	0.02	0.02
CD _(0.05)	0.24	0.06	0.19	0.55	0.09	0.06	0.18	0.05	0.26	0.78	0.07	0.08	0.15	0.04	0.12	0.46	0.05	0.04
Plum																		
T ₁	4.48	0.46	4.06	9.98	1.02	0.39	4.48	0.39	4.05	9.24	0.89	0.36	4.48	0.43	4.06	9.61	0.96	0.38
T ₂	8.99	0.76	8.16	19.98	1.94	0.97	8.81	0.81	8.00	17.69	1.75	0.67	8.90	0.79	8.08	18.84	1.85	0.82
T ₄	20.74	2.15	19.20	45.77	4.92	2.46	20.96	2.38	19.37	42.56	4.45	1.91	20.85	2.27	19.29	44.17	4.69	2.19
S.Ed.	0.78	0.07	0.37	1.49	0.24	0.11	0.71	0.09	0.36	1.33	0.17	0.09	0.51	0.06	0.31	1.03	0.12	0.07
CD _(0.05)	1.70	0.15	0.80	3.24	0.53	0.24	1.55	0.20	0.78	2.90	0.38	0.19	1.12	0.12	0.67	2.24	0.26	0.16
Pomegranate																		
T ₁	2.19	0.26	1.80	2.52	0.53	0.24	1.84	0.23	1.43	2.13	0.43	0.18	2.02	0.25	1.62	2.33	0.48	0.21
T ₃	4.11	0.54	3.37	4.75	1.01	0.54	4.42	0.66	3.24	5.09	0.94	0.42	4.27	0.60	3.31	4.92	0.98	0.48
T ₆	10.58	1.30	8.46	12.04	2.68	1.46	10.37	1.58	7.83	12.43	2.45	1.19	10.48	1.44	8.15	12.24	2.57	1.33
S.Ed.	0.44	0.07	0.28	0.65	0.15	0.12	0.30	0.08	0.34	0.76	0.14	0.15	0.25	0.06	0.24	0.48	0.12	0.11
CD _(0.05)	0.95	0.16	0.61	1.42	0.33	0.27	0.66	0.18	0.75	1.65	0.31	0.32	0.54	0.12	0.53	1.05	0.26	0.23

Appendix - 18

Amount of nutrients added (kg ha⁻¹) to the soil through different sources (Pooled data for two years)

[illegible]

Appendix - 19

Effect of tree-crop combinations on nutrient removal (kg ha⁻¹) by soybean grain and Straw (Pooled data for two years)

Tree-crop Combinations	Grain						Straw					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T ₁	41.77	2.04	11.18	3.02	1.59	2.09	25.89	1.61	11.55	12.93	7.60	3.18
T ₂	43.37	2.18	11.60	3.21	1.72	2.34	26.87	1.60	12.09	13.57	7.74	3.64
T ₃	44.62	2.32	12.14	3.28	1.80	2.45	27.72	1.75	12.39	13.90	8.34	3.61
T ₄	48.07	2.70	13.24	3.58	1.93	2.94	29.86	2.03	13.94	14.76	8.73	4.76
T ₅	46.94	2.60	12.83	3.60	2.01	2.80	29.56	1.93	13.82	14.88	9.06	4.06
T ₆	51.84	3.10	14.52	4.03	2.22	3.48	32.45	2.34	15.75	16.27	9.80	5.21
T ₇	70.94	4.30	20.47	5.49	3.05	4.89	44.58	3.38	21.28	20.55	12.52	7.48
S.Ed.	0.77	0.12	0.26	0.12	0.10	0.12	0.47	0.23	0.48	0.31	0.34	0.24
CD _(0.05)	1.68	0.26	0.57	0.26	0.21	0.26	1.02	0.51	1.05	0.67	0.74	0.52

Appendix - 20

Nutrient removal (kg ha⁻¹) through harvestable biomass of mulberry and plum (Pooled data for two years)

Tree-crop Combina- tions	Branch wood						Leaf					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Mulberry												
T ₁	15.96	1.77	13.75	25.27	3.55	1.55	9.01	0.53	8.21	15.94	3.46	1.60
T ₂	26.48	3.18	22.24	40.60	5.65	2.82	14.28	0.91	12.95	25.27	5.60	2.59
T ₃	27.97	4.05	24.66	42.69	6.99	2.58	18.26	1.23	16.41	32.19	7.23	3.26
T ₅	67.38	8.75	58.63	104.13	16.63	7.00	41.43	2.79	37.05	72.51	16.53	7.57
S.Ed	1.19	0.44	0.96	1.02	0.41	0.28	1.79	0.25	1.54	1.94	0.82	0.29
CD _(0.05)	2.60	0.96	2.10	2.22	0.90	0.60	3.91	0.54	3.35	4.22	1.78	0.64
	Pruned wood						Fruit					
Plum												
T ₁	12.16	3.18	10.78	13.82	1.52	0.69	3.14	0.28	1.99	2.32	0.47	0.07
T ₂	19.44	5.62	17.06	21.60	2.38	1.51	5.69	0.54	3.50	4.17	0.95	0.13
T ₄	40.86	11.35	36.77	46.76	5.90	2.72	13.60	1.40	8.16	10.08	2.17	0.33
S.Ed	1.95	0.85	1.53	1.87	0.28	0.24	0.83	0.10	0.39	0.47	0.14	0.02
CD _(0.05)	4.25	1.85	3.34	4.08	0.62	0.53	1.80	0.22	0.85	1.02	0.30	0.03

Appendix - 21

NPK removal (kg ha⁻¹) through harvestable biomass of different components (Pooled data for two years)

Components	N							P							K						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
A)Soybean																					
- Grain	41.77	43.37	44.62	48.07	46.94	51.84	70.94	2.04	2.18	2.32	2.70	2.60	3.10	4.30	11.18	11.60	12.14	13.24	12.83	14.52	20.47
- Straw	25.89	26.87	27.72	29.86	29.56	32.45	44.58	1.61	1.60	1.75	2.03	1.93	2.34	3.38	11.55	12.09	12.39	13.94	13.82	15.75	21.28
Sub total	67.66	70.24	72.34	77.93	76.5	84.29	115.52	3.65	3.78	4.07	4.73	4.53	5.44	7.68	22.73	23.69	24.53	27.18	26.65	30.27	41.75
B)Plum																					
- Pruned wood	12.16	19.44	-	40.86	-	-	-	3.18	5.62	-	11.35	-	-	-	10.78	17.06	-	36.77	-	-	-
- Fruit	3.14	5.69	-	13.60	-	-	-	0.28	0.54	-	1.40	-	-	-	1.99	3.50	-	8.16	-	-	-
Sub total	15.3	25.13		54.46				3.46	6.16		12.75				12.77	20.56		44.93			
C)Mulberry																					
- Branch wood	15.96	26.48	27.97	-	67.38	-	-	1.77	3.18	4.05	-	8.75	-	-	13.75	22.24	24.66	-	58.63	-	-
- Leaf	9.01	14.28	18.26	-	41.43	-	-	0.53	0.91	1.23	-	2.79	-	-	8.21	12.95	16.41	-	37.05	-	-
Sub total	24.97	40.76	46.23		108.81			2.30	4.09	5.28		11.54			21.96	35.19	41.07		95.68		
D)Pomegranate																					
Total	107.93	136.13	118.57	132.39	185.31	84.29	115.52	9.41	14.03	9.35	17.48	16.07	5.44	7.68	57.46	79.44	65.60	72.11	122.33	30.27	41.75

Appendix – 22

Ca Mg S removal (kg ha⁻¹) through harvestable biomass of different components (Pooled data for two years)

Components	Ca							Mg							S						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
A) Soybean																					
- Grain	3.02	3.21	3.28	3.58	3.60	4.03	5.49	1.59	1.72	1.80	1.93	2.01	2.22	3.05	2.09	2.34	2.45	2.94	2.80	3.48	4.89
- Straw	12.93	13.57	13.90	14.76	14.88	16.27	20.35	7.60	7.74	8.34	8.73	9.06	9.80	12.52	3.18	3.64	3.61	4.76	4.06	5.21	7.48
Sub total	15.95	16.78	17.18	18.34	18.48	20.3	25.84	9.19	9.46	10.14	10.66	11.07	12.02	15.57	5.27	5.98	6.06	7.7	6.86	8.69	12.37
B) Plum																					
- Pruned wood	13.82	21.60	-	46.76	-	-	-	1.52	2.38	-	5.90	-	-	-	0.69	1.51	-	2.72	-	-	-
- Fruit	2.32	4.17	-	10.08	-	-	-	0.47	0.95	-	2.17	-	-	-	0.07	0.13	-	0.33	-	-	-
Sub total	16.14	25.77		56.84				1.99	3.33		8.07				0.76	1.64		3.05			
C) Mulberry																					
- Branch wood	25.27	40.60	42.69	-	104.13	-	-	3.55	5.65	6.99	-	16.63	-	-	1.55	2.82	2.58	-	7.00	-	-
- Leaf	15.94	25.27	32.19	-	72.51	-	-	3.46	5.60	7.23	-	16.53	-	-	1.60	2.59	3.26	-	7.57	-	-
Sub total	41.21	65.87	74.88		176.64			7.01	11.25	14.22		33.16			3.15	5.41	5.84		14.57		
D) Pomegranate																					
Total	73.30	108.42	92.06	75.18	195.12	20.30	25.84	18.19	24.04	24.36	18.73	44.23	12.02	15.57	9.18	13.03	11.90	10.75	21.43	8.69	12.37

Appendix – 23
NPK balance in soil due to different tree-crop combinations

Tree-crop combinations	1997							1998						
	Initial status	Amount added	Total amount (initial+added)	Cumulative removal (trees+crop)	Expected balance	Actual balance	Net gain or loss	Initial status	Amount added	Total amount (initial + added)	Cumulative removal (trees+crop)	Expected balance	Actual balance	Net gain or loss
Available N														
T ₁	391.70	122.20	513.90	106.37	407.53	411.00	+3.47	385.00	121.74	506.74	109.06	397.68	406.30	+8.62
T ₂	395.30	178.21	573.51	133.78	439.73	414.80	-24.93	388.00	178.10	566.10	137.70	428.40	406.30	-22.10
T ₃	386.50	13.71	400.21	112.39	287.82	402.70	+114.88	379.20	14.34	393.54	124.57	268.97	395.30	+126.33
T ₄	398.20	348.74	746.94	134.15	612.79	416.70	-196.09	388.20	348.96	737.16	130.42	606.74	411.30	-195.44
T ₅	388.20	11.91	400.11	171.79	228.32	403.70	+175.38	380.00	12.40	392.40	198.69	193.71	398.30	+204.59
T ₆	391.00	18.58	409.58	85.75	323.83	409.20	+85.37	384.00	18.37	402.37	82.85	319.52	403.20	+83.68
T ₇	382.70	10.00	392.70	115.13	277.57	393.20	+115.63	375.30	10.00	385.30	115.94	269.36	390.30	+120.94
Available P														
T ₁	47.17	68.62	115.79	8.75	107.04	39.33	-67.71	44.33	68.49	112.82	10.10	102.72	38.67	-64.05
T ₂	47.33	90.56	137.89	13.32	124.57	40.33	-84.24	45.17	90.58	135.75	14.41	121.34	41.33	-80.01
T ₃	42.00	24.81	66.81	8.64	58.17	37.50	-20.67	40.67	24.89	65.56	9.62	55.94	37.33	-18.61
T ₄	50.17	157.35	207.52	16.72	190.80	46.17	-144.63	46.50	157.38	203.88	18.21	185.67	43.50	-142.17
T ₅	43.33	24.63	67.96	15.30	52.66	39.50	-13.16	41.17	24.59	65.76	16.37	49.39	37.50	-11.89
T ₆	45.83	25.30	71.13	5.63	65.50	43.33	-22.17	44.33	25.58	69.91	5.25	64.66	43.00	-21.66
T ₇	41.83	30.00	71.83	7.56	64.27	32.83	-31.34	40.33	30.00	70.33	7.80	62.53	32.33	-30.20
Available K														
T ₁	350.20	139.95	490.15	54.82	435.33	340.50	-94.83	348.30	139.48	487.78	59.84	427.94	336.30	-91.64
T ₂	357.80	197.16	554.96	75.99	478.97	349.70	-129.27	352.80	197.13	549.93	82.81	467.12	344.70	-122.42
T ₃	340.70	28.72	369.42	59.62	309.80	332.50	+22.70	338.80	28.84	367.64	71.36	296.28	330.80	+34.52
T ₄	363.30	371.20	734.50	70.54	663.96	357.50	-306.46	356.00	371.37	727.37	73.52	653.85	344.50	-309.35
T ₅	345.00	27.34	372.34	107.98	264.36	339.50	+75.14	341.30	27.85	369.15	135.76	233.39	336.00	+102.61
T ₆	346.70	32.46	379.16	30.38	348.78	340.50	-8.28	344.00	31.83	375.83	30.16	345.67	340.50	-5.17
T ₇	337.80	30.00	367.80	42.05	325.75	326.20	+0.45	334.30	30.00	364.30	41.46	322.84	321.80	-1.04

Appendix – 24
Ca Mg S balance in soil due to different tree-crop combinations

Tree-crop combinations	1997							1998						
	Initial status	Amount added	Total amount (initial+added)	Cumulative removal (trees+crop)	Expected balance	Actual balance	Net gain or loss	Initial status	Amount added	Total amount (initial + added)	Cumulative removal (trees+crop)	Expected balance	Actual balance	Net gain or loss
Exchangeable Ca														
T ₁	2985	163.72	3148.72	67.28	3081.44	2962	-119.44	2973	162.39	3135.39	79.26	3056.13	2955	-101.13
T ₂	2980	228.09	3208.09	100.32	3107.77	2960	-147.77	2970	226.10	3196.10	115.93	3080.17	2949	-131.17
T ₃	2976	46.04	3022.04	78.32	2943.72	2955	+11.28	2969	46.95	3015.95	105.93	2910.02	2950	+39.98
T ₄	2973	418.93	3391.93	71.77	3320.16	2963	-357.16	2970	415.72	3385.72	78.30	3307.42	2958	-349.42
T ₅	2969	46.09	3015.09	166.78	2848.31	2954	+105.69	2967	47.10	3014.10	223.20	2790.90	2955	+164.10
T ₆	2972	50.00	3022.00	20.43	3001.57	2959	-42.57	2967	50.39	3017.39	20.16	2997.23	2957	-40.23
T ₇	2962	47.55	3009.55	25.70	2983.85	2945	-38.85	2950	47.55	2997.55	26.39	2971.16	2937	-34.16
Exchangeable Mg														
T ₁	1690	18.48	1708.48	17.08	1691.40	1669	-22.40	1684	18.22	1702.22	19.10	1683.12	1670	-13.12
T ₂	1689	26.85	1715.85	22.64	1693.21	1676	-17.21	1680	26.68	1706.68	25.18	1681.50	1660	-21.50
T ₃	1685	2.49	1687.49	21.56	1665.93	1674	+8.07	1686	2.48	1688.48	26.68	1661.80	1670	+8.20
T ₄	1685	53.03	1738.03	17.85	1720.18	1679	-41.18	1681	52.56	1733.56	19.65	1713.91	1669	-44.91
T ₅	1676	2.23	1678.23	38.34	1639.89	1664	+24.11	1674	2.45	1676.45	50.16	1626.29	1660	+33.71
T ₆	1680	3.68	1683.68	11.87	1671.81	1664	-7.81	1679	3.45	1682.45	12.16	1670.29	1666	-4.29
T ₇	1669	1.25	1670.25	15.37	1654.88	1652	-2.88	1662	1.25	1663.25	15.78	1647.47	1648	+0.53
Available S														
T ₁	38.67	62.13	100.80	8.50	92.30	31.50	-60.80	35.50	62.19	97.69	9.76	87.93	28.33	-59.60
T ₂	39.50	86.22	125.72	12.37	113.35	31.17	-82.18	34.33	85.91	120.24	13.60	106.64	30.50	-76.14
T ₃	32.00	15.50	47.50	11.01	36.49	26.17	-10.32	31.67	15.42	47.09	12.79	34.40	26.67	-7.63
T ₄	39.67	157.76	197.43	10.01	187.42	34.33	-153.09	36.00	157.21	193.21	11.09	182.12	32.17	-149.95
T ₅	34.00	15.54	49.54	19.45	30.09	28.33	-1.76	31.17	15.70	46.87	23.18	23.69	25.00	+1.31
T ₆	36.17	16.05	52.22	8.70	43.52	33.33	-10.19	34.83	15.78	50.61	8.68	41.93	31.33	-10.60
T ₇	28.50	18.23	46.73	12.14	34.59	24.83	-9.76	25.00	18.23	43.23	12.60	30.63	21.17	-9.46

Appendix – 25

Effect of tree-crop combinations on per cent soil moisture content in 0-15 and 15-30 cm soil depth during soybean crop season

Tree-crop combinations	1997										1998									
	Soil depth (cm)										Soil depth (cm)									
	0-15					15-30					0-15					15-30				
	July	Aug.	Sept.	Oct.	Mean	July	Aug.	Sept.	Oct.	Mean	July	Aug.	Sept.	Oct.	Mean	July	Aug.	Sept.	Oct.	Mean
T ₁	8.65	17.33	10.47	6.63	10.77	7.48	16.79	12.10	6.84	10.80	13.06	14.42	17.20	5.75	12.61	12.89	11.93	18.49	7.56	12.72
T ₂	8.82	17.53	10.58	6.87	10.95	7.58	16.86	12.37	6.94	10.94	13.12	14.73	17.57	5.91	12.83	13.06	12.12	19.09	7.72	13.00
T ₃	9.06	17.65	10.76	7.05	11.13	7.71	17.01	12.93	7.04	11.17	13.53	14.92	17.97	6.00	13.11	13.19	12.45	19.41	7.87	13.23
T ₄	9.36	17.80	10.90	7.10	11.29	8.01	17.35	12.98	7.38	11.43	13.60	15.23	18.25	6.35	13.36	13.40	12.71	19.60	8.36	13.52
T ₅	9.19	17.73	10.85	7.28	11.26	7.82	17.43	13.01	7.62	11.47	13.66	15.05	18.60	6.51	13.46	13.29	12.61	19.72	8.65	13.57
T ₆	9.74	17.96	11.06	7.34	11.53	8.54	17.58	13.08	7.70	11.71	13.87	15.82	18.76	6.73	13.79	13.53	12.81	19.89	8.76	13.75
T ₇	10.06	18.14	11.21	6.71	11.53	9.14	17.75	13.16	6.83	11.72	14.24	15.98	18.96	5.56	13.69	14.00	13.04	20.02	7.40	13.62
Mean	9.27	17.73	10.83	7.00		8.04	17.25	12.80	7.19		13.58	15.16	18.19	6.12		13.34	12.52	19.46	8.04	

T x D	S.Ed.	CD _(0.05)	S.Ed.	CD _(0.05)
M x D	0.073	0.15	0.069	0.14
T x M x D	0.056	0.11	0.052	0.10
	0.147	0.29	0.138	0.27

Appendix – 26

Total biomass (q ha⁻¹) due to different tree-crop combinations

Components	1997							1998						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
Soybean														
Grain	9.28	9.57	9.79	10.45	10.29	11.23	14.57	8.75	9.01	9.31	9.81	9.68	10.64	14.07
Straw	23.10	23.60	23.81	25.01	24.85	25.87	32.93	22.93	23.33	23.84	24.61	24.35	26.19	33.53
Sub-Total	32.38	33.17	23.60	35.46	35.14	37.10	47.50	31.68	32.34	33.15	34.42	34.03	36.83	47.60
Mulberry														
Leaf	14.01	22.20	22.80	-	55.20	-	-	15.49	24.40	36.00	-	77.60	-	-
Fuel wood	18.96	31.60	32.00	-	75.20	-	-	25.37	39.00	41.60	-	100.00	-	-
Sub-total	32.97	53.70	54.80	-	130.40	-	-	40.86	63.40	77.60		177.60	-	-
Plum														
Fruit	22.70	36.80	-	94.00	-	-	-	14.42	28.72	-	62.40	-	-	-
Pruning wood	12.68	19.40	-	40.80	-	-	-	14.95	23.80	-	50.00	-	-	-
Sub-Total	35.38	56.20	-	134.80	-	-	-	29.37	52.52	-	112.40	-	-	-
Pomegranate														
Nil	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	100.73	143.07	88.40	170.26	165.54	37.10	47.50	101.91	148.26	110.75	146.82	211.63	36.83	47.60

Appendix – 27

Gross returns (Rs. ha⁻¹) due to different tree-crop combinations

Components	1997							1998						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
Soybean														
Grain	9280.00	9570.00	9790.00	10450.00	10290.00	11230.00	14570.00	8750.00	9010.00	9310.00	9810.00	9680.00	10640.00	14070.00
Straw	693.00	708.00	714.30	750.30	745.50	776.10	987.90	687.90	699.90	715.20	738.30	730.50	785.70	1005.90
Sub-Total	9973.00	10278.00	10504.30	11200.30	11035.50	12006.10	15557.90	9437.90	9709.90	10025.20	10548.30	10410.50	11425.70	15075.90
Mulberry														
Leaf	630.45	999.00	1026.00	-	2484.00	-	-	774.50	1220.00	1800.00	-	3880.00	-	-
Fuel wood	2502.72	4171.20	4224.00	-	9926.40	-	-	3348.84	5148.00	5491.20	-	13200.00	-	-
Sub-total	3133.17	5170.20	5250.00	-	12410.40	-	-	4123.34	6368.00	7291.20	-	17080.00	-	-
Plum														
Fruit	13620.00	22080.00	-	56400.00	-	-	-	11536.00	22976.00	-	49920.00	-	-	-
Pruning wood	1597.68	2444.40	-	5140.80	-	-	-	1883.70	2998.80	-	6300.00	-	-	-
Sub-Total	15217.68	24524.40	-	61540.80	-	-	-	13419.70	25974.80	-	56220.00	-	-	-
Pomegranate														
Nil	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	28323.85	39972.60	15754.30	72741.10	23445.90	12006.10	15557.90	26980.94	42052.70	17316.40	66768.30	27490.50	11425.70	15075.90

Appendix – 28

Total biomass and gross returns due to different tree-crop combinations (Pooled data for two years)

Components	Total biomass (q ha ⁻¹)							Gross returns (Rs. ha ⁻¹)						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
Soybean														
Grain	9.02	9.29	9.55	10.13	9.99	10.94	14.32	9015.00	9290.00	9550.00	10130.00	9985.00	10935.00	14320.00
Straw	23.02	23.47	23.83	24.81	24.60	26.03	33.23	690.45	703.95	714.75	744.30	738.00	780.90	996.90
Sub-Total	32.04	32.76	33.38	34.94	34.59	36.97	47.55	9705.45	9993.95	10264.75	10874.30	10723.00	11715.90	15316.90
Mulberry														
Leaf	14.75	23.30	29.40	-	66.40	-	-	702.48	1109.50	1413.00	-	3182.00	-	-
Fuel wood	22.17	35.30	36.80	-	87.60	-	-	2925.78	4659.60	4857.60	-	11563.20	-	-
Sub-total	36.92	58.06	66.20	-	154.00	-	-	3628.26	5769.10	6270.60	-	14745.20	-	-
Plum														
Fruit	18.56	32.76	-	78.20	-	-	-	12578.00	22528.00	-	53160.00	-	-	-
Pruning wood	13.82	21.60	-	45.40	-	-	-	1740.69	2721.60	-	5720.40	-	-	-
Sub-Total	32.38	54.36	-	123.60	-	-	-	14318.69	25249.60	-	58880.40	-	-	-
Pomegranate														
Nil	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	101.34	145.72	99.58	158.54	188.59	36.97	47.55	27652.40	41012.65	16535.35	69754.70	25468.20	11715.90	15316.90

Appendix – 29

Total biomass, total costs, gross returns and net returns due to different tree-crop combinations

	1997							1998						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇
Total biomass (q ha⁻¹)	100.73	143.07	88.40	170.26	165.54	37.10	47.50	101.91	148.26	110.75	146.82	211.63	36.83	47.60
Total costs (Rs. ha⁻¹)	13113.88	16670.88	6920.88	25505.88	7835.88	6005.88	7507.35	13784.48	17523.48	7332.48	26694.48	8352.48	6312.48	7890.60
Gross returns (Rs. ha⁻¹)	28323.85	39972.60	15754.30	72741.10	23445.90	12006.10	15557.90	26980.94	42052.70	17316.40	66768.30	27490.50	11425.70	15075.90
Net returns (Rs. ha⁻¹)	15209.97	23301.72	8833.42	47235.22	15610.02	6000.22	8050.55	13196.46	24529.22	9983.92	40073.82	19138.02	5113.22	7185.30

APPENDIX - 30

Cost of cultivation of Soybean

Particulars	Operational input (ha ⁻¹)	T ₁ - T ₆ (Rs.)*		T ₇ (Rs.)*	
		1997	1998	1997	1998
Seed	70Kg.	560.00	560.00	700.00	700.00
CAN	40Kg.	135.04	135.04	168.80	168.80
SSP	188Kg.	391.04	391.04	488.80	488.80
MoP	50Kg.	148.00	148.00	185.00	185.00
Lasso	3Lt.	612.00	612.00	765.00	765.00
One ploughing	5Hrs.	620.00	620.00	775.00	775.00
Two harrowing And planking	7Hrs.	868.0	868.0	1085.00	1085.00
Sowing	14 Mandays	512.40	571.20	640.50	714.00
Weedicide application	7 Mandays	256.20	285.60	320.25	357.00
Hand weeding	12 Mandays	439.20	489.60	549.00	612.00
Harvesting	19 Mandays	695.40	775.20	869.25	969.00
Threshing	21 Mandays	768.60	856.80	960.75	1071.00
Total		6005.88	6312.48	7507.35	7890.60

(A) 1 Manday = 8 hours of single labour unit

(B) Net cropped area :

$$T_1 - T_6 = 0.8 \text{ ha}$$

$$T_7 = 1.0 \text{ ha}$$

* Costs have been calculated on the basis of net cropped area

APENDIX - 31

Cost (Rs.) of maintenance of mulberry and plum trees and harvest of their produce

Components	Operational input for 100 trees	T ₁		T ₂		T ₃		T ₄		T ₅	
		1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
Mulberry											
Lopping	5 mandays	610	680	915	1020	915	1020	-	-	1830	2040
Plum											
CAN	100 Kg.	1125	1125	1688	1688	-	-	3376	3376	-	-
SSP	80 Kg.	554	554	832	832	-	-	1664	1664	-	-
MoP	50 Kg.	493	493	740	740	-	-	1480	1480	-	-
FYM	20 q	1600	1600	2400	2400	-	-	4800	4800	-	-
TSO	250 ml	28	28	42	42	-	-	84	84	-	-
Blitox	200 gm	106	106	160	160	-	-	320	320	-	-
Lin seed oil	150 ml	30	30	45	45	-	-	90	90	-	-
Fertilizer application	2 mandays	244	272	366	408	-	-	732	816	-	-
FYM application	4 mandays	488	544	732	816	-	-	1464	1632	-	-
Basin preparation	8 mandays	976	1088	1464	1632	-	-	2928	3264	-	-
Pruning	7 mandays	854	952	1281	1428	-	-	2562	2856	-	-
Total		7108	7472	10665	11211	915	1020	19500	20382	1830	2040

APPENDIX - 32

Prices of various inputs and outputs

S.No	Inputs	Rate		S.No.	Outputs	Rates	
		1997	1998			1997	1998
1.	Tractor charges	Rs. 155.00/ha	Rs. 155.00/ha	1.	Soybean grain	Rs. 1000.00/q	Rs. 1000.00/q
2.	Labour charges	Rs. 45.75/manday	Rs. 51.00/manday	2.	Soybean straw	Rs. 30.00/q	Rs. 30.00/q
3.	Soybean seed cost	Rs. 10.00 /kg	Rs. 10.00 / kg	3.	Mulberry leaf fodder	Rs. 45.00/q	Rs. 50.00/q
4.	Fertilisers and manures			4.	Mulberry fuel wood*	Rs. 132.00/q	Rs. 132.00/q
	a) CAN	Rs. 422.00/q	Rs. 422.00/q	5.	Plum fuel wood*	Rs. 126.00/q	Rs. 126.00/q
	b) SSP	Rs. 260.00/q	Rs. 260.00/q	6.	Plum fruit	Rs. 600.00/q	Rs. 800.00/q
	c) MOP	Rs. 370.00/q	Rs. 370.00/q	* Computed values in terms of calorific values Kerosene oil = Rs. 2.80/lit 1 lit. Kerosene oil = 9259 K cal/lit 1 kg. Morus branch wood = 4363 K cal/kg 1 kg. Plum branch wood = 4181 K cal/kg			
	d) FYM	Rs. 30.00/q	Rs. 30.00/q				
5.	Lasso	Rs. 255.00/lit.	Rs. 255.00/lit				
6.	TSO	Rs. 42.00/lit	Rs. 42.00/lit				
7.	Blitox	Rs. 200.00/kg	Rs. 200.00/kg				
8.	Lin seed oil	Rs. 75.00/lit	Rs. 75.00/lit				

APPENDIX- 33

Nutrient content of FYM and Fertilizers

Nutrient content (%)	FYM	CAN	SSP	MoP
N	0.75***	25.00*	-	-
P ₂ O ₅	0.18***	-	16.00*	-
K ₂ O	0.55***	-	-	60.00*
Ca	0.91**	3.90**	24.25**	0.80**
Mg	0.19**	1.81**	0.23**	0.19**
S	0.49**	0.04**	9.68**	0.01**

Source : * Tandon (1993)
 ** Arora *et al.* (1975)
 *** Gaur (1992)

CURRICULUM VITAE

Name : **Manoj Kumar**
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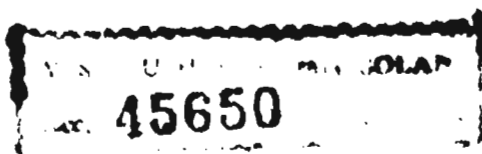
Educational Qualifications

Certificate/Degree	Percentage of marks	Division	Board/University
Matric	72.73	First	HP Board of School Education
B.Sc. (Forestry)	76.40	First	Dr. Y.S. Parmar UHF, Nauni, (Solan) HP
M.Sc. (Agroforestry)	80.20	First	Dr. Y.S. Parmar UHF, Nauni, (Solan) HP
Ph.D. (Agroforestry)	77.00	First	Dr. Y.S. Parmar UHF, Nauni, (Solan) HP

Whether sponsored by some State/Central Govt./Univ./SAARC : **No**

Scholarship/Fellowships, if any :

B.Sc. : **Merit Scholarship**
M.Sc. : **Junior Research Fellowship (UNDP)**
Ph.D. :
i) **Merit scholarship**
ii) **Senior Research Fellowship (UNDP)**



THESIS ABSTRACT

Title of Thesis : Tree-crop interaction studies in agroforestry system – productivity, moisture and nutrient dynamics
Name of the student : Manoj Kumar
Admission number : F-95-3-D
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Major field : Agroforestry
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ii) Soil Science
Degree awarded : Ph.D. Agroforestry
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ABSTRACT

The present investigations entitled, "Tree-crop interaction studies in agroforestry system – productivity, moisture and nutrient dynamics" were carried out during the *khari* season, 1997-98; involving seven tree-crop combinations viz., plum-mulberry-pomegranate-soybean (T_1), plum-mulberry-soybean (T_2), pomegranate-mulberry-soybean (T_3), plum-soybean (T_4), mulberry-soybean (T_5), pomegranate-soybean (T_6) and sole soybean (T_7). Availability of soil moisture; soil and plant nutrients; growth and yield of soybean, plum, mulberry and pomegranate vis-à-vis litter production and decomposition; xylem water potential; relative light intensity; allelopathy and economic returns due to the interaction effects of above seven tree-crop combinations were evaluated.

Soybean plant growth, yield and nutrient concentration were significantly lower under tree-crop combinations (T_1 - T_6) than sole cropping (T_7). Mulberry depressed these characters more adversely than plum and pomegranate. Mulberry, plum and pomegranate have shown their respective maximum growth, biomass yield, litter production and nutrient concentration in the harvested biomass as well as in litter under tree-crop combination involving single tree species only. Plum litter decomposed rapidly followed by pomegranate and mulberry.

The surface (0-15 cm) soil layer contained higher amounts of OC, N, P, K and S, whereas, Ca and Mg were more in sub-surface (15-30 cm) layer. Nutrient sorption zone of soybean was established to be the sub-surface layer. Nutrient balance has shown higher net gain of N, Ca and Mg in T_5 and of K in T_3 . P and S showed net loss in all the combinations including sole crop.

Mulberry caused more depletion in soil moisture than plum to the soybean crop, and pomegranate the least. Shading pattern during the crop season (July-October) revealed more shade due to mulberry in July-August and under plum in September-October. Pomegranate cast least shade throughout the season. Allelopathic effects on soybean germination, growth and vigour index were higher in case of plum followed by pomegranate and mulberry, studied after Tukey and Mecklenberg, 1964.

The tree-crop combination mulberry-soybean (T_5) gave higher biomass yield and pomegranate-soybean (T_6) the least. The costs incurred, gross returns and net returns were higher in tree-crop combinations involving plum as one of the component with soybean and was in the order : $T_4 > T_2 > T_1$.

Based on economic and biophysical attributes studied viz., net returns, total cost, total biomass, product diversification, and soil nutrients, the different tree-crop combinations have been rated suitable for sub-temperate sub-humid mid hill conditions of the North-Western Himalaya: plum-soybean = plum-mulberry-soybean > plum-mulberry-pomegranate-soybean > mulberry-soybean > pomegranate-mulberry-soybean > pomegranate-soybean > soybean.

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