

TREE-CROP INTERACTION STUDIES IN AGRIHORTISILVICULTURE SYSTEM

THESIS

by

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— Agroforestry

Accessioned by *Pr. Chakraborty*



Dedicated

to

my beloved

mother

“Agroforestry is arguably the single most important discipline for the future of sustainable development in Africa”

P. Harrison

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CERTIFICATE-I

This is to certify that the thesis entitled "**Tree-crop interaction studies in agrihortisilviculture system**", submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE in AGROFORESTRY** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan (H.P.) is a bonafide research work carried out by **Mr. Mulugeta Woubshet Zegeye (F-97-15-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

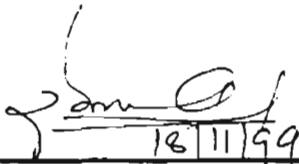
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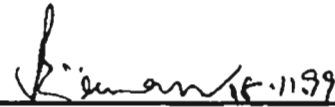
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This is to certify that the thesis entitled "Tree-crop interaction studies in agrihortisilviculture system", submitted by Mr. Mulugeta Woubshet Zegeye (F-97-15-M) to Dr. Yashwant Singh Pamar University of Horticulture and Forestry, Solan (H.P.), in partial fulfilment of the requirements for the award of degree of MASTER OF SCIENCE in AGROFORESTRY has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the external examiner.



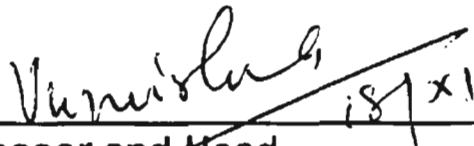
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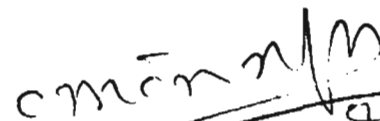
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all my inmost being, praise his holy name.
..... and forget not all his benefits”*

Ps.103:1-2

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(Mulugeta Woubshet Zegeye)

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ACRONYMS AND ABBREVIATIONS


AH	:	Agrihorticulture
AHS	:	Agrihortisilviculture
AS	:	Agrisilviculture
ASH	:	Agrisilvihorticulture
CAM	:	Calcium ammonium nitrate
C.D.	:	Critical difference
cm	:	Centimeter
DAS	:	Days after sowing
DBH	:	Diameter at breast height
E.C.	:	Electrical conductivity
FYM	:	Farm yard manure
g	:	Gram
ha	:	Hectare
H.P.	:	Himachal Pradesh
hr	:	Hours
ICAR	:	Indian Council for Agricultural Research
ICRAF	:	International Center for Research in Agroforestry
ICRISAT	:	International Crop Research Institute for Semi-Arid Tropics
K	:	Potassium
kg	:	Kilogram
l	:	Liter
m	:	Meter
ml	:	Milliliter
MoP	:	Muriate of potash
N	:	Nitrogen
O.C.	:	Organic carbon
P	:	Phosphorus
PS	:	Pastoralsilviculture
PSH	:	Pastoralsilvihorticulture
q	:	Quintal
R.I.	:	Relative illumination
Rs.	:	Rupees
SC	:	Sole cropping
S.E.	:	Standard error
SSP	:	Single super phosphate
t	:	Tonnes
T.C.I.	:	Tree-crop-interface
%	:	Per cent

INTRODUCTION

INTRODUCTION

Component interaction refers to the influence of one component of a system on the performance of the other component as well as the system as a whole (Nair, 1993). If one is to understand and predict the results of combining trees and crops under different circumstances, it is important to know the underlying principles that control these changes and to appreciate their potential effect on plant growth and development. To explain why particular agroforestry systems work in one environment and not another, and how to manage them, requires a 'process-based' approach in order to cover the large number of possible plant combinations and wide range of ecozones. Only by taking this approach can the unjustified extrapolation of agroforestry systems from one area to another be avoided, and the development of appropriate management practices be achieved (Brenner, 1996).

In order to predict the outcome of the interaction information is required on the dependence of the rates of growth of each species on resource availability (Tilman, 1986). The rate and extent to which biophysical resources are captured and utilized by the components of an agroforestry system are determined by the nature and intensity of interaction between the components. The net effect of these interactions is expressed in terms of such quantifiable responses as soil fertility changes, microclimate modifications, resource (water, nutrient and light) availability and utilization, etc. Hence, quantifying the magnitude of interactions over a range of species, soil, management, and climatic conditions will help determine the biophysical limits of the system (Rao, *et al.*, 1998).



Fundamental to the design and management of sustainable agroforestry systems is understanding the interactions between crop and tree components. How do these interactions affect the growth resources and their utilization, the environment and ultimately productivity. Research in this context is strategic in nature, aimed at (1) finding solutions to specific problems affecting the development and design of agroforestry technologies in major agroecozones and (2) developing predictive capacity for extrapolation of results to other environments.

The present investigations also address this need for improved knowledge of the aboveground and belowground tree-crop interactions in an agrihortisilvicultural system involving wheat, almond (*Prunus amygdalus*), *Grewia optiva* and *Morus alba* as its components.

Grewia optiva (Bhimal) which is native to Western Himalayan region is rated as number one preference among different fodder tree species in the hills (Verma *et al.*, 1989). Its leaves and twigs are highly palatable, tannin free and nutritious (Joshie and Narain, 1992).

Morus alba (white mulberry), another rich source of fodder is also native species grown in combination with various agricultural crops in Western Himalayan region.

Almond is considered as a prized fruit in India and has been included in the system as an economic enterprise. It can be grown in shallow, marginal soils with limited water, but it responds well to deep, well drained soils with adequate irrigation by better growth and much higher yields. Wheat is the major *rabi* crop of the region.

The objectives of the study are:

- i) Study the resource use characteristics both below and above-ground.
- ii) Ascertain the nature of tree-crop association based on above and below-ground resource use patterns and biomass production.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The available literature relevant to the study has been reviewed under the following heads:

2.1 Plant growth and yield

2.1.1 Field crops

2.1.2 Fodder trees

2.1.3 Fruit trees

2.2 Plant nutrient content and uptake

2.2.1 Field crops

2.2.2 Fodder trees

2.2.3 Fruit trees

2.3 Soil characteristics

2.3.1 Moisture

2.3.2 Nutrient dynamics

2.4 Root architecture and distribution

2.5 Economic evaluation

2.1 PLANT GROWTH AND YIELD

In perennial-annual mixtures, the perennial usually has a greater and more long-lasting effect on the environment, that in turn influences the performance of the annual. According to the competitive production principles,

a mixture becomes successful only if both components can exploit available resources more efficiently when grown together than grown in monocultural situations. The facilitative production principle may also come into play, i.e., the environment of one species (usually the annual) is modified by the presence of a second species (the perennial) in such a way as to facilitate the growth of the first species. Often these principles operate simultaneously and inseparably. The net effect of these interactions will manifest itself in terms of the performance of the individual plant and of the system as a whole (Nair, 1990).

2.1.1 Field crops

Khan and Aslam (1974) reported a decrease in wheat yield upto 30.88, 23.60, and 12.7 per cent at the distances of 3, 4.5 and 6 m, respectively from single shisham tree, as compared to the yield recorded from the centre of the field. Similar results were reported by Sheikh and Cheema (1976) while studying the effect of poplar windbreaks (tree rows) on the yield of wheat crop. Tree shade does cause deleterious effect (Sheikh and Haq, 1978) on wheat crop yield. The maximum loss being within 2 meters radius of the tree and on the northern side. Distance from the tree base and the direction of the shade, both the factors had highly significant depressing effect on the wheat yield grown with *Acacia nilotica* and *Dalbergia sissoo*, separately.

In spite of the above facts, Chirko *et al.* (1996) indicated that although tree shade did have some adverse effect on wheat yield, factors such as tree morphology (a long clear bole), N-S tree row orientation, wide inter-row spacing and late leaf flush resulted in a compatible intercrop system between paulownia tree and wheat.

Akbar *et al.* (1990) while studying the effect of 5 years old tree species viz. eucalyptus, albizia, morus and leucaena on the wheat crop under rainfed condition indicated that trees impact on wheat yield can be experienced upto 2

m distance, there is little, if any, impact upto 6 m distance and almost no impact at 8, 10 and 12 m distances.

Khybri *et al.* (1992) studied tree-crop interaction under rainfed condition in Dehra Dun valley and showed that grewia, morus and eucalyptus had depressing effect on crop yields of rice and wheat. Morus affected rice the most, while wheat was affected more by grewia. The depressing effect varied on an average from 28-34 per cent depending upon the species. They observed 39 per cent decrease in crop yield up to 1 m, 33 per cent from 1-2 m, 25 per cent from 2-3 m and 12 per cent from 3-5 m, distance from tree rows.

The study conducted by Chauhan *et al.* (1995) on the effect of trees on the yield of rainfed wheat crop in the sub-montane subtropical zone of Himachal Pradesh revealed that mulberry and poplar reduced yield upto 4 m distance, whereas 6 m and higher distances indicated negligible effect on wheat yield.

Contrary to the depressing effect, Wang and Shogren (1992) reported that wheat yield was found to be on an average 2478.3 kg ha⁻¹ when it was intercropped with *Paulownia elongata* as compared to 2113.5 kg ha⁻¹ in sole cropping. Thousand grain weight was found to be 37.3 and 36.2 g, respectively. Likewise, Sharma and Singh (1992) indicated that the total loss in grain yield in the poplar affected area (240 m²) was worked out to be 4.50 kg while the increased yield due to beneficial influence (6.60 m²) came to 14.83 kg. The total increased yield upto 15 m distance from tree line would, therefore, be 10.3 kg. This again proved that poplar tree line had a positive influence on wheat crop yield.

✓ On fertilizer use, an eight year alley cropping trial conducted by Kang *et al.* (1989) in Southern Nigeria showed that supplementing the prunings of leucaena with 80 kg N/ha increased maize yield from 2 to 3 t/ha. Yamoah *et al.*

(1986b) reported that to increase the yield of maize alley cropped with cassia, gliricidia and flemingia, it was necessary to add nitrogen. Similarly, in a study conducted in Philippines, O'Sullivan (1985) reported that when maize was intercropped with leucaena, yield of 2.4 t/ha (with fertilizer) and 1.2 t/ha (without fertilizer) was obtained.

In an experiment conducted on the performance of wheat cultivars grown in a monoculture cropping system under rainfed conditions of Kumaon hills of Uttar Pradesh (Singh *et al.*, 1995), the variety HD-2285 gave yield varying from 2333 to 2375 kg ha⁻¹ at recommended fertilizer level (90 kg N + 45 kg P₂O₅ + 45 kg K₂O ha⁻¹), whereas, it gave yield of 1565 to 1620 kg ha⁻¹ under farmers' practice (40 kg N ha⁻¹).

Singh and Singh (1995) also studied relative performance of different wheat varieties at various levels of nitrogen fertilizer. They found that the variety HD-2285 showed an average grain yield of 25.1q ha⁻¹, straw yield of 45.7 q ha⁻¹, plant number m⁻¹ (row) of 41.75, plant height of 73.6 cm, ear length of 8.75 cm, number of grain per ear of 32.85, 1000 grain weight of 43.1 g.

2.1.2 Fodder trees.

While studying the tree-crop interactions under hedgerow intercropping with rice and wheat in Dehra Dun valley for 13 years during 1997-1990, Khybri *et al.* (1992) reported that *Grewia optiva* could produce 1.08 t ha⁻¹ yr⁻¹ of branches and 0.26 t ha⁻¹ yr⁻¹ of leaves (air dry weight), while *Morus alba* yielded 1.28 t ha⁻¹ yr⁻¹ of branches and 0.28 t ha⁻¹ yr⁻¹ of leaves. Similar studies carried out by Akbar *et al.* (1990) on five years old *Morus alba* trees planted along the boundary of wheat field 1.5m apart showed DBH and height values varying from 5.4-6.09 cm and 4.09-5.74 m, respectively. Joshie and Narain (1992) also indicated that in a 4 years old silvipastoral plantation where grewia was planted in association with *Chrysopogon fulvus* at a spacing of 4x4 m, the

average height of the trees was 4.06 m, collar diameter 7.2 cm, and crown spread 2.6 m. The oven dry yield of leaf fodder was recorded to be 11 q ha⁻¹yr⁻¹.

Khosla *et al.* (1992) worked out the net primary productivity of 4 years old grewia in Solan area. The values were 0.322 kg ha⁻¹ yr⁻¹ (62%) for bole, 0.099 kg ha⁻¹ yr⁻¹ (19%) for branches, 0.099 kg ha⁻¹ yr⁻¹ for leaves with a total of 0.520 kg ha⁻¹ yr⁻¹ above-ground biomass. Bisht and Toky (1992) studied the growth pattern and architecture of nine important tree species in an arid region of India, and observed 6.4 cm DBH and 5.2 m height for 6 years old *Morus alba* trees when grown in monoculture at a spacing of 5x5 m. In another study, Toky and Bisht (1992), reported the average crown spread of 6 years old morus trees to be 390.8 cm.

Karki and Yadava (1994) studied the leaf forage and fuel wood production of ten fodder tree species. They reported 1.6 kg tree⁻¹ leaf forage and 2.4 kg tree⁻¹ fuelwood from *Morus alba* in mid hills after 3 years of planting. Branch and leaf biomass yield of 5 years old plants of morus were studied by Kumar (1996) in agrisilviculture system at a spacing of 8 x 3.5 m. Maximum branch wood biomass of 50.97 q ha⁻¹ and 20.44 q ha⁻¹ of leaf biomass was noted at 1.5 m cutting height.

2.1.3 Fruit trees

Yield of over 2200 kg of edible kernels (meats) per hectare are reported to be relatively common when almond trees are grown under intensive conditions where deep, well drained, light to medium textured soils with adequate irrigation are available (Micke and Kester, 1998). Talhouk *et al.* (1998) worked out the nut and kernel characteristics for thirteen different varieties of almond and found that the nut weight varied from 1.8-5.3 g while the kernel weight ranged from 0.4-2.5 g.

Edstrom and Micke (1998) reported that the harvest nut weight from almond trees of 5-8 years old planted in single hedgerow with a spacing of 4.6x6.1 m for 358 trees ha⁻¹ under drip irrigation averaged to be 2004 kg ha⁻¹. The mean trunk circumference at 30 cm above the soil surface for 9 years old trees was recorded to be 59.8-64.9 cm.

2.2 PLANT NUTRIENT CONTENT AND UPTAKE

The nutrient resource consumption rate of each species i.e. amount of each nutrient per unit biomass per unit time, is determined by the growth rate and the dynamics of the resource supply (Tilman, 1986). Nutrient uptake by plants is proportional to soil solution nutrient concentrations at the root surface and is determined by the soil supply (Anderson and Sinclair, 1993).

2.2.1 Field crops

Patil and Mahendra (1991) studied the inter-relationship of nitrogen, phosphorus and potassium in wheat at various stages of growth at IARI, New Delhi and found that wheat plant had mean nitrogen concentration of 4.1, 3.3 and 1.7 per cent at 30, 60 and 90 days after sowing with 1.8 and 0.39 in grain and straw, respectively. The corresponding mean values for phosphorus status were 0.5, 0.4 and 0.3 per cent at 30, 60 and 90 DAS with 0.3 and 0.1 per cent in grain and straw, whereas, potassium content was 2.2, 1.9, 0.9 per cent 30, 60 and 90 DAS with 0.3 and 1.2 per cent in grain and straw. The N, P and K content dropped slowly upto 90 DAS. They further reported that the mean nitrogen uptake by wheat was 72.1 and 23.8 kg N ha⁻¹ by grain and straw, respectively. The mean phosphorus accumulation was 12.8 and 5.5 kg P ha⁻¹ in grain and straw. The corresponding values for potassium were 11.2 and 72.6 kg ha⁻¹ in grain and straw, respectively.

Sud *et al.* (1990) indicated that the total N uptake by grain, straw and wheat crop increased significantly with the increase in N levels which might be either due to increase in N contents or increased yield or both. The total N uptake by grain and wheat crop increased with the increase in soil moisture availability too.

Kumar (1996) indicated that the N, P and K content in grain of wheat intercropped with morus and peach in agrisilvicultural and agrihortisilvicultural systems ranged from 1.36-1.41, 0.33-0.36, and 0.44-0.46 per cent, respectively. The corresponding values for N, P and K in straw were 0.25-0.27, 0.15-0.17, and 0.63-0.64, per cent, respectively. The monoculture plot showed 1.41, 0.38 and 0.48 per cent concentration of N, P and K while the respective values in straw were 0.29, 0.19 and 0.66 per cent, respectively. He worked out the uptake by the grain to range from 35.88-43.60, 8.92-11.23, and 11.61-14.49 kg ha⁻¹ for N, P and K, respectively, in case of intercropping. The respective values of N, P and K in straw ranged from 13.02-15.60, 7.78-9.98 and 31.97-36.64 Kg ha⁻¹. The uptake by grain in case of monoculture was 49.47, 13.32 and 16.96 kg ha⁻¹ for N, P and K, respectively. The corresponding figures for straw were 17.47, 11.57 and 40.04 for N, P and K.

2.2.2 Fodder trees

Verma and Mishra (1989) carried out nutrient dynamics study in agroforestry species of Western Himalaya and pointed out that N concentration in *Grewia optiva* leaves exhibited a significant increase from April to May (2.91-3.32%). Thereafter, a sharp decrease in N concentration was observed with increase in time till October and November. Contrary to N, the P concentration of leaves in general, showed a steady decline with the advancement of season. About half of the P concentration was disappeared in November (0.13%) when compared with its initial value of 0.25 per cent in April. Khosla *et al.* (1992) also indicated that the crude protein in the leaves of

grewia was much higher (upto 22%) in the young leaves and decreased remarkably with leaf maturation.

Kaushal (1998) reported that the nitrogen concentration in grewia leaves varied from 2.71-3.03 per cent on an average during *khari* season in agrisilviculture and agrihortisilviculture systems, and P values ranged from 0.16-0.19 per cent, whereas the respective values for K varied from 2.25-2.73 per cent. The N concentration in branches of grewia ranged from 1.08-1.15 per cent. The P value was between 0.075 and 0.078 per cent, whereas, K value ranged from 1.35-1.39 per cent. He worked out the uptake by leaves of grewia to range from 3.5-12.66, 0.22-0.78 and 2.98-10.86 kg ha⁻¹ for N, P and K, respectively. The corresponding uptake values by branches were 4.92-17.98, 0.34-1.26 and 6.16-22.32 kg ha⁻¹ for N, P and K, respectively in various tree-crop combinations.

Khatta and Katoch (1983) while analyzing the nutrient composition of some fodder tree leaves in the sub-mountainous regions of Himachal Pradesh reported that morus leaves contain 26.40, 11.63, 5.06, 16.28, 40.63, 2.38 and 0.35 per cent of crude protein, crude fiber, ether extract, ash, nitrogen free extract, calcium and phosphorus, respectively, in Palampur locality whereas, their corresponding values for Jawalamukhi locality being 18.24, 10.28, 6.21, 13.84, 51.43, 3.91 and 0.48 per cent, respectively.

The nitrogen content in the leaves of morus intercropped with soybean in different tree-crop combinations (Kaushal, 1998) ranged from 2.47-2.79, 0.16-0.20 and 1.84-2.2 per cent for N, P and K, respectively. The uptake of N, P and K by leaves was calculated to be 1.93-5.65, 0.13-0.39 and 1.48-2.52 kg ha⁻¹, respectively. The concentration of N, P and K in branches was 0.87-0.88, 0.078-0.083 and 0.93-0.98 per cent, while their uptake by branches was worked out as 4.73-14.92, 0.45-1.32 and 5.06-16.62 kg ha⁻¹ for N, P and K, respectively..

2.2.3 Fruit trees

Literature on nutrient status of almond trees/fruits/leaves integrated with annual crop system presently, is scarcely available. Nevertheless few reports, though remotely relevant to current studies are yet reviewed here.

Das (1990) reported N content of 2.3-2.48 per cent in leaves, 0.75-0.83 per cent in pruned branches, 1.35-1.47 per cent in abscised leaves, 4.44-4.72 per cent in kernel, 0.34-0.39 per cent in shell and 1.28-1.4 per cent in hull for different cultivars of almond. The corresponding P content was 0.14 per cent in leaves, 0.08 per cent in pruned branches, 0.09 per cent in abscised leaves, 0.53-0.56 per cent in kernel, 0.06 per cent in shell and 0.15-0.17 per cent in hull. The concentration of K was 2.05-2.17 per cent, 0.71-0.83 per cent, 1.71-1.97 per cent, 0.97-1.03 per cent, 0.25-0.26 per cent and 2.14-2.26 per cent, respectively. The total amount of proteins in almond fruit at the time of commercial maturity varied from 12 to 32 per cent depending on the cultivar and ecological conditions (Polesello and Rizzolo, 1989).

The tree-crop interaction study by Kaushal (1998) indicated that the monthwise variation of nitrogen in almond leaves ranged from 1.77 to 2.15 per cent in different tree-crop combinations, whereas the respective values for P and K were 0.095 to 0.127 per cent and 1.90 to 2.15 per cent, respectively. Nutrient concentration in branches was recorded to be 0.065-0.65 per cent for N, 0.078-0.083 per cent for P and 0.81-0.88 per cent for K.

The removal of nutrients by almond fruit was reported by Das (1990) as 15.75-20.33, 1.87-2.68 and 15.15-19.79 kg ha⁻¹ yr⁻¹ for N, P and K, respectively.

2.3 SOIL CHARACTERISTICS

The oft-repeated suggestion that agroforestry holds considerable promise as a practical land management alternative for maintaining soil fertility and

productivity is based on the assumption that trees and other vegetation improve the soil beneath them. Trees add organic matter, nutrients and growth-promoting substances to soil. However, they may also have some adverse effects on soils. The net effect of all these factors will depend upon management and location specific factors (Nair, 1990). Interactions related to soil fertility and competition for nutrients appear to be major factor affecting the performance of hedgerow intercropping on non-steep-sloping lands (Rao *et al.*, 1998).

2.3.1 Soil moisture

In a four-year study carried out at ICRISAT near Hyderabad, India, hedgerow species outperformed the crops when there was limited moisture, resulting in reduced crop yields (ICRISAT, 1989). The soil water depletion was found to be greater under the fast growing and high-biomass producing *Senna spectabilis* than under the slow growing and less biomass producing *Senna siamea* in hedgerow intercropping with maize-cowpea annual crop system at Machakos, Kenya (McIntyre *et al.*, 1997).

Malik and Sharma (1990) reported reduction over 30 per cent of wheat and mustard yield grown at a distance less than 10 m from the 3.5 years old *Eucalyptus tereticornis*. The reduction in yield of crops was attributed to competition for soil moisture.

2.3.2 Nutrient dynamics

An advantage commonly attributed to agroforestry and other tree based systems is that they promote more efficient nutrient cycling than many other systems and thus, have a greater potential to improve soil fertility (Nair, 1984).

Intercropping of peach with *rabi* and *kharif* crops, (Gupta *et al.*, 1982), could add about 10 kg of leaf litter to the soil during November to December

when trees attained the age of 5 years. The leaf litter gets recycled into the soil, thus providing 35 kg N, 8 kg P and 25 kg K ha⁻¹ yr⁻¹. Pruned branches and abscised leaves of almond cultivars (Das, 1990) recycled 1.72-3.23 and 1.07-1.36 kg ha⁻¹ yr⁻¹ N, 0.17-0.32 and 0.07-0.09 kg ha⁻¹ yr⁻¹ P, 1.63-2.98 and 1.34-1.65 kg ha⁻¹ yr⁻¹ K, respectively.

2.4 ROOT ARCHITECTURE AND DISTRIBUTION

Knowledge of the structural development of root systems is essential to understand the ecological niche of a tree species and for management in order to optimize the productivity of trees and crop plants in various agroforestry systems (Toky and Bisht, 1992).

Spatially, the effective root systems of woody perennials tend to be deeper than annual crop components having the shallow root system. This should be desirable in any agroforestry system since the roots of the tree and crop will be feeding from different depths, hence, less competition and at the same time tree roots could act as a trap for nutrients leached out of the top soils (Dhyani *et al.*, 1990).

In a study, conducted to observe the growth pattern and architecture of 6 years old important multipurpose trees in Hisar, *Morus alba* was seen to have superficial root system confined to 80 cm below the soil surface. The total number of roots varied from approximately 814 to 1253 (Bisht and Toky, 1992).

Another observation from a study on the rooting pattern of some 6 years old agroforestry trees in an arid region of the north-western India also revealed that *Morus alba* had adventitious superficial roots mostly concentrated in 80 cm of the soil profile. The highest density of roots was observed around the root stock associated with fan-shaped 8-15 laterals from the tap root. The spread was asymmetrical with roots penetrating predominantly in one or two directions.

Morus had 814 total number of roots with a decreasing trend for increasing depth. The top 30 cm contained 78 to 84 per cent of the total biomass. Length of the main root was only 72 cm. The number of primary, secondary and tertiary roots was 26, 187 and 601, respectively. The horizontal root spread, angle of primary roots, angle of secondary roots were found to be 291 cm, 75.3° and 53.3°, respectively (Toky and Bisht, 1992).

Dhyani *et al.* (1990) investigated the root distribution of five multipurpose tree species in Doon valley, India, one of which was *Grewia optiva* (28 months old). The absorbing zone of the lateral roots of *Grewia* was within a depth of 30-60 cm. The lateral roots, especially in the top layers of the soils exhibited a tendency of spreading parallel to the ground level but with a positive geotropism. *Grewia* trees with mean collar diameter of 4.12 cm and mean height of 2.4 m had root depth and maximum lateral root spread of 2.45 m and 1.35 m, respectively.

2.5 ECONOMIC EVALUATION

The productivity of agroforestry systems cannot be assessed by conventional measures of the per hectare yields of the separate crops taken individually. This is true for the simple reason that, although, the yield of individual intercrop may be depressed relative to their yields in monoculture, the total production of the yield may be higher than that obtained when the individual crops are grown as sole crops on the same amount of land (Raintree, 1983). It would be better, then, to compare the biomass in terms of money to get a conclusive idea about the system (Riley, 1986).

Khybri *et al.* (1992) inferred that growing of crops (wheat and rice) without trees is most economical as compared to the intercropping systems involving *Morus alba*, *Grewia optiva*, and *Eucalyptus hybrid*. Among the tree species, eucalyptus was found more economical than other two tree species.

On the other hand, for agroforestry systems involving fruit tree components, the gross returns in wheat-soybean cropping sequence followed the sequence AH > AHS > AS > SC. The net returns also followed same trend with incomes of Rs. 30195, Rs. 28810, Rs. 25140 and Rs. 24314 ha⁻¹ yr⁻¹, respectively (Kumar, 1996). Similarly, Majumdar (1991) studied four production systems of Himachal and found that horticultural system furnished the highest gross returns amounting to Rs. 91557.20 annually which was about 6.6 and 31.5 fold higher than those of hortisilvipastoral and grassland systems, respectively. Upadhaya (1998) conducted study in Balh Valley of Himachal Pradesh and reported that in marginal, small and medium group of farmers, more net returns were obtained from ASH system as compared to AS, PS, PSH systems of agroforestry.

MATERIALS & METHODS

MATERIALS AND METHODS

The study entitled "Tree-crop Interaction Studies in Agrihortisiviculture System" was undertaken at the Experimental Farm of the Department of Silviculture and Agroforestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauli, Solan (H.P.) during the *rabi* season of 1997-98. The details about the site, materials used and methodology adopted are given as under:


3.1 SITE DESCRIPTION

3.1.1 Location

The study was conducted in the mid-hill region of western Himalaya at an altitude of 1250 m above mean sea level. The area is located at 30°51' N latitude and 76°11' E longitude (Survey of India Toposheet No. 55F/1).

3.1.2 Climate

The climate of the area is transition between sub-humid tropical to sub-temperate with an average annual rainfall of 1150 mm, most of which is concentrated in the monsoon period (mid-June to mid-September). May and June are the hottest months whereas December and January are the coldest and experience frost. The average annual temperature ranges from 3°C to 32°C whereas, mean annual temperature is 18°C. The meteorological data for the experimental site is presented in Fig. 1.



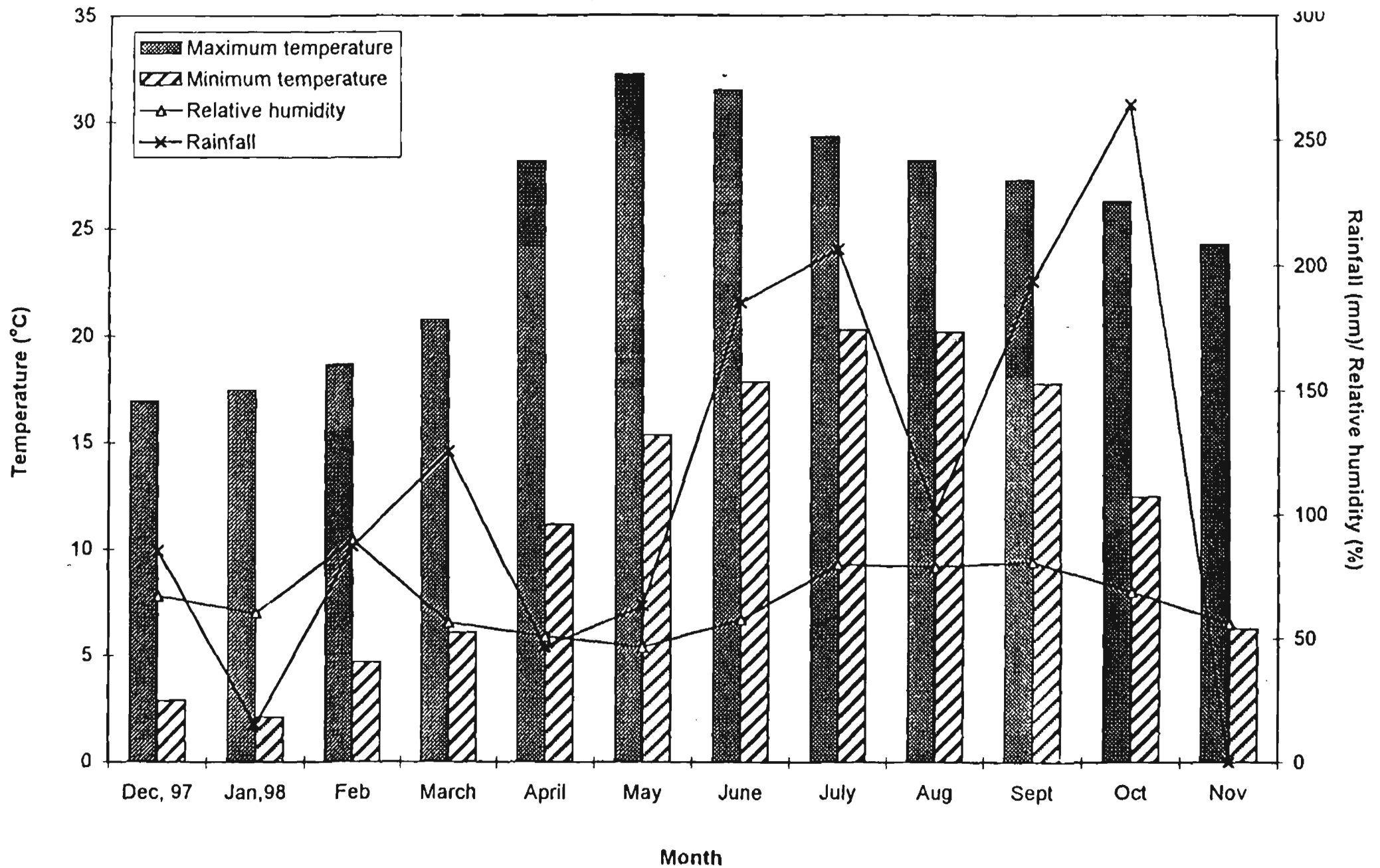


Fig. 1. Ombrothermic diagram for the study site based on one year data (1997-98)

3.2 EXPERIMENTAL METHODOLOGY

The experimental details and methods used are described as below:

Agroforestry system : Agrihortisilviculture

3.2.1 Structural components

Field crop : Wheat (*Triticum aestivum*, HD-2255)

Fodder trees : *Grewia optiva* and *Morus alba*

Fruit crop : Almond (*Prunus amygdalus*)

3.2.2 Planting geometry

Combination Code	Planting geometry	Total number of tree plot ¹	
		Fodder	Fruit
C ₁	Morus-Morus-Morus-Wheat	3	-
C ₂	Morus-Almond-Morus-Wheat	2	1
C ₃	Grewia-Almond-Grewia-Wheat	2	1
C ₄	Grewia-Grewia-Grewia-Wheat	3	-
C ₅	Wheat alone	-	-

The trees have been planted in lines drawn from east to west. Almond being an economic enterprise has been planted using recommended spacing of 5 m from one plant to another. Two fodder trees either morus or grewia are planted spaced 1 m apart between the two and 1.5 m from the almond in both sites within a row. Wheat was sown in the alley space or between the two tree lines.

3.2.3 Treatments

A. Tree-crop combination

The following tree-crop combinations were superimposed on the original layout in order to study the tree-crop interactions more precisely.

Tree crop combination code	Combination system	Agroforestry
Morus-Morus-Morus-Wheat	T ₁	Agrisilviculture
Morus-Almond-Morus-Wheat	T ₂	Agrihortisilviculture
Grewia-Almond-Grewia-Wheat	T ₃	Agrihortisilviculture
Grewia-Grewia-Grewia-Wheat	T ₄	Agrisilviculture
Sole wheat	T ₅	Agricultural

Observations on tree-crop-soil interactions were recorded at the below mentioned nitrogen levels, distances and directions.

B. Nitrogen levels

- N₁ : 80 kg ha⁻¹ (recommended dose)
 N₂ : 100 kg ha⁻¹ (25% more than recommended dose)

C. Distance

- D₁ : 1.5 m away from tree base
 D₂ : 3.5 m away from tree base

D. Direction

- DR₁ : North of tree row
 DR₂ : South of tree row

Design :	RBD
Plot size :	10x4 m
Bund area :	1x4 m
Net cropped area :	9x4 m
Replication :	3
Date of tree planting :	23.1.1993
Date of sowing field crop :	16.12.1997
Date of harvesting field crop:	2.6.1998

3.2.4 Tree management

Fodder trees : Complete lopping at a fixed height of 1 m during winter every year.

Fruit trees : Light pruning is used as a standard practice for maintaining the almond trees.

3.3 OBSERVATIONS RECORDED

3.3.1 Plant

Growth and productivity

Fodder trees : Diameter 5 cm above the ground, crown height, crown spread, branch and leaf biomass, root structure and distribution.

Fruit tree : Diameter 5 cm above the graft union, height, crown spread, number of fruits per tree and fruit yield, pruned biomass, root structure and distribution.

Field crop : Germination per cent, number of tillers, number of plant m^{-2} , plant height, number of grain per ear, number of ear per plant, 1000 grain weight, grain yield, straw yield and harvest index.

Nutrient

Trees : N, P and K concentration as well as uptake in leaves, fruits and pruned branches have been determined.

Field crop : N, P and K concentration in plants at tillering, panicle initiation, milking and harvesting stages; N, P and K uptake by grain and straw.

3.3.2 Soil

Soil moisture, organic carbon, available N, P and K; pH and E.C. at tillering, panicle initiation, milking and harvesting stage of wheat.

3.3.3 Light

Light interception by trees at tillering, panicle initiation, milking and harvesting stages of wheat.

3.3.4 Economic evaluation

Cost of cultivation

Gross returns

Net returns

3.4 OBSERVATIONAL PROCEDURES

The details about the observational procedure related to different parameters studied are given as below :

3.4.1 Trees

Diameter

Diameter was measured in centimeters at 5 cm above the ground level in grewia, morus and 5 cm above the graft union in almond with the help of a calliper, in the directions corresponding to major and minor axis of the tree trunk and the average of two was computed to get diameter growth. The measurements were made in December, 1997 and May, 1998, the sowing and harvesting time of wheat, respectively.

Height

Crown height in grewia and morus; and plant height in almond was measured in meters with the help of properly graduated wooden rod. The measurements were made in December, 1997 and May, 1998, the sowing and harvesting time of wheat, respectively.

Crown spread

Crown spread was measured from the trunk in east-west and north-south directions with the help of a properly graduated wooden rod. The measurements were made in December, 1997 and May, 1998, at sowing and harvesting of wheat crop.

Branch and leaf biomass

Branch and leaf biomass of morus and grewia were recorded in last week of November, 1998. The branches were lopped completely. The leaves were separated from the branches and their individual fresh weight was taken in the field. Branch and leaf samples were oven dried at 110°C to calculate dry weight. Leaf and branch biomass was expressed in $q\ ha^{-1}$ on green (fresh) weight basis.

Pruned biomass

In almond trees, the weight of pruned branches was recorded at the time of pruning in January, 1998. The prunings were oven dried at 110°C to calculate dry weight.

Number of fruits plant⁻¹ : Fruits from an almond tree were harvested in May, 1998, counted and expressed as the average number of fruits plant⁻¹

Fruit yield : The yield was recorded during harvesting season of 1997-98 (late May, 1998) by weighing the total number of fruits on a single tree and expressed in kg tree⁻¹ on fresh weight basis.

Root structure and distribution : One plant from each tree species was selected for excavation on the basis of having mean height and diameter. The roots were excavated by the Skeleton Method (dry excavation), digging manually along the coarse followed by the roots in the soil mass. Pick-axe, spade and small tools were used for digging the soil. The root-crowns were anchored to retain their normal position throughout the process of digging and exposing the roots. Measurements and sketching of the root system were done while digging.

Light interception : Solar radiation on a cloudy day was recorded at distance D_1 (below the crown) and in the open land with a lux photometer (Blackman and Wilson, 1951). Radiation interception was expressed as percentage of radiation below and outside the canopy at tillering, panicle initiation, milking and harvesting stages of the wheat.

3.4.2 Wheat

For recording the observations on growth and yield attributes, 1 m² sampling plots were laid out in each treatment at a distance of 1.5 m and 3.5 m

away from the tree base in both the directions i.e., north and south of the tree row.

Germination count

After complete emergence, all the plants in 1 m² area were recorded and percentage germination was worked out.

Number of tillers plant⁻¹

Number of tillers produced by 5 randomly selected plants were counted and expressed as number of tillers plant⁻¹.

Number of plants m⁻²

Total number of plants in the sampling plot were counted and expressed as number of plants m⁻².

Plant height

Plant height was measured from ground level to the tip of the plant in cm and expressed as average plant height by dividing with total number of plants in the sampling plot.

Number of ear plant⁻¹

All the ears born by the 5 randomly selected plants of each sample plot were counted and divided by five to determine the mean number of ears per plant.

Number of grain per ear

The ears collected from the above mentioned 5 plants were hand-threshed and grains were counted. Mean number of grains per ear was determined by dividing the total number of grains by five.

Length of ear

The length of the main shoot borne ear by the 5 randomly selected plants was measured from the base of the lowest spikelet to the tip of the topmost spikelet. Mean ear length was determined by dividing the total length of the ears of the selected plants by five.

1000 grain weight

A random sample of grains from the produce of the sampling plot was drawn which was threshed and cleaned. Thousand grains were counted and their weight was expressed in grams.

Grain yield

The weight of the total produce of the sampling plot was recorded, threshed and cleaned. The weight of the grains obtained was recorded and expressed in q ha⁻¹, though the actual sown area of wheat was 9000 m² in a hectare of land.

Straw yield

After reducing the weight of grain from weight of total produce, the straw yield of the sampling plot was obtained and expressed in q ha⁻¹, though the actual sown area for wheat was 9000 m².

Harvest index

Harvest index was calculated as per the following standard formula :

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Total biological yield (Grain+straw)}} \times 100$$

Cultural schedule

The details about cultural schedules adopted for wheat are as under :

Variety	:	HD-2285
Date of sowing	:	16.12.1997
Seed rate	:	120 kg ha ⁻¹
Spacing	:	22 cm (RxR)

Manures and fertilizers applied

Entire quantity of phosphorus @ 40 kg ha⁻¹ through SSP, 40 kg ha⁻¹ potassium through MoP alongwith 1/2 dose of nitrogen was applied at the sowing time. The remaining half dose of nitrogen was top dressed after 45 days.

Weedicide application : 2,4-D @ 400 g ha⁻¹ in 750 l water.

3.4.3 Nutrient analysis

3.4.3.1 Plants

Collection of samples

Tree leaves : For grewia and morus, full grown leaves from current season growth were collected in a composite sample. Each sample composed of 30-40 leaves. Leaf samples were collected from each tree starting at the branch terminal and proceeding towards the main stem ignoring the multilated ones (Cain, 1959). In case of almond, composite sample consist of not less than 100 leaves per tree was collected in a band around (N,S,E,W) sides of the crown, from middle of shoot growth, ten weeks after full bloom (Chapman, 1964). The branches of trees were collected randomly from each sampling unit a week before their harvesting period and brought to laboratory in paper bags.

Wheat : Wheat plant except root was taken at tillering, panicle initiation, milking and crop harvest.

Preparation of samples : All the samples were washed serially with tap water, 0.1 N HCl and again with distilled water. The washed samples were first air dried and subsequently in oven at $60\pm 5^{\circ}\text{C}$ for 48 hours.

Chemical analysis : For estimation of N, 0.5 g of plant sample was digested in concentrated H_2SO_4 using standard Kjeltabs in place of digestion mixture. After digestion, N was determined in Kjeltac auto 1030 analyzer. For estimation of P and K, wet digestion of plant samples was carried out in di-acid mixture consisting of nitric acid and perchloric acid in the ratio of 4:1 and final volume of the digest was made to 100 ml. Total P in the digest was determined by Vanado-molybdo-phosphoric yellow colour method using Spectronic 20-D and total K was estimated with Flame photometer as described by Jackson (1957).

Nutrient uptake : Uptake of total N, P and K in different harvested components of wheat, grevia, morus and almond was worked out by multiplying the concentration of each nutrient with respective dry matter yield using the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration} \times \text{dry matter (kg ha}^{-1}\text{)}}{100}$$

3.4.3.2 Soil

Collection and preparation of samples

Soil samples were collected from 0-15 cm depth before sowing and at all the four active growth stages of wheat viz. tillering, panicle initiation, milking and harvesting. Random samples were collected with the help of post hole

auger, composited (plot-wise), air dried, crushed, passed through 2 mm sieve and analyzed for various chemical characteristics.

Soil moisture

Soil moisture was determined by gravimetric method. Soil samples were taken from the field and were dried in hot air oven at 105°C until a constant weight was attained. The difference in weight between the wet and oven dry samples gave the moisture content.

Chemical analysis of the soil

The following standard procedures have been used to analyze the chemical properties of the soil.

Sr.No.	Parameters	Method employed
1.	Organic carbon (%)	Walkley and Black (1934)
2.	Available N (kg ha ⁻¹)	Subbiah and Asija (1956)
3.	Available P (kg ha ⁻¹)	Olsen <i>et al.</i> (1954)
4.	Available K (kg ha ⁻¹)	Merwin and Peech (1951)
5.	pH	1 : 2.5 soil water suspension with the help of digital pH meter (Jackson, 1957)
6.	E.C. (dsm ⁻¹)	Jackson (1957)

3.4.4 Nutrient addition and removal

Nutrients N, P and K added to wheat and almond were worked out on hectare basis (Appendix-XXVII). Nutrient removal was worked out by adding up the nutrients removed through the harvested biomass (Appendix-XXVIII).

3.4.5 Nutrient balance

At harvesting of wheat, the nutrient balance was calculated on the following assumptions :

- a) Detailed considerations, such as loss of nutrients by leaching, weeds and the rate of release of slowly available forms of these nutrients to available forms were not considered.
- b) Amount of nutrients retained by the non-harvested tree components were not included since complete harvest of the trees was not practicable.
- c) Net gain or 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 the soil.

Expected balance in soil was worked out as follows :

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

3.4.6 Economic studies

Cost of cultivation

The cost of cultivation of the field crop as well as maintenance of fodder and fruit trees and harvest of their produce was worked out on the basis of net cropped area and number of trees ha⁻¹ (Appendix-XXX and XXXI). The requirements of labour and mechanical power for different operations such as ploughing, harrowing, weeding and harvesting were calculated per hectare as per the rates prevalent at Experimental Farm. Cost of inputs such as fertilizers, seed, insecticide and weedicide were calculated based on the actual amounts applied to the land use system.

Gross returns

The prevailing local market prices were used to convert the yield of field crop, fodder and fruit tree in rupees ha⁻¹. The fuelwood value of morus and grewia was computed on the basis of calorific value. The market prices of the harvested products have been given in Appendix-XXIX.

Net returns

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

$$\text{Net returns} = \text{Gross returns} - \text{Total cost}$$

3.4.7 Statistical analysis

The data obtained were subjected to statistical analysis using RBD (Gomez and Gomez, 1984). Wherever the effects exhibited significance at 5 per cent level of probability, the least significant difference (LSD) was calculated.

EXPERIMENTAL RESULTS

EXPERIMENTAL RESULTS

The experimental results obtained for the present studies are given in this chapter under the following heads :

4.1 Field crop

4.1.1 Growth and yield of wheat

4.1.2 Foliar nutrient concentration and uptake

4.2 Tree species

4.2.1 Growth and harvested biomass

4.2.2 Foliar nutrient concentration and uptake

4.2.3 Root characteristics

4.3 Soil studies

4.3.1 Soil moisture

4.3.2 Organic carbon, available macronutrients, pH and EC status of soils

4.4 Relative illumination

4.5 Nutrient balance

4.6 Economic returns

4.6.1 Gross returns

4.6.2 Net returns

4.1 FIELD CROP

4.1.1 Growth and yield of wheat

The influence of different tree-crop combinations, nitrogen levels, distance and direction of the crop was studied on the growth and yield parameters of wheat.

4.1.1.1 Growth

The growth parameters studied were germination per cent, number of tillers per plant, number of plants per m² and plant height. The data are tabulated in Table 1 and Appendix II-IV.

Germination per cent

Germination per cent was significantly influenced due to different tree-crop combinations (Table 1). The maximum germination (83.96) was observed in T₃ (Sole Wheat), whereas the minimum (76.31) was recorded in T₂ (Morus-Almond-Wheat).

Influence of nitrogen level on germination per cent was non-significant, while distance and direction showed statistically significant effects with higher values at distance D₂ and direction DR₂ over D₁ and DR₁, respectively.

Combined effect of tree-crop combination x nitrogen level, tree-crop combination x distance and tree crop combination x direction on germination per cent of wheat was statistically non-significant (Appendix II-IV).

Number of tillers per plant

Tree-crop combinations affected the number of tillers per plant significantly. Among these the highest number was exhibited by T₃ (5.02) and the lowest by T₁ (4.20).

Table 1. Growth and yield attributes of wheat as influenced by tree-crop combinations, nitrogen doses, crop distance and direction

A) Tree-crop combination

Combinations	Growth				Yield						
	Germination percentage	Number of tillers plant ⁻¹	Number of plants m ⁻²	Plant height (cm)	Number of grain per ear	Number of ear per plant	1000 grain weight (g)	Length of ear (cm)	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest index (%)
T ₁	77.73	4.20	74.08	70.14	27.04	3.13	35.49	7.31	15.61	33.40	31.65
T ₂	76.31	4.30	78.42	70.70	28.25	3.35	37.62	7.73	17.10	37.54	31.12
T ₃	78.00	4.56	86.58	70.30	28.96	3.48	39.03	7.95	17.85	39.04	31.23
T ₄	81.37	4.36	81.67	68.91	27.42	3.22	36.66	7.50	16.26	35.87	31.01
T ₅	83.96	5.02	92.37	74.82	33.58	3.88	42.00	8.56	21.73	43.36	33.35
S.E.(diff.)	0.57	0.01	0.37	0.15	0.25	0.01	0.09	0.03	0.11	0.22	0.18
C.D. _{0.05}	1.14	0.03	0.73	0.29	0.50	0.02	0.17	0.07	0.21	0.44	0.36

B) Nitrogen doses

N ₁	79.26	4.11	79.28	67.29	27.70	3.40	37.39	7.65	15.95	36.37	30.32
N ₂	79.69	4.87	85.97	74.29	30.40	3.49	38.93	7.97	19.47	39.32	33.02
S.E.(diff.)	0.36	0.01	0.23	0.10	0.16	0.01	0.06	0.02	0.07	0.14	0.11
C.D. _{0.05}	NS	0.02	0.46	0.19	0.32	0.02	0.11	0.04	0.13	0.28	0.23

Contd...

Growth and yield attributes of wheat as influenced by tree-crop combinations, nitrogen doses, crop distance and direction

C) Distance

Distance	Growth				Yield						
	Germination percentage	Number of tillers plant ⁻¹	Number of plants m ⁻²	Plant height (cm)	Number of grain per ear	Number of ear per plant	1000 grain weight (g)	Length of ear (cm)	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest index (%)
D ₁	78.59	4.36	80.82	70.42	27.95	3.33	37.72	7.68	16.42	36.34	30.90
D ₂	80.36	4.62	84.83	71.52	30.15	3.50	38.60	7.94	19.00	39.34	32.44
S.E.(diff.)	0.36	0.01	0.23	0.09	0.16	0.01	0.06	0.02	0.07	0.14	0.11
C.D. _{0.05}	0.72	0.02	0.46	0.86	0.32	0.02	0.11	0.04	0.13	0.28	0.22

D) Direction

DR ₁	78.41	4.36	79.90	70.44	28.38	3.39	37.92	7.74	16.74	36.56	31.21
DR ₂	80.54	4.62	85.35	71.50	29.72	3.43	38.40	7.88	18.68	39.13	32.14
S.E.(diff.)	0.36	0.01	0.23	0.09	0.16	0.01	0.06	0.02	0.07	0.14	0.11
C.D. _{0.05}	0.72	0.02	0.46	0.18	0.32	0.02	0.11	0.04	0.13	0.28	0.22

Nitrogen levels, distance and direction independently also had significant effect on the number of tillers per plant; higher values being observed at nitrogen level N_2 , distance D_2 and direction DR_2 over N_1 , D_1 and DR_1 , respectively.

Similarly, the data in Appendix II-IV indicated that combined effects of tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction on number of tillers per plant resulted in significant differences.

Number of plants per m^2

Number of plants m^{-2} was also significantly influenced by tree-crop combinations. T_5 i.e. sole crop showed the maximum number (92.37) followed by T_3 (86.58), T_4 (81.67), T_2 (78.42) and T_1 (74.08) (Table 1). Nitrogen levels, distance and direction showed results similar to above. Their individual respective values were significantly higher at nitrogen level N_2 , distance D_2 and direction DR_2 over N_1 , D_1 and DR_1 .

The interaction effects between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction (Appendix II-IV) were also significant.

Plant height (cm)

Height of wheat plants growing in association with various tree-crop combinations was seen to have statistically significant difference (Table 1). Maximum height of 74.82 was recorded in sole crop. Among the combinations (T_1 - T_4), it was maximum at T_2 (70.70) followed by T_3 (70.30), T_1 (70.14) and at

T_4 (68.91) the minimum. T_3 and T_1 , however, were statistically at par with each other.

Plant height was maximum at nitrogen level N_2 which was statistically higher than at N_1 . Their respective values were 67.29 and 74.29 cm. Height of wheat plants growing at distance D_2 was significantly higher over D_1 showing the values of 71.52 and 70.42 cm, respectively. Direction effect also exhibited significant results. Direction DR_2 achieved higher plant height (71.50) over DR_1 (70.44).

Plant height was found to be significantly influenced due to interaction effects between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction (Appendix II-IV).

4.1.1.2 Yield ($q\ ha^{-1}$)

The yield parameters namely, number of grains per ear, number of ears per plant, thousand grain weight, length of ear, grain yield, straw yield and harvest index of wheat responded to the treatments as follows :

Number of grains per ear

The data on different tree-crop combinations (Table 1) have shown a significant effect on the number of grains per ear. The maximum number was seen in sole crop (33.58) and the minimum (27.04) in combination T_1 . The number of grains per plant was significantly higher at nitrogen level N_2 , distance D_2 and direction DR_2 over their corresponding treatments N_1 , D_1 and DR_1 .

The interaction effects between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction (Appendix II-IV) were also significant.

Number of ears per plant

Tree-crop combination had a significant effect on the number of ears per plant. Maximum number was observed under T_5 (3.88) followed by T_3 (3.48), T_2 (3.35), T_4 (3.22) and T_1 (3.13). All the treatments were statistically different from one another.

The number of ears per plant was seen to be significantly higher at nitrogen level N_2 , distance D_2 and direction DR_2 than N_1 , D_1 and DR_1 , respectively.

The interaction effects between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction (Appendix II-IV) were also significant.

Thousand grain weight (g)

Thousand grain weight was significantly higher (42.00) in sole crop (T_5) than all other tree-crop combinations. The minimum thousand grain weight (35.49) was found in tree-crop combination T_1 (Morus-Wheat).

The individual effects of nitrogen level, distance and direction were also significant. Nitrogen level N_2 , distance D_2 and direction DR_2 showed considerably higher thousand grain weight (Table 1).

The interaction effects were significant between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x

direction. Combination T_3N_2 gave the highest (42.96) value and T_1N_1 (34.71) the lowest (Appendix II-IV).

Length of ear (cm)

Ear length was significantly influenced by different tree-crop combinations. It was maximum (8.56) in T_3 and minimum (7.31) in T_1 . All combinations had significant difference between themselves. Nitrogen level, distance and direction also had significant effects on the length of ear where N_2 , D_2 and DR_2 exhibited higher values over N_1 , D_1 and DR_1 , respectively (Table 1).

The interaction effects too were significant in case of tree-crop combination x nitrogen level and tree-crop combination x distance, whereas it was non-significant in case of tree-crop combination x direction (Appendix II-IV).

Grain yield ($q\ ha^{-1}$)

Tree-crop combination effect showed significant differences in grain yield. The highest grain yield was in sole crop i.e. in T_3 (21.73) followed by T_3 (17.85), T_2 (17.10), T_4 (16.26) and T_1 (15.61). All the combinations behaved statistically different with one another. Individual effect of nitrogen level, distance and direction on grain yield was also significant. N_2 had remarkably higher yield (19.47) over N_1 (15.95). Distance D_2 (19.00) increased the yield significantly over D_1 (16.42). Similarly, DR_2 direction had significantly higher yield (18.68) over DR_1 (16.74) (Table 1).

The combined effects of tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction were also significant. The highest yield was obtained at T_3N_2 (23.17) while the lowest

was in T_1N_1 (13.79) (Table 2). The interaction effect between nitrogen level x distance (Table 3), irrespective of tree-crop combination, showed significantly higher grain yield (18.06) at D_1N_2 over D_2N_1 (17.13).

Straw yield ($q\ ha^{-1}$)

Straw yield due to effect of tree-crop combination, nitrogen level, distance and direction followed similar trend to grain yield (Table 1) as explained above.

Straw yield was highest (43.36) in T_5 and lowest (33.40) in T_1 . All the combinations were statistically different from one another. Nitrogen level, distance and direction influenced the straw yield significantly too. Their values at N_2 , D_2 and DR_2 were remarkably higher than N_1 , D_1 and DR_1 , respectively.

Interaction effects between tree-crop combination x nitrogen level, tree-crop combination x distance and tree-crop combination x direction were significant (Appendix II-IV). Pertaining the combined effect of tree-crop combination x nitrogen level, T_5N_2 gave the highest straw yield and the lowest (31.37) was obtained from T_1N_1 . The interaction effect between nitrogen level x distance, irrespective of tree-crop combination, showed straw yield of 37.92 and 37.97 at D_1N_2 and D_2N_1 , respectively, which were statistically at par.

Harvest index (%)

Tree-crop combinations influenced the harvest index significantly. The highest harvest index value (33.35) was worked out for the sole crop (T_5) which was statistically higher from the rest of the combinations. It was followed by tree-crop combination T_1 (31.65), T_3 (31.23), T_2 (31.12) and T_4 (31.01). However, T_2 , T_3 and T_4 were statistically alike (Table 1).

Table 2. Grain yield and straw yield of wheat as influenced by interaction between tree-crop combination x nitrogen level and tree-crop combination x distance

Combination	Grain yield (q ha ⁻¹)				Straw yield (q ha ⁻¹)			
	Nitrogen levels		Distance		Nitrogen levels		Distance	
	N ₁	N ₂	D ₁	D ₂	N ₁	N ₂	D ₁	D ₂
T ₁	13.79	17.42	14.01	17.20	31.37	35.43	31.27	35.53
T ₂	15.22	18.97	15.50	18.70	36.27	38.81	35.60	39.48
T ₃	16.07	19.63	16.21	19.49	38.10	39.99	37.75	40.34
T ₄	14.37	18.15	14.62	17.90	34.37	37.36	33.64	38.09
T ₅	20.29	23.17	21.75	21.71	41.72	45.00	43.46	43.27
S.E.(diff.)	0.15		0.15		0.32		0.32	
C.D. _{0.05}	0.30		0.30		0.63		0.63	

Table 3. Interaction effect of nitrogen level x distance on grain yield and straw yield of wheat

N levels	Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)	
	D ₁	D ₂	D ₁	D ₂
N ₁	14.77	17.13	34.76	37.97
N ₂	18.06	20.83	37.92	40.71
S.E.(diff.)	0.09		0.20	
C.D. _{0.05}	0.19		0.40	

The independent effects of nitrogen level, distance and direction have also been significant where higher values were found out for N_2 , D_2 and DR_2 over N_1 , D_1 and DR_1 , respectively.

The combined effects of tree-crop combination x nitrogen level and tree-crop combination x distance were significant, whereas that of tree-crop combination x direction was non-significant.

In case of interaction between tree-crop combination x nitrogen level, T_3N_2 showed the highest harvest index value (33.98), while the lowest (29.41) was calculated for T_4N_1 .

4.1.2 Foliar nutrient concentration and uptake

4.1.2.1 Nutrient concentration (%) in wheat during active growth stages

Variation in plant N, P and K concentration of wheat due to different tree-crop combinations, nitrogen levels, distance and direction was investigated at various critical growth stages. The findings are described below :

Nitrogen (%)

Tree-crop combination significantly influenced the concentration of N in wheat at all the active growth stages (Table 4).

At tillering stage N concentration was maximum (3.02%) in T_3 followed by T_2 (2.98%) which was statistically at par with T_4 (2.97%). Combinations T_5 (2.95%) and T_1 (2.95%) which were statistically alike came after. Significantly higher values for N concentration were observed at nitrogen level N_2 , distance D_1 and direction DR_2 over their counter-treatments N_1 , D_2 and DR_1 , respectively.

Table 4. Influence of tree-crop combination, nitrogen level, distance and direction on nitrogen concentration (%) of wheat at various stages of growth

A) Tree-crop combination

Combinations	Tillering	Panicle initiation	Milking	Harvesting	
				Grain	Straw
T ₁	2.94	2.45	1.34	1.63	0.29
T ₂	2.98	2.54	1.38	1.69	0.31
T ₃	3.02	2.62	1.42	1.74	0.32
T ₄	2.97	2.65	1.37	1.66	0.25
T ₅	2.95	2.67	1.46	1.78	0.35
S.E.(diff.)	0.007	0.013	0.007	0.008	0.005
C.D. _{0.05}	0.014	0.025	0.013	0.016	0.010

B) Nitrogen levels

N ₁	2.92	2.53	1.35	1.65	0.29
N ₂	3.03	2.65	1.43	1.74	0.31
S.E.(diff.)	0.004	0.008	0.004	0.005	0.003
C.D. _{0.05}	0.009	0.016	0.008	0.010	0.006

C) Distance

D ₁	2.99	2.56	1.34	1.67	0.30
D ₂	2.95	2.61	1.44	1.73	0.31
S.E.(diff.)	0.004	0.008	0.004	0.005	0.003
C.D. _{0.05}	0.009	0.016	0.008	0.010	0.006

D) Direction

DR ₁	2.96	2.56	1.37	1.67	0.30
DR ₂	2.99	2.62	1.42	1.73	0.31
S.E.(diff.)	0.004	0.008	0.004	0.005	0.003
C.D. _{0.05}	0.009	0.016	0.008	0.010	0.006

At panicle initiation stage maximum N concentration was found in T_4 (2.67%) which was statistically at par with T_4 (2.65%). The minimum N concentration (2.45%) was in T_1 . Intermediate values of 2.53 and 2.61 per cent were seen in T_2 and T_3 , respectively.

Effect of nitrogen levels and direction showed similar trend to that of tillering stage; while the effect of distance was reversed. Distance D_2 showed markedly higher N concentration (2.61%) over D_1 (2.56%) at panicle initiation stage, probably as a result of growth initiation in the trees.

At milking stage highest N concentration was in T_5 (1.45%) which was significantly different from the remaining combinations. Minimum value (1.34%) was observed in T_1 .

Effect of nitrogen level, distance and direction followed same fashion as that of panicle initiation stage with greater values at N_2 , D_2 and DR_2 .

At harvesting stage the N concentration in grain was highest (1.77%) in sole crop (T_5). It was statistically higher than all other tree-crop combinations. The lowest N concentration was present in T_1 (1.63%). All the tree-crop combinations remained statistically different from one another.

Nitrogen level, distance and direction effects followed same trend to the preceding growth stages where higher values were recorded at N_2 , D_2 and DR_2 .

In straw, concentration of N was found to be maximum (0.34%) in T_5 , which was significantly higher over all other combinations. Minimum (0.25%)

concentration was in T_4 . Combinations T_2 and T_3 with their respective N concentration of 0.31 and 0.32 were statistically alike.

Application of nitrogen, crop distance and direction increased the N concentration in straw at level N_2 applied, at distance D_2 in direction DR_2 over its concentration at level N_1 and distance D_1 in DR_2 direction.

Phosphorus (%)

Phosphorus concentration at tillering stage was maximum in combinations T_2 and T_3 (Table 5). Both have shown the same value of 0.45 per cent. These two combinations in which almond is part of the system unit were statistically different from rest of the combinations. However, T_1 , T_4 and T_5 were statistically at par with T_2 (0.37) and T_3 (0.37). The lowest value (0.33) was in T_1 .

Influence of N application, distance and direction on P concentration was significant and more concentration values were observed at nitrogen level N_2 , distance D_2 and direction DR_2 over N_1 , D_1 and DR_1 , respectively.

At milking stage highest P value (0.31) was observed in T_1 and lowest (0.24) in T_5 . The remaining combinations T_2 (0.27), T_3 (0.27) and T_4 (0.28) were statistically at par with one another.

Phosphorus concentration responded significantly to the nitrogen application, distance and direction at milking stage. Treatments level N_1 , D_1 and DR_1 outranked their counter-treatments N_2 , D_2 and DR_2 . At harvesting, wheat grain and straw components were analysed separately for their P concentration. In case of grains maximum P was in T_1 (0.35) followed by T_4

Table 5. Influence of tree-crop combination, nitrogen level, distance and direction on phosphorus concentration (%) of wheat at various stages of growth

A) Tree-crop combination

Combinations	Tillering	Panicle initiation	Milking	Harvesting	
				Grain	Straw
T ₁	0.43	0.34	0.31	0.35	0.18
T ₂	0.46	0.35	0.27	0.33	0.14
T ₃	0.46	0.37	0.27	0.32	0.13
T ₄	0.44	0.38	0.28	0.34	0.15
T ₅	0.43	0.37	0.24	0.29	0.10
S.E.(diff.)	0.005	0.005	0.004	0.005	0.004
C.D. _{0.05}	0.010	0.010	0.008	0.010	0.008

B) Nitrogen levels

N ₁	0.43	0.35	0.28	0.33	0.142
N ₂	0.45	0.37	0.27	0.32	0.135
S.E.(diff.)	0.003	0.003	0.002	0.003	0.002
C.D. _{0.05}	0.006	0.007	0.005	0.006	0.005

C) Distance

D ₁	0.46	0.35	0.29	0.33	0.14
D ₂	0.43	0.37	0.27	0.31	0.13
S.E.(diff.)	0.003	0.003	0.002	0.003	0.002
C.D. _{0.05}	0.006	0.007	0.005	0.006	0.005

D) Direction

DR ₁	0.43	0.35	0.28	0.33	0.14
DR ₂	0.45	0.37	0.27	0.31	0.13
S.E.(diff.)	0.003	0.003	0.002	0.003	0.002
C.D. _{0.05}	0.006	0.007	0.005	0.006	0.005

(0.34), T_2 (0.33), T_3 (0.32) and T_4 (0.29). In case of straw, P concentration followed the trend similar to its concentration in grains.

Unlike N and K concentration, substantially higher P concentration in grain was noticed at nitrogen level N_1 , distance D_1 and direction DR_1 over their corresponding treatments N_2 , D_2 and DR_2 . Concentration of P in the straw also exhibited similar trend to that of grain.

Potassium (%)

Tree-crop combinations significantly influenced the concentration of K in the wheat plant at all the active growth stages studied (Table 6).

At tillering stage, the highest K concentration (1.91) was recorded in T_3 , followed by T_2 (1.90), T_4 (1.82), T_1 (1.80) and lastly the sole crop (1.78). All of the combinations were statistically different from one another. Its concentration was significantly higher at nitrogen level N_2 , distance D_1 and direction DR_2 over N_1 , D_2 and DR_1 , respectively.

Maximum K concentration of 1.78 per cent in T_3 and minimum of 1.68 per cent in T_1 was found at panicle initiation stage. At this stage T_3 (1.77) has risen to a level statistically at par with T_2 . Nitrogen application, distance of the crop and direction increased the K concentration significantly at N_2 , D_2 and DR_2 levels over their corresponding levels.

Although K concentration in wheat plants at milking stage was about half of its magnitude present during tillering and panicle initiation stage, yet its maximum concentration was in T_3 (0.92) followed by T_2 and T_4 . The later two showed the values of 0.91 and 0.90, respectively. The minimum value was observed in T_1 . Potassium concentration at nitrogen level N_2 , distance D_2 and

Table 6. Influence of tree-crop combination, nitrogen level, distance and direction on potassium concentration (%) of wheat at various stages of growth

A) Tree-crop combination

Combinations	Tillering	Panicle initiation	Milking	Harvesting	
				Grain	Straw
T ₁	1.81	1.69	0.86	0.31	0.81
T ₂	1.90	1.76	0.90	0.35	0.91
T ₃	1.91	1.78	0.91	0.37	0.96
T ₄	1.82	1.73	0.87	0.33	0.86
T ₅	1.79	1.77	0.92	0.39	1.02
S.E.(diff.)	0.005	0.005	0.005	0.006	0.006
C.D. _{0.05}	0.008	0.009	0.009	0.010	0.013

B) Nitrogen levels

N ₁	1.84	1.74	0.89	0.34	0.90
N ₂	1.85	1.75	0.90	0.35	0.92
S.E.(diff.)	0.002	0.003	0.003	0.003	0.004
C.D. _{0.05}	0.005	0.006	0.006	0.006	0.008

C) Distance

D ₁	1.87	1.72	0.86	0.34	0.88
D ₂	1.81	1.77	0.92	0.36	0.94
S.E.(diff.)	0.002	0.003	0.003	0.003	0.004
C.D. _{0.05}	0.005	0.006	0.006	0.006	0.008

D) Direction

DR ₁	1.83	1.74	0.88	0.34	0.89
DR ₂	1.86	1.75	0.90	0.35	0.93
S.E.(diff.)	0.002	0.003	0.003	0.003	0.004
C.D. _{0.05}	0.005	0.006	0.006	0.006	0.008

direction DR₂ was significantly higher over their counter-treatments N₁, D₁ and DR₁, respectively.

At harvesting stage K concentration in grain and straw followed same trend to that of milking stage with maximum values of 0.38 and 0.81 per cent in grain and straw, respectively. All the combinations were statistically different from one another in both the cases of grain and straw. Markedly higher values of K concentration in grain as well as straw was found at N₂ level of fertilization, D₂ distance and DR₂ direction than at N₁, D₁ and DR₁, respectively.

4.1.2.2 Uptake (kg ha⁻¹)

Grain

The uptake of N, P and K by wheat grain was significantly influenced due to tree-crop combinations, nitrogen levels, distance and direction independently (Table 7).

Maximum uptake of N (38.65) by grain was recorded in T₅ (sole crop) and minimum (25.66) has been in T₁ (Morus-Wheat). All the combinations were statistically different from one another. Similarly, uptake of P and K was maximum (6.21 and 8.37) in T₅ and minimum (5.35 and 4.80) in T₁, respectively.

The uptake of N, P and K due to the effect of variable nitrogen levels, distance and direction was significantly higher at nitrogen level N₂, distance D₂ and direction DR₂ over their respective values at N₁, D₁ and DR₁.

Straw

Uptake of N, P and K in wheat straw was significantly affected by tree-crop combinations (Table 7). Maximum N uptake (15.00) was recorded in T₅ and the minimum (8.94) in T₄. All of the combinations were statistically

Table 7. Nutrient uptake (kg ha^{-1}) in wheat as influenced by tree-crop combination, nitrogen level, distance and direction

A) Tree-crop combination

Combinations	Grain			Straw		
	N	P	K	N	P	K
T ₁	25.66	5.35	4.80	9.75	5.80	27.20
T ₂	29.00	5.52	5.94	11.68	5.10	34.28
T ₃	31.22	5.59	6.55	12.53	4.87	37.56
T ₄	27.22	5.41	5.32	8.94	5.44	30.98
T ₅	38.65	6.21	8.38	15.00	4.46	44.04
S.E.(diff.)	0.23	0.09	0.10	0.21	0.15	0.31
C.D. _{0.05}	0.46	0.19	0.20	0.42	0.31	0.62

B) Nitrogen levels

N ₁	26.56	5.13	5.50	10.69	5.07	33.06
N ₂	34.14	6.10	6.89	12.47	5.20	36.57
S.E.(diff.)	0.15	0.06	0.06	0.13	0.10	0.20
C.D. _{0.05}	0.29	0.12	0.12	0.27	NS	0.40

C) Distance

D ₁	27.62	5.34	5.59	11.00	5.01	32.29
D ₂	33.09	5.90	6.81	12.16	5.17	37.33
S.E.(diff.)	0.15	0.06	0.06	0.13	0.10	0.20
C.D. _{0.05}	0.29	0.12	0.12	0.27	NS	0.39

D) Direction

DR ₁	28.17	5.45	5.69	10.97	5.15	33.05
DR ₂	32.53	5.79	6.70	12.19	5.11	36.58
S.E.(diff.)	0.15	0.06	0.06	0.13	0.01	0.20
C.D. _{0.05}	0.29	0.12	0.12	0.27	NS	0.39

different from one another. Uptake of K has been highest (44.04) in T_3 and lowest (27.20) in T_1 , where all of the combinations remained statistically different from one another. In case of P, maximum uptake (5.80) was recorded in T_1 and minimum (4.46) in T_3 . T_2 and T_3 were statistically at par with each other.

The influence of variable levels of nitrogen, distance and direction was significant in case of N and K uptake only. Non-significant results were obtained for uptake of P (Table 7). Uptake of N and K at the nitrogen level N_3 , distance D_2 and direction DR_2 was significantly higher than their respective values at N_1 , D_1 and DR_1 .

4.2 TREE SPECIES

4.2.1 Growth and harvested biomass

Growth

Growth characters, namely, crown height (for fodder trees), plant height (for almond), collar diameter and crown spread were measured at sowing time as well as harvesting time of the wheat. The increase in growth attributes was taken as the difference between the two measurements. Separate statistical analysis was done for each species, since out of five tree-crop combinations, one individual species existed in only two depending upon a particular combination. The results so obtained have been described species-wise as below :

Morus

Morus represented T_1 (Morus-Wheat) and T_2 (Morus-Almond-Wheat) combinations. The data on crown height (Table 8) have shown its maximum value (1.90) in T_1 . The collar diameter growth in morus did not show significant change due to tree-crop combination. The crown spread (N-S) due

Table 8. Effect of tree-crop combinations on growth attributes of trees and their biomass yield

Combinations	Tree height (m)	Collar diameter (cm)	Crown spread (m)		Green biomass yield (q ha ⁻¹)			
			N-S	E-W	Leaf	Branch	Fruit	
Morus	T ₁	1.90	0.38	2.64	1.75	18.61	30.99	-
	T ₂	1.61	0.43	2.00	1.99	8.77	13.28	-
	Mean	1.75	0.40	2.32	1.87	13.69	22.13	-
	S.E.(diff.)	0.8	0.07	0.15	0.16	2.65	3.56	-
C.D. _{0.05}	0.19	NS	0.38	NS	6.48	8.71	-	
Grewia	T ₃	0.66	0.29	1.23	0.99	2.77	9.23	-
	T ₄	0.72	0.33	1.60	1.24	5.12	17.09	-
	Mean	0.69	0.31	1.41	1.11	3.94	13.16	-
	S.E.(diff.)	0.05	0.03	0.18	0.12	0.44	2.32	-
C.D. _{0.05}	NS	NS	NS	NS	1.09	5.67	-	
Almond	T ₂	0.49	0.88	0.73	0.67	-	-	12.56
	T ₃	0.42	0.93	0.78	0.71	-	-	12.65
	Mean	0.45	0.90	0.75	0.69	-	-	-
	S.E.(diff.)	0.07	0.09	0.03	0.02	-	-	0.78
C.D. _{0.05}	NS	NS	NS	NS	-	-	NS	

to tree-crop combination was significantly higher (2.64) in T_1 over T_2 (2.00), whereas the change was non-significant for E-W direction. The mean values for crown height, collar diameter, crown spread N-S as well as E-W were 1.75 m, 0.45 cm, 2.32 m and 1.87 m, respectively. Effect of nitrogen levels applied to the wheat was non-significant on the growth parameters of grewia except crown spread in N-S direction which showed higher value (2.54) at N_2 over N_1 (Table 9).

Grewia

Grewia represented tree-crop combinations T_3 (Grewia-Almond-Wheat) and T_4 (Grewia-Wheat). All the growth attributes for grewia showed non-significant changes due to tree-crop combinations as well as nitrogen levels applied to the wheat (Table 8 and 9).

Almond

Almond represented tree-crop combinations T_2 (Morus-Almond-Wheat) and T_3 (Grewia-Almond-Wheat). All the growth parameters of almond responded non-significantly for both tree-crop combinations effect as well as variable nitrogen doses applied to wheat (Table 8 and 9).

Biomass yield ($q\ ha^{-1}$)

The leaf and branch yield has been expressed as the average fresh weight value. The results so obtained have been presented as under :

Morus

Tree-crop combinations influenced the leaf and branch biomass yield of morus significantly (Table 8). A remarkably higher leaf biomass yield of 18.61 $q\ ha^{-1}$ was recorded in T_1 followed by 8.77 $q\ ha^{-1}$ in T_2 . The branch biomass yield also followed similar trend with maximum value of 30.99 $q\ ha^{-1}$ in tree-crop combination T_1 followed by 13.28 $q\ ha^{-1}$ in T_2 .

Table 9. Effect of nitrogen levels on growth attributes of trees and their biomass yield

Notrogen levels	Tree height (m)	Collar diameter (cm)	Crown spread (m)		Biomass yield (q ha ⁻¹)		
			N-S	E-W	Leaf	Branch	Fruit
Morus							
N ₁	1.69	0.39	2.11	1.78	10.70	16.70	-
N ₂	1.82	0.42	2.54	1.96	16.68	27.57	-
Mean	1.75	0.40	2.32	1.87	13.69	22.13	-
S.E.(diff.)	0.08	0.07	0.15	0.16	2.65	3.56	-
C.D. _{0.05}	NS	NS	0.38	NS	NS	8.71	-
Grewia							
N ₁	0.69	0.32	1.49	1.15	4.01	14.52	-
N ₂	0.69	0.30	1.35	1.08	3.89	11.80	-
Mean	0.69	0.31	1.42	1.11	3.95	13.16	-
S.E.(diff.)	0.05	0.03	0.18	0.12	0.44	2.32	-
C.D. _{0.05}	NS	NS	NS	NS	NS	NS	-
Almond							
N ₁	0.43	0.99	0.75	0.72	-	-	12.51
N ₂	0.48	0.82	0.72	0.72	-	-	12.70
Mean	0.45	0.90	0.73	0.72	-	-	12.60
S.E.(diff.)	0.07	0.09	0.03	0.02	-	-	0.78
C.D. _{0.05}	NS	NS	NS	NS	-	-	NS

The influence of nitrogen levels applied to wheat on leaf biomass yield was non-significant, whereas it caused significant changes in branch biomass yield. Nitrogen level N_2 gave higher yield (27.57) over N_1 (16.70) (Table 9).

Grewia

The biomass yield of both leaf and branch from grewia was significantly influenced by tree-crop combinations. Combination T_4 gave higher yields of 5.12 q ha⁻¹ and 17.09 q ha⁻¹ for leaf and branch biomass, respectively, whereas lower values of 2.77 q ha⁻¹ and 9.23 q ha⁻¹ were obtained from T_3 for leaf and branch, respectively (Table 8).

The variable dose of nitrogen applied to the wheat had non-significant effect on both the biomass yield of leaf and branch from grewia (Table 9).

Almond

The average almond fruit yield showed non-significant response for both tree-crop combinations as well as nitrogen levels applied to wheat (Table 10).

Table 10. Yield of almond fruits as influenced by tree-crop combination and nitrogen level

A. Tree crop combination

Combinations	Number of fruits per plant	Yield of fruits in kg per plant	Yield of fruits in kg ha ⁻¹
T_2	353.30	5.02	1256.00
T_3	352.80	5.06	1265.00
S.E.(diff.)	21.67	0.31	77.85
C.D. _{0.05}	NS	NS	NS

B. Nitrogen level

N_1	354.20	5.02	1251.00
N_2	352.00	5.08	1270.00
S.E.(diff.)	21.67	0.31	77.85
C.D. _{0.05}	NS	NS	NS

4.2.2 Foliar nutrient concentration and uptake

Foliar nutrient concentration of morus, grewia and almond was analysed to determine the influence of wheat crop association and nitrogen supply to it on the trees nutritional status. The results thus obtained have been described as below :

Morus

Morus species was present only in combinations T_1 and T_2 . Concentration of N in the tree leaves was significantly higher (2.52%) under tree-crop combination T_2 (Morus-Almond-Wheat) over T_1 (Morus-Wheat). In branch wood there was no significant change in N concentration due to tree-crop combinations though numerically higher value was seen in T_2 (Table 11). Change in P and K concentration of morus tree leaves due to tree-crop combinations was also non-significant, nevertheless, their concentration in branch wood differed significantly. P was more in T_2 over T_1 and K in T_1 over T_2 .

Grewia

This tree species was present in combinations T_3 and T_4 only. Nitrogen concentration in the leaves as well as branches exhibited significant changes due to tree-crop combinations. T_3 gave higher values of 2.76 and 1.41 per cent over their corresponding values of 2.63 and 1.39 per cent in T_4 , respectively for leaves and branches (Table 11). Concentration of P both in leaves as well as branches did not respond significantly to tree-crop combination. Potassium concentration in leaves showed significant difference due to tree-crop combination. Higher value (2.63) was in T_3 over T_4 (2.58). In lopped branch wood, despite of figuratively higher value in T_3 , the difference was non-significant.

Table 11. Nutrient concentration (%) of the tree foliage and branch wood as influenced by tree-crop combination and nitrogen level

a) Tree-crop combination

Combinations	N		P		K		
	Leaves	Branches	Leaves	Branches	Leaves	Branches	
Morus	T ₁	2.46	0.89	0.16	0.078	1.86	0.99
	T ₂	2.52	0.90	0.16	0.083	1.85	0.94
S.E.(diff.)	0.02	0.01	0.002	0.001	0.01	0.01	
C.D. _{0.05}	0.04	NS	NS	0.003	NS	0.02	
Grewia	T ₃	2.76	1.41	0.177	0.08	2.63	1.41
	T ₄	2.63	1.39	0.170	0.08	2.58	1.39
S.E.(diff.)	0.008	0.005	0.007	0.0005	0.010	0.01	
C.D. _{0.05}	0.020	0.011	NS	NS	0.025	NS	
Almond	T ₂	2.24	0.78	0.118	0.08	2.09	0.77
	T ₃	2.29	0.79	0.123	0.08	2.11	0.76
S.E.(diff.)	0.01	0.02	0.001	0.001	0.008	0.01	
C.D. _{0.05}	NS	NS	NS	NS	NS	NS	

b) Nitrogen levels

Morus	N ₁	2.45	0.89	0.16	0.08	1.85	0.96
	N ₂	2.53	0.91	0.16	0.08	1.86	1.00
S.E.(diff.)	0.02	0.01	0.002	0.001	0.01	0.01	
C.D. _{0.05}	0.04	NS	NS	NS	NS	NS	
Grewia	N ₁	2.65	1.38	0.17	0.08	2.61	1.40
	N ₂	2.74	1.42	0.18	0.08	2.60	1.40
S.E.(diff.)	0.008	0.005	0.007	0.001	0.01	0.01	
C.D. _{0.05}	0.020	0.011	NS	NS	NS	NS	
Almond	N ₁	2.23	0.78	0.123	0.079	2.14	0.76
	N ₂	2.30	0.79	0.118	0.081	2.06	0.77
S.E.(diff.)	0.01	0.02	0.001	0.001	0.008	0.01	
C.D. _{0.05}	NS	NS	NS	0.003	NS	NS	

Almond

In almond leaves N, P and K concentration was analysed from matured leaves collected in the month of May i.e., ten weeks after full bloom. Tree-crop combinations as well as nitrogen levels applied to wheat caused non-significant differences in N, P and K concentration. Similarly, the concentration of the above three nutrient elements in pruned branch wood also responded non-significantly to tree-crop combination.

The response of morus, grewia and almond to the application of nitrogen in wheat crop at levels N_1 and N_2 (Table 11) was observed as follows :

In morus leaves N concentration was significantly higher (2.53) at N_2 level over N_1 (2.45). In grewia N concentration both in leaves as well as branch wood was also significantly more at N_2 over N_1 level. Almond leaves and pruned wood, however, did not respond significantly to the wheat applied nitrogen. Phosphorus and potassium concentration in leaves and pruned wood of the above three tree species remained statistically non-significant except P in the pruned wood of almond.

Uptake

The N, P and K uptake has been influenced significantly in case of morus and grewia. Almond, however, did not experience significant change due to tree-crop combinations (Table 12). In morus T_1 gave significantly higher values for N, P and K in both leaves and branch wood. Similarly, higher uptake values of N, P and K were observed in T_4 (Grewia-Wheat) over T_3 (Grewia-Almond-Wheat) in case of grewia.

Table 12. Nutrient uptake (kg ha⁻¹) in loppings of fodder trees, leaves and pruned branches of almond as influenced by tree-crop combination and nitrogen level

a) Tree-crop combination

Combinations	N		P		K	
	Leaves	Branches	Leaves	Branches	Leaves	Branches
Morus						
T ₁	10.10	8.62	0.65	0.75	7.62	9.54
T ₂	4.86	3.77	0.30	0.35	3.57	3.91
S.E.(diff.)	1.42	0.98	0.09	0.09	1.06	1.08
C.D. _{0.05}	3.47	2.40	0.23	0.21	2.60	2.65
Grewia						
T ₃	4.41	11.64	0.28	0.65	4.22	10.86
T ₄	8.23	22.03	0.53	1.25	8.07	21.96
S.E.(diff.)	0.70	2.95	0.04	0.17	0.70	3.44
C.D. _{0.05}	1.71	7.23	0.11	0.41	1.71	8.42
Almond						
T ₂	10.41	2.22	0.71	0.23	13.34	2.49
T ₃	7.89	2.66	0.53	0.27	10.13	2.55
S.E.(diff.)	1.47	0.50	0.10	0.05	1.84	0.45
C.D. _{0.05}	NS	NS	NS	NS	NS	NS

b) Nitrogen levels

Morus						
N ₁	5.73	4.64	0.38	0.42	4.37	5.05
N ₂	9.23	7.74	0.58	0.68	6.82	8.40
S.E.(diff.)	1.42	0.98	0.09	0.09	1.06	1.08
C.D. _{0.05}	3.47	2.40	NS	0.21	NS	2.65
Grewia						
N ₁	6.31	15.65	0.41	0.90	6.24	15.07
N ₂	6.33	18.02	0.40	1.00	6.05	17.75
S.E.(diff.)	0.70	2.95	0.04	0.17	0.70	3.44
C.D. _{0.05}	NS	NS	NS	NS	NS	NS
Almond						
N ₁	6.54	2.32	0.46	0.23	8.89	2.27
N ₂	11.75	2.56	0.78	0.26	14.58	2.47
S.E.(diff.)	1.47	0.50	0.10	0.05	1.84	0.45
C.D. _{0.05}	3.60	NS	0.25	NS	4.51	NS

Nitrogen level applied to wheat influenced the uptake of N in leaves and branches of morus, N_2 being remarkably higher over N_1 . On the other hand, P and K uptake showed significant change in branch wood only. The uptake values were higher at N_2 level. In grewia, the influence of variable nitrogen on the uptake of N, P and K for both leaves and branches was found to be non-significant. In case of almond the results were statistically significant. Nitrogen level N_2 gave more values for each of the three nutrient elements, but their respective uptake values in pruned wood were statistically at par with the other corresponding values obtained at N_1 level.

4.2.3 Root characteristics

The root characteristics of the tree species namely the root depth, horizontal spread, number of roots, and root angle were studied by excavating the roots. The data presented in Table 13 indicated that almond had the deepest (122 cm) root system, whereas, grewia and morus possessed shallow roots penetrating to the depth of 68 and 74 cm, respectively. No tap root was recognised in morus and grewia (Figs. 2&3). Well defined tap root was found in almond (Fig. 4). The horizontal root spread was more in morus (2.91) followed by grewia (2.83) and almond (2.42). Total number of roots was maximum (850) in grewia, morus standing second (726) and almond being last (622). The root angle for the primary roots with reference to the vertical axis was highest in morus (81°), closely followed by grewia (79°) and the least value for almond (72°). The root angle for secondary roots also depicted same trend but with less readings. Maximum root mass was observed in the south-west direction for morus and grewia while it was maximum in north-east direction for almond (Figs. 2, 3 and 4).

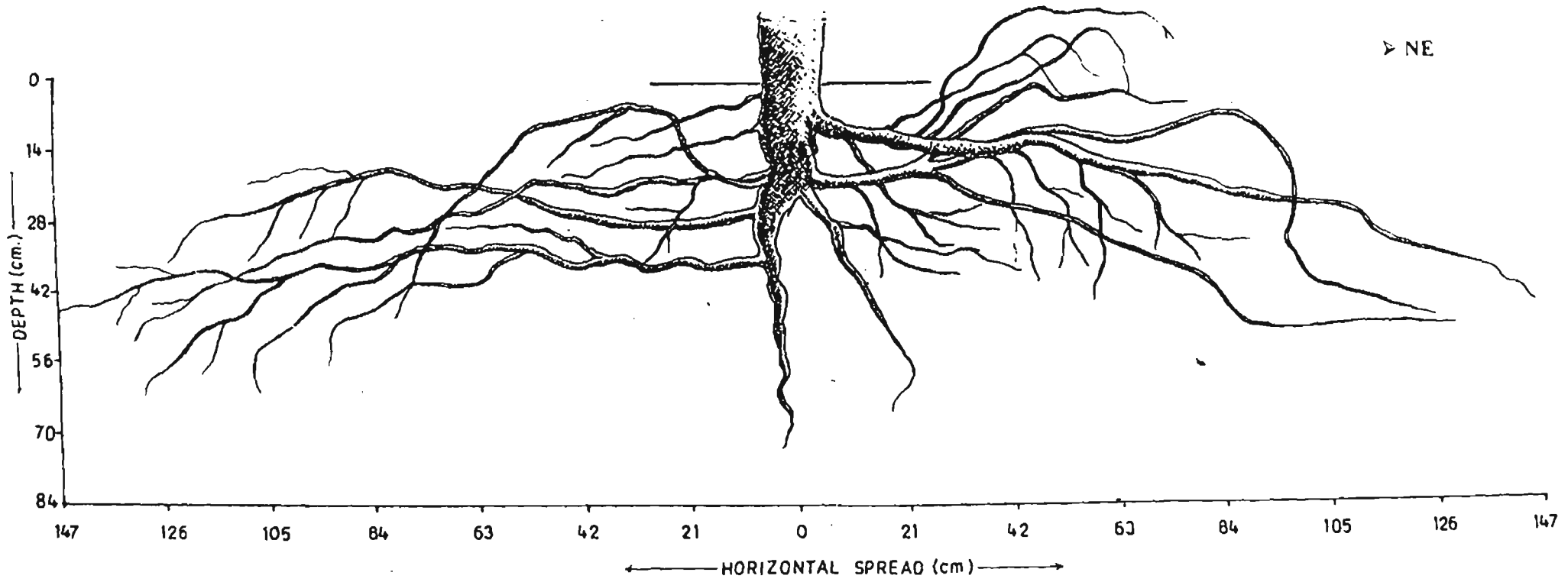


Fig. 2. The architecture and distribution of coarse roots in morus

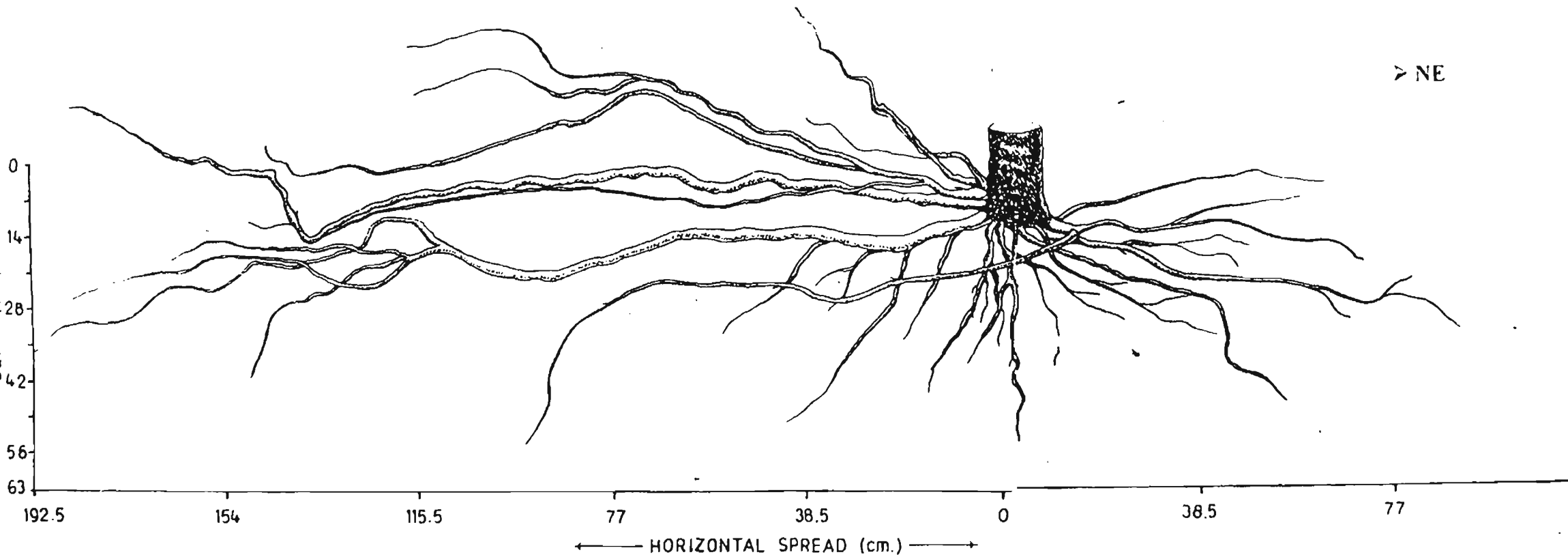


Fig. 3. The architecture and distribution of coarse roots in grewia

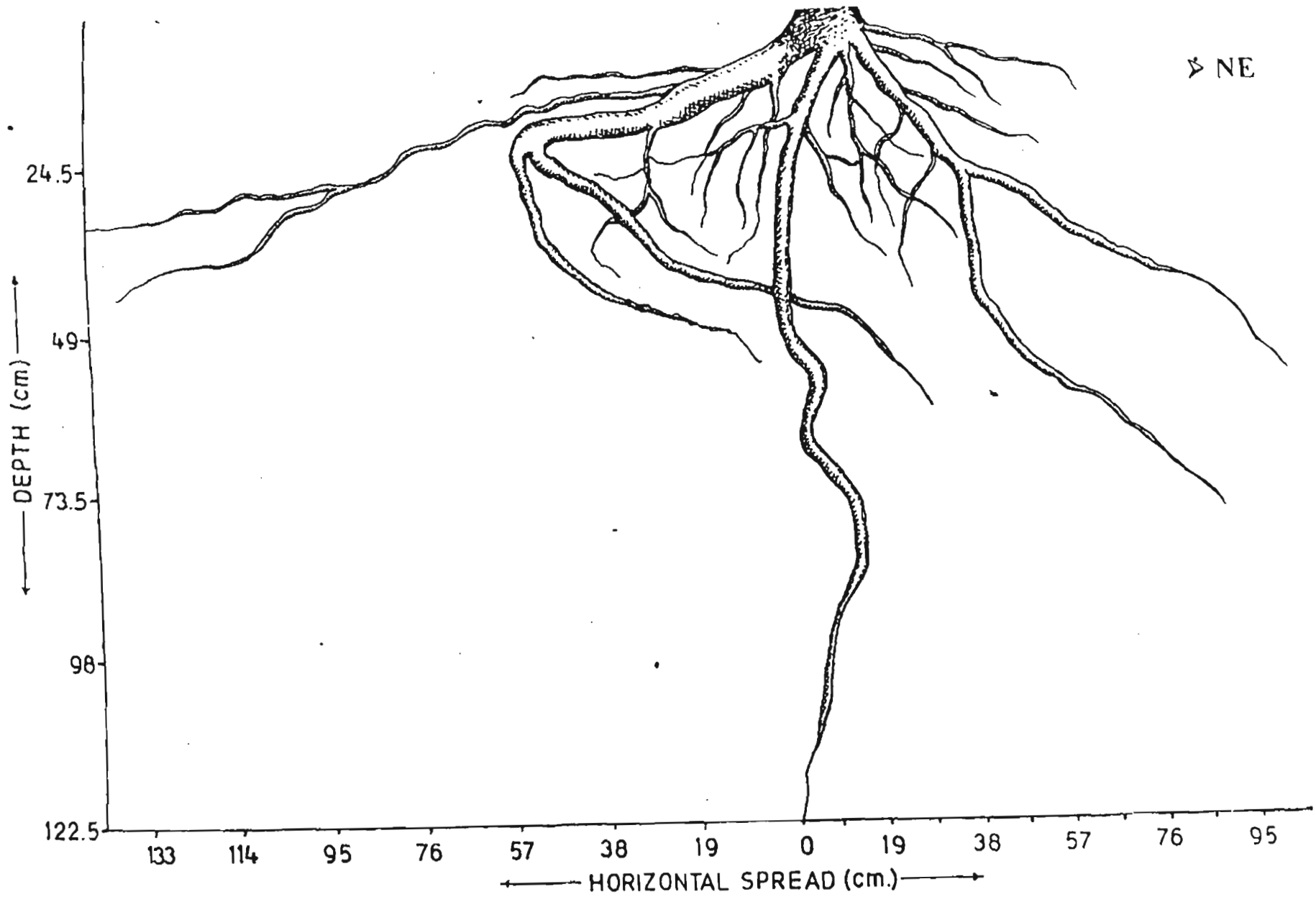


Fig. 4. The architecture and distribution of coarse roots in almond

Table 13. Growth attributes of Morus, Grewia and almond trees

Species	Collar diameter (cm)	Height (m)	Crown spread (m)				Root depth (cm)	Horizontal root spread (m)	Number of roots				Root angle (°)	
			North	South	East	West			Primary	Secondary	Tertiary	Total	Primary	Secondary
Morus	8.06	Lopped	1.30	1.35	0.85	0.95	74.00	2.91	19.00	169.00	538.00	726.00	81.00	58.00
Grewia	7.73	Lopped	0.73	0.87	0.60	0.63	68.00	2.83	34.00	197.00	619.00	850.00	79.00	55.00
Almond	8.46	3.55	1.40	1.56	1.12	1.23	122.00	2.42	29.00	96.00	497.00	622.00	72.00	46.00

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4.3 SOIL STUDIES

4.3.1 Soil moisture content (%)

Soil moisture content in the upper most 15 cm depth was significantly influenced due to tree-crop combinations, nitrogen levels, distance and direction independently at all the active growing stages for wheat except for distance effect at tillering stage (Table 14).

At tillering stage maximum soil moisture content was recorded in T_3 (7.86) followed by T_2 (7.68), T_5 (6.75), T_4 (6.48) and T_1 (6.27). All of the combinations were statistically different from one another. At panicle initiation stage, the highest soil moisture was in T_3 (19.05) and the minimum was in T_1 (15.04). The highest soil moisture (17.10) was recorded again in T_3 at milking stage and the lowest (9.35) was in T_1 . At harvesting stage maximum soil moisture has been found in T_5 (6.48) and minimum in T_1 (4.57).

In general, the soil moisture content increased from tillering to panicle initiation stage in more than double the amount which, however, showed continuous decline towards the crop maturity.

Application of nitrogen to wheat crop helped in maintaining the soil moisture at significantly higher levels during all the active crop growth stages, though practically the difference in values between N_1 and N_2 levels was negligible. Variations in soil moisture due to distance were more or less similar to above. Except at tillering during which more values were observed at distance D_2 over D_1 .

As to direction effect, significantly higher values were recorded in DR_2 over DR_1 for the first two active growing stages, whereas the reverse was observed during the later two growing stages (Table 14).

Table 14. Per cent soil moisture at various stages of growth as affected by tree-crop combination, nitrogen level, distance and direction

A) Tree-crop combination

Combinations	Per cent soil moisture			
	Tillering	Panicle initiation	Milking	Harvesting
T ₁	6.28	15.04	9.35	4.58
T ₂	7.68	15.20	13.49	5.13
T ₃	7.86	19.05	17.10	5.86
T ₄	6.48	18.01	16.39	5.51
T ₅	6.68	17.62	16.52	6.48
S.E.(diff.)	0.05	0.05	0.06	0.05
C.D. _{0.05}	0.10	0.11	0.12	0.10

B) Nitrogen levels

N ₁	6.80	16.87	14.46	5.43
N ₂	7.19	17.10	14.68	5.60
S.E.(diff.)	0.03	0.03	0.04	0.03
C.D. _{0.05}	0.06	0.07	0.07	0.06

C) Distance

D ₁	7.02	16.78	14.00	4.68
D ₂	6.97	17.18	15.14	6.34
S.E.(diff.)	0.03	0.03	0.04	0.03
C.D. _{0.05}	NS	0.07	0.07	0.06

D) Direction

DR ₁	7.47	17.08	14.33	5.37
DR ₂	6.52	16.88	14.80	5.65
S.E.(diff.)	0.03	0.03	0.04	0.03
C.D. _{0.05}	0.06	0.07	0.07	0.06

4.3.2 Organic carbon, available macronutrients, pH and EC status of soils

Effects of various tree-crop combinations, nitrogen levels, distance and direction on organic carbon, available macronutrients, pH and EC were studied before sowing as well as at all the four active growth stages of wheat. The pertinent data are given in Appendix-XXI-XXVI.

Organic carbon

Organic carbon content of the soil was significantly influenced due to tree-crop combination. In those combinations involving almond (T_2 and T_3) slightly higher values were observed throughout the growth stages. T_1 (sole wheat) was seen to have lowest values.

Effect of nitrogen levels was non-significant for all the growth stages except at harvesting stage. Distance affected organic carbon content significantly at all the growth stages in such a way that D_1 had significantly higher value over D_2 . Direction effect was non-significant except for harvesting stage.

Available N, P and K

The change in available N, P and K in the soils due to different tree-crop combinations, nitrogen levels, distance and direction was studied (Appendix-XXII-XXIV). Though, the variations in the values for all the nutrients observed at each of the active growth stages of wheat in different tree-crop combinations were statistically significant, yet in view of fertility management the differences were negligible. This is true since N ranged from 432 to 452, P from 53 to 57 and K from 347 to 352 kg ha⁻¹ irrespective of any particular treatment effect.

pH in the soil was found to be significantly affected by tree-crop combination except at milking stage. Its change was significant due to distance effect at all the four stages of growth. The effects of nitrogen level and direction were non-significant. Slightly lower pH was recorded at harvesting stage as compared to tillering stage. Higher pH values were seen in those combinations involving almond (T_2 and T_3). The lowest pH values were observed in sole wheat (T_4), while T_1 and T_4 were in between.

E.C.

Tree-crop combinations were seen to influence E.C. significantly except at tillering stage. The trend was similar with pH. Distance also had significant effect, where D_1 showed slightly higher values over D_2 . Nitrogen levels and directions had non-significant effects.

4.4 PER CENT RELATIVE ILLUMINATION (RI)

Tables 15 to 17 show per cent relative illumination below the tree canopy (D_1). The observations have been taken during the active growth stages of wheat and at various phenophases of the trees. The forest trees (grewia and morus) were completely lopped before sowing of wheat, while almond trees were shading their leaves.

At all the active growth stages studied for wheat statistically significant difference in RI was caused due to tree-crop combinations. T_4 was always receiving full incident radiation as it was without trees.

At tillering 100 per cent RI was under combinations Morus-Wheat and Grewia-Wheat (T_1 and T_4). The almond trees in T_2 and T_3 reduced the light

Table 15. Relative illumination (%) as affected by tree-crop combination and direction

A) Tree-crop combination

Combinations	Per cent relative illumination			
	Tillering	Panicle initiation	Milking	Harvesting
T ₁	100.00	70.12	57.38	55.03
T ₂	87.04	67.12	51.82	50.04
T ₃	87.27	74.75	63.08	58.25
T ₄	100.00	100.00	75.00	67.33
T ₅	100.00	100.00	100.00	100.00
S.E.(diff.)	0.62	0.62	0.62	0.61
C.D. _{0.05}	1.26	1.26	1.25	1.23

D) Direction

DR ₁	91.97	77.85	68.90	64.60
DR ₂	97.76	79.85	70.01	67.66
S.E.(diff.)	0.40	0.40	0.40	0.40
C.D. _{0.05}	0.80	0.80	0.80	0.80

Table 16. Relative illumination (%) as affected by interaction between tree-crop combination x direction

Combinations	Per cent relative illumination							
	Tillering		Panicle initiation		Milking		Harvesting	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	100.00	100.00	69.58	70.67	56.68	58.08	52.33	57.73
T ₂	79.75	94.33	66.67	67.58	51.25	52.40	48.00	52.08
T ₃	80.08	94.45	72.50	77.00	62.33	63.83	56.50	60.00
T ₄	100.00	100.00	100.00	100.00	74.25	75.75	66.17	68.50
T ₅	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
S.E.(diff.)	0.56		0.89		0.87		0.86	
C.D. _{0.05}	1.13		1.78		NS		0.17	

Table 17. Influence of tree-crop combination on the RI (%) and soil moisture (%) at different phenophases of trees and wheat growth stages

Month	Phenophases/ growth stages				Tree-crop combinations									
	Grewia	Morus	Almond	Wheat	T ₁		T ₂		T ₃		T ₄		T ₅	
					RI	Soil moisture	RI	Soil moisture	RI	Soil moisture	RI	Soil moisture	RI	Soil moisture
Mid. Dec	Dormant	Dormant	Leafless/ dormant	Sowing	100	6.10	84	7.74	85	7.90	100	6.60	100	6.80
Late Jan	Dormant	Dormant	Leafless/ end of dormancy	Tillering	100	6.28	87	7.68	87	7.86	100	6.48	100	6.68
Mid Mar	Bud sprouting	Leaf emergence / expansion	Fruit setting	Panical initiation	70	15.04	67	15.20	75	19.05	100	18.01	100	17.62
Late Apr	Leaf emergence/ expansion	Crown formation	Fruit developme nt	Milking	57	9.35	52	13.49	63	17.10	75	16.39	100	16.52
Early June	Crown formation	Crown formation	Green fruit harvesting	Harvesting	55	4.58	50	5.13	58	5.86	67	5.51	100	6.48

intensity at the crop level to 87.04 and 87.27 per cent. Combination T_4 was still showing 100 per cent RI at panicle initiation stage since sprouting did not take place. T_3 allowed penetration of 74.75 per cent of the incident radiation followed by T_1 (70.12) and T_2 (67.12). Maximum RI (75) was recorded under T_4 at milking stage also. It was again followed by T_3 (63.08), T_1 (57.38) and T_2 (51.82). Similarly, at harvesting stage also T_4 exhibited the highest RI (67.33). T_3 (58.25), T_1 (55.03) and T_2 (50.04) followed in sequence.

Generally, the wheat crop in T_4 started experiencing shade from milking stage onwards and allowed maximum light penetration to the crop level. Trees in T_2 and T_3 were intercepting some portion of the incident radiation at all the growth stages wherein the tree canopy in T_2 was absorbing maximum radiation. In T_1 shade occurrence began from panicle initiation stage. In all the combinations a continuous decline in RI was noticed along with tree crown development and minimum values were observed at harvesting stage.

4.5 NUTRIENT BALANCE IN SOILS

Nutrient balance in the soils was calculated for N, P and K. The total amount of N, P and K added through FYM, fertilizer and leaf litter vis-a-vis their amounts removed through tree-crop harvest were taken as input/addition and output/removal during the crop season.

The input and output data have been appended in Appendix XXVII and XXVIII and presented in Table 18. Addition and removal of N, P and K have been calculated separately for each tree-crop combination. Each tree-crop combination, considering the nature of components involved, also form a particular agroforestry system with a definite system unit. Hence, separate calculations have been made to understand the behaviour of nutrient addition and removal in each tree-crop combination or an agroforestry system.

Table 18. Nutrient balance in soils due to tree-crop combinations

Tree-crop combination	Initial status	Amount added*	Total amount (initial + added)	Cumulative removal (tree + crop)	Expected balance	Actual balance	Net gain or loss
Available N							
T ₁	442.70	80.00	522.70	54.13	468.57	430.00	-38.57
T ₂	452.50	159.72	612.22	70.01	542.21	449.20	-93.01
T ₃	447.70	457.63	605.33	81.22	524.11	451.70	-72.41
T ₄	433.00	80.00	513.00	66.42	446.58	447.70	-1.12
T ₅	432.30	80.00	512.30	53.65	458.65	425.10	-33.55
Available P							
T ₁	56.54	40.00	96.54	12.56	83.98	52.58	-31.40
T ₂	57.54	69.56	127.10	13.77	113.33	53.71	-59.62
T ₃	57.46	69.41	126.87	14.02	112.85	54.46	-58.39
T ₄	56.71	40.00	96.71	12.63	84.08	54.58	-29.50
T ₅	53.92	40.00	93.92	10.67	83.25	50.54	-32.71
Available K							
T ₁	350.70	40.00	390.70	49.16	341.54	348.90	+7.36
T ₂	351.60	123.21	474.81	59.16	415.65	350.20	-65.45
T ₃	352.10	120.36	472.46	71.24	401.22	351.00	-50.22
T ₄	351.80	40.00	391.80	66.33	325.47	349.50	+24.03
T ₅	347.80	40.00	387.80	52.41	335.39	348.80	+13.41

* Nitrogen added at N₁ level only has been used

Addition

It is seen from Table 18 that tree-crop combinations T_2 and T_3 had higher amounts of N, P and K addition than T_1 , T_4 and T_5 . In case of T_1 , the total quantity of N, P and K added was 80, 40 and 40 kg ha⁻¹, respectively. The values were same for T_4 and T_5 . In T_2 total quantity of N, P and K added was 159.72, 69.56 and 123.21, whereas the respective values for T_3 were 157.63, 69.41 and 120.36 kg ha⁻¹.

Removal

Removal of N, P and K through the harvested biomass among the tree-crop combinations followed the trend almost similar to addition of N, P and K. However, it was seen from the results (Appendix-XXVII and XXVIII) that removal of N was about two times less than its addition in T_2 and T_3 , whereas it was less than addition by 17-33 per cent in T_1 , T_4 and T_5 . In case of P, the removal was less than addition by almost 3 times in T_1 and T_4 , nearly 5 times in T_2 and T_3 , and about 4 times in T_5 . Pertaining to K, removal was seen to be higher than addition in T_1 , T_4 and T_5 , whereas in T_2 and T_3 removal was 2 times and 1.5 times less than addition, respectively.

Balance

It is evident from the data (Table 18) that the N in all the tree-crop combinations had a negative balance at crop harvest. The net losses of N for different tree-crop combinations ranged from 1.12 to 93.01 kg ha⁻¹. Similarly, phosphorus in soils showed net losses ranging from 29.50 to 59.62 kg ha⁻¹. In case of potassium, T_1 , T_4 and T_5 have shown net gains, whereas T_2 and T_3 depicted net losses.

Table 19. Variation in gross returns (Rs. ha⁻¹) due to tree-crop combination and nitrogen level

Components	T ₁		T ₂		T ₃		T ₄		T ₅	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
Wheat										
Grain	6895.00	8710.00	7610.00	9485.00	8035.00	9815.00	7185.00	9075.00	10145.00	11585.00
Straw	7842.50	8857.50	9067.50	9702.50	9525.00	9997.50	8592.50	3940.00	10430.00	11250.00
Sub-total	14737.50	17567.50	16677.50	19187.50	17560.00	19812.50	15777.50	18415.00	20575.00	22835.00
Morus										
Leaf	837.45	837.45	394.65	394.65	-	-	-	-	-	-
Branch	1276.30	1276.30	546.92	546.92	-	-	-	-	-	-
Sub-total	2113.75	2113.75	941.57	941.57	-	-	-	-	-	-
Grewia										
Leaf	-	-	-	-	152.35	152.35	281.60	281.60	-	-
Branch	-	-	-	-	640.93	640.93	1186.73	1186.73	-	-
Sub-total	-	-	-	-	793.28	793.28	1468.33	1468.33	-	-
Almond										
Fruit	-	-	37680.00	37680.00	37950.00	37950.00	-	-	-	-
Total	16851.25	19681.25	55299.07	57809.07	56303.28	58555.78	17245.83	19883.33	20575.00	22835.00

Table 20. Biomass productivity, total cost and net returns due to tree-crop combination and nitrogen level

Components	T ₁		T ₂		T ₃		T ₄		T ₅	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
Biomass (q ha ⁻¹)	94.76	102.45	86.10	92.39	78.82	84.27	70.95	77.72	62.01	68.17
Gross returns (Rs. ha ⁻¹)	16851.25	19681.25	55299.07	57809.07	56303.28	58555.78	17245.83	19883.33	20575.00	22835.00
Total costs (Rs. ha ⁻¹)	10084.88	10288.28	17329.57	17532.97	17329.57	17532.97	10084.88	10288.28	7393.27	7618.94
Net returns (Rs. ha ⁻¹)	6766.37	9392.97	37969.50	40276.10	38973.71	41022.81	7160.95	9595.05	13181.73	15216.06

4.6 ECONOMIC RETURNS

4.6.1 Gross returns

The gross returns from all the tree-crop combinations have been presented in Table 19. The data clearly indicates that maximum gross returns for both the nitrogen levels were obtained from T_3 (Grewia-Almond-Wheat), closely followed by T_2 (Morus-Almond-Wheat), T_5 (Sole Wheat), T_4 (Grewia-Wheat) and lastly T_1 (Morus-Wheat). In each tree-crop combination a substantial increase of gross returns was gained at nitrogen level N_2 over N_1 .

4.6.2 Net returns

Data from Table 20 shows that total costs incurred were highest for tree-crop combinations T_2 and T_3 , as compared to T_1 and T_4 and T_5 , at both the nitrogen levels. There was an increase in total cost of Rs. 203.40 in combinations T_1 - T_4 and Rs. 225.67 in T_5 , due to additional nitrogen applied at N_2 level.

The net returns were highest for T_3N_2 (Rs. 41022.81) followed by T_2N_2 (Rs. 40276.10). The net returns from T_2 and T_3 at N_1 nitrogen level were Rs. 37969.50 and Rs. 38973.71, respectively. Sole crop (T_5) could generate higher net returns over T_1 and T_4 at both the N levels. T_1 gave the least net income of Rs. 6766.37 and Rs. 9392.97 at N_1 and N_2 levels, respectively.

DISCUSSION

The effects emerged due to growing wheat in various tree-crop combinations and supplied with variable doses of nitrogen have been explained providing to each scientific framework. Response of system components and the system as a whole in terms of growth, yield, nutrient use, soil moisture availability, sharing of radiant energy, etc. has 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 Field crop

5.1.1 Growth and yield of wheat

5.1.2 Foliar nutrient concentration and uptake

5.2 Trees

5.2.1 Growth and harvested biomass

5.2.2 Foliar nutrient concentration and uptake

5.2.3 Root characteristics

5.3 Soil characteristics

5.3.1 Soil moisture

5.3.2 Organic carbon, available N, P and K, pH and EC

5.4 Relative illumination

5.5 Nutrient balance

5.5.1 Addition and removal of N, P and K

5.5.2 Balance of N, P and K

5.6 Economic returns

5.1 FIELD CROP

5.1.1 Growth and yield performance of wheat

Growth

The growth characters of wheat namely germination per cent, number of tillers per plant, number of plants per m^2 and plant height were significantly influenced due to different tree-crop combinations (Table 1). Wheat plants grown in association with trees in any of the combinations i.e., either with fodder trees alone or fodder plus almond trees, acquired lesser values for all the above growth parameters than in sole wheat plots. The tree species in various combinations have also shown some specificity of their association on the growth of wheat. Lower values of germination per cent in tree-crop combinations other than sole wheat may be due to the mild shade effect from the almond trees, possessing some leaves for the want of complete leaf fall. However, the morus and grewia trees were lopped fully.

The wheat plants grown in association with Grewia (T_4) or Grewia-Almond (T_3) showed significantly higher number of tillers per plant as well as number of plants per m^2 compared to Morus (T_1) or Morus-Almond (T_2). This may be attributed to the earlier initiation of growth (sprout) and faster growth rate in morus than grewia. Nevertheless, plant height followed reverse trend may be owing to the coincidence of growth initiation (leaf emergence) in grewia and shoot elongation stage for wheat, resulting into more competition for available resources viz. nutrients and moisture. Thus, it can be inferred from the above findings that grewia grown with wheat in combination with almond or alone has less adverse effect on the growth of wheat crop than morus-wheat or morus-almond-wheat except for plant height.

Better germination value at distance D_2 is the reflection of less shade from trees (almond in present case) and less probability for allelopathic effects

from fodder trees at farther distances. More sunlight in the south direction and the resultant increase in soil temperature can be responsible for the higher germination in DR₂ direction.

Yield

The yield attributes (Table 1) responded almost similarly to growth attributes. The yield attributes viz. number of grain per ear, number of ear per plant, 1000 grain weight; ear length, grain yield and straw yield had significantly higher values in sole crop (T₃) followed by combinations T₃ (Grewia-Almond-Wheat), T₂ (Morus-Almond-Wheat), T₄ (Grewia-Wheat) and T₁ (Morus-Wheat).

The higher yield from wheat grown in association with grewia or grewia-almond over morus or morus-almond may be in consequence of lesser competition from grewia as a result of the periodicity of its phenophases (Negi, 1995) which manifests late leaf flush and twig growth pattern as compared to morus which initiates its sprout early in the growing season (Bisht and Toky, 1993). This makes grewia stand in a better temporal complementarity to the wheat crop.

Higher foliage nutrient concentration (Table 4, 5 and 6) in wheat plants grown in association with grewia or grewia-almond over morus or morus-almond is indicative of the above reasons. Additionally, the crown spread of grewia was less than that of morus in N-S direction towards which wheat has been grown (Table 8). The moisture content of the soil (Table 14) also showed maximum competition in case of morus.

The results reported above could be endorsed by the findings reported by Akbar *et al.* (1990), Khybri *et al.* (1992), Chauhan *et al.* (1995), Kumar (1996)

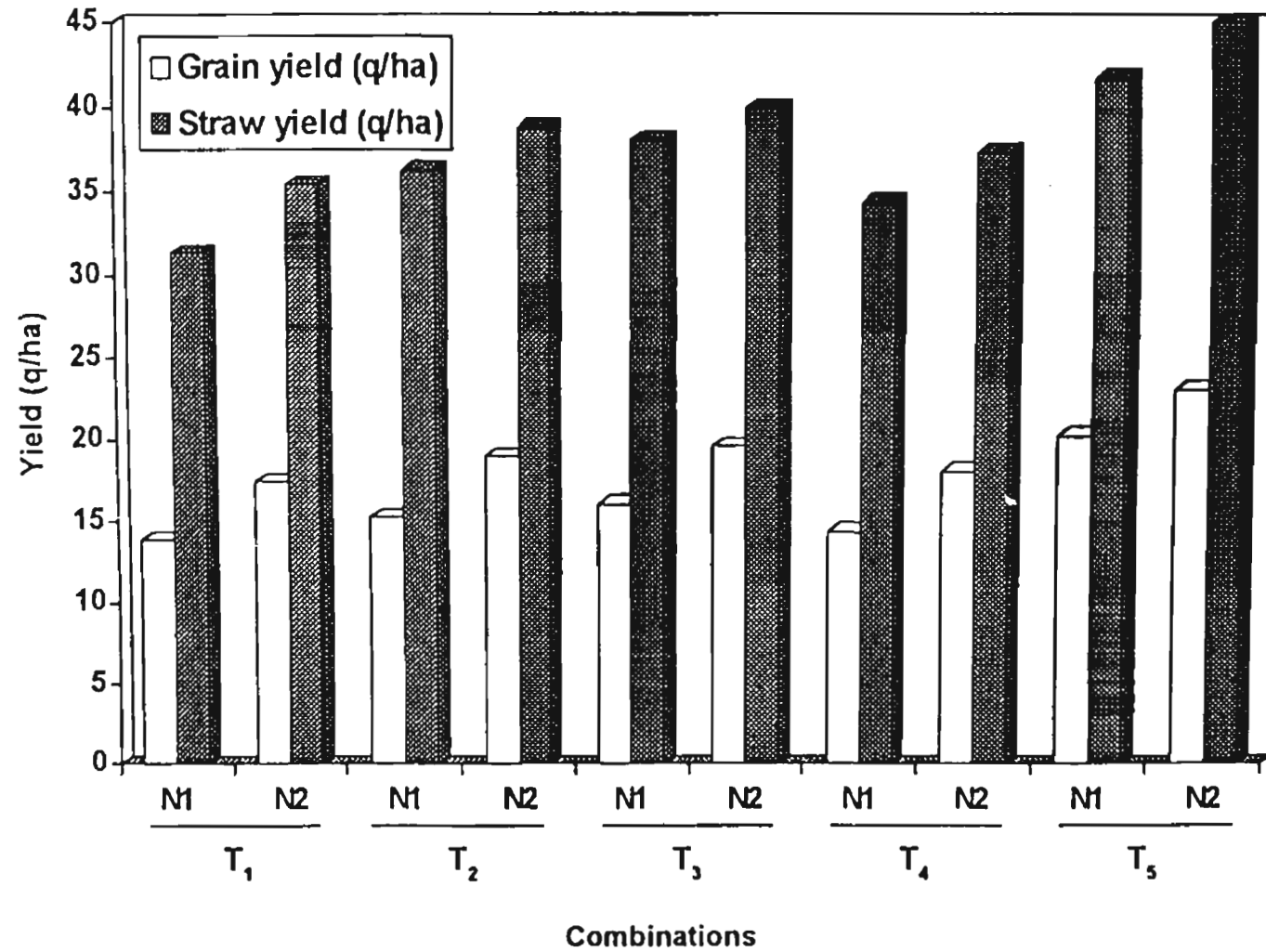


Fig. 5. Variation in grain and straw yield of wheat due to tree-crop combinations

and Kaushal (1998) on the suppressing effect of morus and grewia trees on field crops as compared to monocropping.

Furthermore, the better performance of wheat in association with grewia as compared to morus is supported by the findings of Khosla *et al.* (1992), Bisht and Toky (1993) and Negi (1995) who studied the phenology and growth patterns of the species considering their implications for agroforestry.

Therefore, because of early initiation of shoot growth, fast growing nature, wider spreading crown and much extended surfical root system, morus trees may have caused relatively higher depressing effect on growth and yield parameters of wheat.

All the yield attributes were enhanced due to higher dose of nitrogen (N_2) i.e., 25 per cent more than the recommended dose. This is in conformity with the work of O'Sullivan (1985), Yamoah *et al.* (1986), Kang *et al.* (1989) and Szott and Kass (1993) who indicated that supplementing alley cropping with N fertilizer in addition to prunings is necessary.

The positive yield response to higher N dose was spectacular in all the tree-crop combinations. This is attributed to the fact that increased N fertilization results in increased LAI and photosynthesis which in turn enhances the dry matter accumulation (Campbell *et al.*, 1979). Similar findings have also been reported by Singh and Singh (1995) for the variety HD-2285 indicating that yield contributing characters were significantly improved up to 120 kg N ha⁻¹.

Hence, it can be inferred from the present study that in tree-crop systems where the loppings are always removed from the system for fodder and fuel purposes, supplementary application of N is required at least to the extent of 25% of the normal dose recommended in field crops particularly wheat.

The various yield attributes were negatively influenced at distance D_1 (below the crown) in comparison to distance D_2 (outside the crown), obviously due to the combined effect of shade from the canopy as well as competition for moisture and nutrients. These effects are reflected on the yield of wheat. Study conducted by Shiekh and Haq (1986) revealed depressed wheat yield upto a distance of 5 m from tree row. Malik and Sharma reported decreased moisture extraction and increased yields of wheat and mustard linearly with increasing distance. The results are, further, in line with the findings of Yamoah (1986), Sharma (1992), Chauhan *et al.* (1995), Kumar (1996) and Kaushal (1998).

The higher values for yield and yield attributes of wheat in the south direction (DR_2) are most likely due to relatively higher RI (Table 15). These results are well supported by the findings of Shiekh and Haq (1978), Dhillon *et al.* (1984), Puri and Bangarwa (1992) and Kumar (1996).

5.1.2 Nutrient concentration and uptake

Concentration of N, P and K in the wheat plants was significantly influenced due to various tree-crop combinations at all the growth stages of wheat (Tables 4, 5 and 6).

At tillering stage maximum N, P and K concentration was observed in T_3 (Grewia-Almond-Wheat), closely followed by T_2 (Morus-Almond-Wheat), while T_5 (Sole Wheat) and T_1 (Morus-Wheat) were showing minimum values. This may be in consequence of higher nutrient accumulation in the soil through nutrient cycling and also supply of fertilizers to almond trees in the tree-crop combinations involving almond.

At panicle initiation stage T_3 , exhibited highest N, P and K concentration followed by T_4 . This may have occurred due to the commencement of active growth phase (leaf emergence) for the trees except grevia, and the resultant competition for belowground growth resources:

At milking stage maximum concentration of N and K was observed in T_5 (Sole Wheat) and minimum in T_1 (Morus-Wheat), whereas P concentration followed reverse trend. Similar results were reported by Patil and Lal (1991) which indicated that content of P has negative correlation with wheat yield from 60 DAS onward. The N, P and K concentration in wheat grain and straw also followed same trend as that of milking stage.

In general, a steady decrease in N, P and K concentration has been observed from the advancement in growth stages from tillering to milking stage. This reduction may have resulted due to dilution effect. Concentration of N and P was higher in grain than in straw, whereas, in case of K higher concentration was observed in straw.

Concentration of N, P and K was influenced significantly by variable N levels. The values were higher at N_2 level during all the growth stages except in case of P, which showed reverse trend from milking stage onwards. This may be due to the reason that increased N uptake also caused increased uptake of P and K (Sharma, 1987). Distance D_1 depicted higher values of N, P and K concentration at tillering stage obviously because of higher concentration of the nutrients in the soils near the tree row and negligible competition at that time.

The effect of distance on concentration of the nutrients was reversed at panicle initiation stage which implicitly explains that N, P and K concentration in wheat plants due to closer distance to trees (D_1) is decreased, may be through competition in soil or impeded supply in modified microclimatic conditions.

Less relative illumination can be one of the factors as is evident from the present study (Table 15).

Same was the trend followed by N and K at milking stage also, except that P concentration was seen to be higher at D_1 . Thereafter, the trend was alike for grain and straw too. Direction DR_2 showed higher values of nutrient concentration for all the stages except in case of P which followed reverse trend right from milking stage onwards.

Uptake of N, P and K in grain and straw of wheat reflected the pattern similar to their foliage concentration due to tree-crop combination, nitrogen level, distance and direction, except P, that too during the later stages viz. milking and harvesting. Maximum uptake was in T_3 whereas minimum in T_1 .

5.2 TREE SPECIES

5.2.1 Growth and harvested biomass

The data on tree growth (height, collar diameter and crown spread) and yield (leaf and branch biomass, and fruit yield) attributes have been presented in Table 8.

Morus

Higher crown height has been recorded in T_1 (Morus-Wheat) over T_2 (Morus-Almond-Wheat). The change in collar diameter was non-significant between the combinations even though more values were found in T_2 . This seems to be the consequence of no inter-species competition in T_1 since it includes only morus trees lopped at equal height whereas in T_2 almond trees though pruned yet lightly and are maintained at the top canopy level. Morus trees are at middle canopy level and growing closer to the almond trees suffer more competition than those growing in T_1 independently. This close proximity

of morus trees to almond in T_2 may have resulted into less height growth and more diameter.

It was further noticed that morus crown spread was significantly less towards N-S direction in T_2 . This same suppressing effect may have resulted from the adjoining almond trees in this treatments. The branch and leaf biomass yield was also higher in T_1 . Higher leaf and branch biomass in T_1 was obvious since it contained more number of morus trees per unit area compared to T_2 .

Grewia

All the growth attributes in grewia depicted non-significant changes due to tree-crop combination. This may have been owing to the too short a time period i.e. between the start of sprouting in the species till the end of the crop season (late March-early June) to manifest significant differences in growth attributes. Biomass yield was more in T_4 obviously due to the more number of trees per unit area.

Almond

All growth parameters failed to show significant differences in almond due to tree-crop combination. Same was the case in fruit yield too. This can be attributed to the vertical stratification between almond trees and both the fodder trees aboveground as well as belowground enabling them to utilize resource pools at separate levels both above and belowground as is evident from the present studies.

5.2.2 Foliar nutrient concentration and uptake

The effect of different tree-crop combinations on the N concentration in the leaves of morus and grewia was significant, whereas non-significant results were recorded for P in both the tree species. K concentration was also seen to

have influenced significantly in grewia due to tree-crop combinations. N, P and K concentration in almond leaves showed non-significant differences due to tree-crop combinations.

In case of branch wood, P and K concentration was significantly influenced due to tree-crop combinations in morus, whereas in grewia branch wood, only N concentration was observed to be influenced significantly. The values were more in combinations where almond happened to be an associated tree species either with morus or grewia. This can be ascribed to the increased availability of nutrient elements in soils due to application of fertilizer to almond, being a fruit crop. The concentration of N, P and K in pruned branches of almond responded non-significantly to tree-crop combinations.

Differential doses of nitrogen supplied to wheat significantly affected the N concentration in tree foliage. Higher concentration was found at N_2 level over N_1 . This indicates that the trees have made use of the applied nitrogen either through direct competition with the wheat crop or by utilizing the leachable nitrogen. The values obtained for N, P and K concentration in foliages of trees were similar to those obtained by Verma and Mishra (1989), Khosla *et al.* (1982) for grewia, Pal *et al.* (1979), Singh (1992), Kumar (1996) for morus, and Das (1990) for almond.

5.2.3 Root characteristics

Fodder trees

The maximum length of the single longest root was 1.47 m for morus and 1.92m for grewia which extended in south-west direction may be due to favourable growth conditions both in terms of soil moisture and temperature in this direction. The maximum root mass was also in the same direction. The very little root mass in the east and west direction (Fig. 6) can be attributed to the probable competition between the adjoining trees as they are planted in east-

west direction. The lateral roots, especially in the upper layer of the soil exhibited a tendency of spreading almost parallel to the ground level but definitely showed a positive geotropism. In morus and grewia root branching was more pronounced. The property of accumulating maximum roots in upper soil profile provide the plants an easy access to the moisture and nutrients from top soil. However, the bulk of their roots concentrated near the surface are indicative of strong root competition with the intercropped plants. These observations are in close conformity with the findings by Dhyani *et al.* (1990), Toky and Bisht (1992), and Bisht and Toky (1993).

Pruning/lopping of the fodder trees to benefit from loppings and to reduce shading may have negative effects on the root distribution (Noordwijk and Purnomosidhi, 1995) which enhance belowground competition. Lopping probably induces formation of new adventitious roots which tend to grow in the upper soil layers. More specifically, a lower height of stem pruning/lopping may lead to increased number of superficial/proximal roots of smaller diameter. One more factor which can likely reduce the rooting depth of trees and divert the direction of lateral roots in agroforestry associations is fertilization of the field which makes the topsoil more accessible for tree roots (Schroth, 1995) and may favour the formation of shallow root systems.

It can be seen from Fig. 5 that horizontal spread of major/coarse roots was 1.03 and 1.47 m in the north and south directions, respectively, for morus. The respective figures for grewia were 0.85 in north and 1.47 in south. These dimensions form the belowground tree-crop interface (TCI) in the north and south direction towards which the crops are sown. The distance of the actual cropped area from tree trunk in both the sides was 0.5 m, hence the net TCI distance was 0.53 and 0.97 m in north and south direction, respectively, for morus. The respective values for grewia were 0.35 and 0.97 m in north and south.

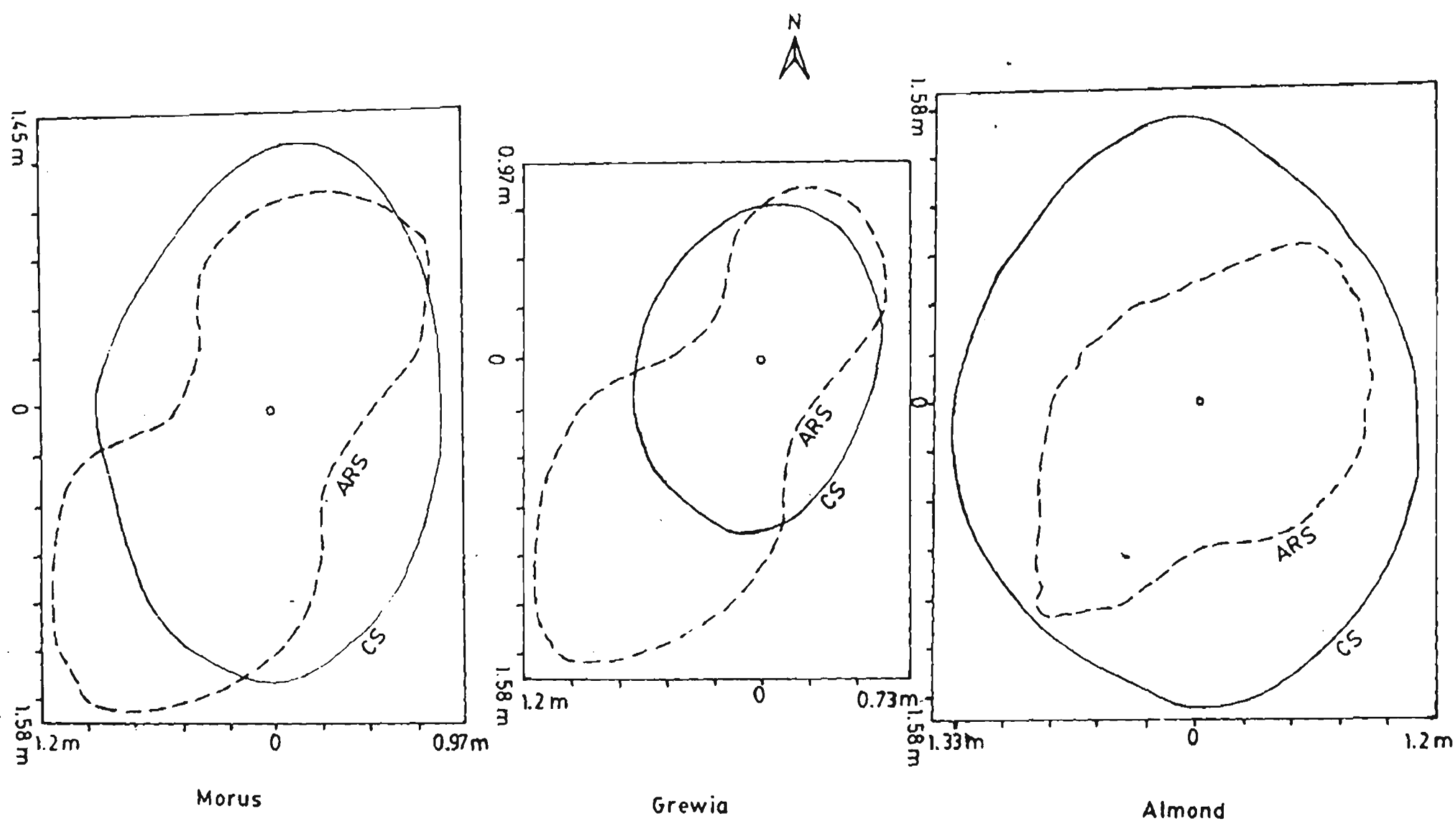


Fig. 6. The tree-crop interface (TCI) area as delineated by the crown spread (CS) and area of the root spread (ARS)

The crown projection presented in Fig 5. indicated maximum crown spread upto 1.30 and 1.33 m in north and south direction, respectively, for morus. The corresponding values for grewia were 0.72 in north and 0.77 m in south directions. Since 1 m is the width of the bund, the effective above-ground TCI was 0.80 and 0.83 m towards north and south for morus, while it was 0.22 and 0.27 m for grewia, respectively.

The above discussion reveal that actual aboveground TCI and belowground TCI was 0.83 and 0.97 m in case of morus whereas the respective values for grewia were 0.27 and 0.97 m. The proportion of TCI aboveground : belowground was 0.86 for morus and 0.28 for grewia at the end of the crop season.

Almond

Almond had the deepest root system with well defined tap root (Fig. 4). The horizontal spread was limited to maximum length of 142.5 cm in the south west direction. Likewise, the maximum root mass also occurred in same direction. The underground TCI area (Fig. 5) was limited to 0.80 m in the north and 0.99 m in the south direction. On the other hand, the aboveground TCI area was much more than the underground. This is owing to the more wide-spread crown structure of almond as compared to horizontal spread of its roots. In this case, the aboveground TCI was about 1.7 times greater than belowground.

5.3 SOIL CHARACTERISTICS

5.3.1 Soil moisture

The soil moisture content was maximum in T₃ (Grewia-Almond-Wheat) right from tillering stage up to milking stage. This may be in consequence of the improved water holding late capacity of soils in plots supporting trees. Secondly, almond trees had deep root system resulting in less competition for moisture in surface layer (0-15 cm). However, at harvesting stage when all the

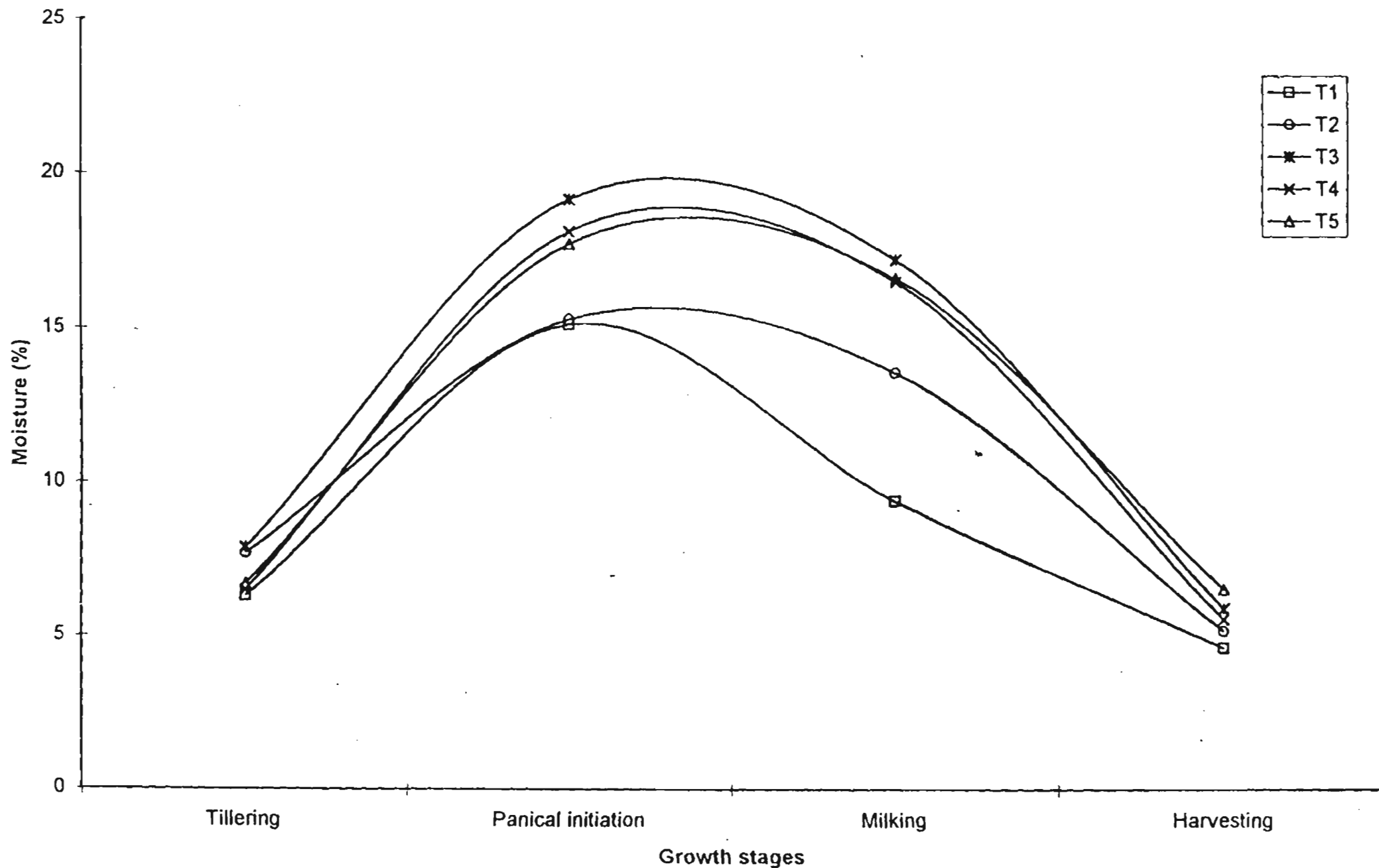


Fig. 7. Moisture content of the soil at various growth stages of the wheat as affected by tree-crop combinations

trees were in their active growth phase, T₂ (Sole Wheat) showed the highest soil moisture content.

The significantly higher soil moisture content observed at distance D₂ (outside the canopy) over D₁ (under the canopy) for all the growth stages except tillering is perhaps due to the competition for moisture by surfical root systems of the fodder trees and higher evaporative demands of the tree species. The results were reverse at tillering stage as the forest trees were in dormancy and almond provided mild shade.

Pertaining to the effect of direction, higher soil moisture content was observed in DR₁ (north) during the first two growth stages. The reason being more sunlight and higher temperature prevailing in the direction DR₂ (south). The trend was reversed during the last two active growth stages likely due to the changed position of sun and the resultant shade from trees towards south (DR₂). These results are in complete agreement with the observations of Kumar (1996).

5.3.2 Organic carbon, available NPK, pH and E.C.

Organic carbon was more in tree-crop combinations where almond was in association. Higher values of organic carbon in these plots (Appendix XXI) can be attributed to the additional biomass deposited in plots through litterfall from almond trees. The values were more under the canopy i.e., at distance D₁ which may be ascribed to more leaf litter accumulation and root turnover from trees.

Concentration of available N, P and K followed the trend similar to organic carbon content of the soil, however, the values resulting from various tree-crop combinations (Appendix XXII, XXIII and XXIV) has been considered to be negligible from fertility management point of view. In earlier works too

nutrient addition by trees to the soil has been reported amply by Gupta *et al.*, 1982; Nair, 1984; Toky *et al.*, 1989 and Nair, 1990.

The pH of the soil ranged from 6.80 to 7.00 and E.C. ranged from 0.164 to 0.217. The increase in above parameters though was significant yet negligible from fertility management considerations.

5.4 RELATIVE ILLUMINATION

The tree-crop combination T_2 (Morus-Almond-Wheat) showed the least RI under the tree canopy at all the growth stages of the wheat. The wide spreading and heavy crown of almond and its associate species morus resulted in absorption of the highest portion of incident radiation. Combination T_1 (Morus-Wheat) intercepted second highest incident radiation. The absorption of more radiation by combination T_2 over T_1 can be ascribed to the larger crown size and denser foliage in almond as compared to morus. In this regard, grewia is seen to be more compatible for association with wheat as it allowed maximum infiltration of sunlight to the crop.

For most part of the growing season RI was greater in south direction as compared to north owing to greater availability of sunlight as the trees have been planted in east-west direction. Similar results have been reported by Hazara and Tripathi (1986), Singh *et al.* (1989), Jaishwal *et al.* (1993).

In all the tree-crop combinations RI declined alongwith succeeding growth stages following the increasing canopy growth.

5.5 NUTRIENT BALANCE

5.5.1 Addition and removal of N, P and K

Addition of N, P and K was more in tree-crop combinations which included almond as a component (T_2 and T_3). This may be the consequence of additional supply of fertilizer and FYM to almond trees. Moreover, litterfall

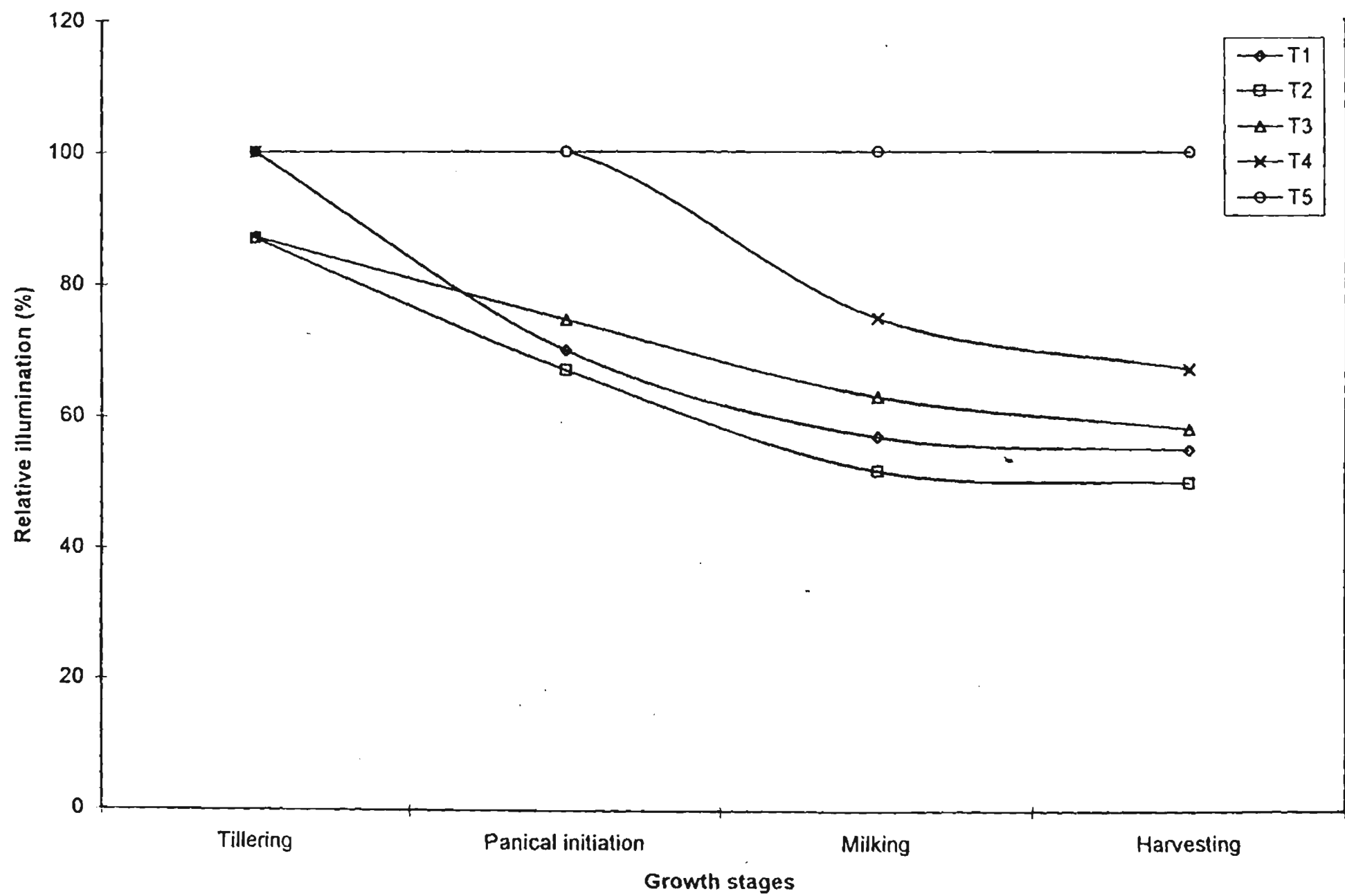


Fig. 8. Relative illumination under the canopy of the trees at various growth stages of the wheat crop

from almond trees has also contributed partly to the system. Removal of N, P and K was also higher in these plots. The additional biomass yield of fruits with higher nutrient concentration (Appendix XVII) accounts for the higher removal of nutrient elements from these plots.

5.5.2 Balance of N, P and K

Nitrogen and phosphorus have shown depletion in their quantities in all the tree crop combinations. In case of potassium, T_1 , T_4 and T_5 depicted net gains, while T_2 and T_3 (plots containing almond) showed depletion.

The negative balance for nutrients can be attributed to the reason that actual balance in the soil was lower than expected balance. The higher expected balance was due to their high amount found initially in the soil. This positive balance with K in T_1 , T_4 and T_5 may be due to less addition of K in T_2 and T_3 as compared to their requirement.

5.6 ECONOMIC RETURNS

Gross returns were more in T_3 and T_2 (plots containing almond) obviously because of the handsome returns from almond fruits. T_1 and T_4 showed lesser gross returns than T_5 .

Net return was highest in T_3 (Grewia-Almond-Wheat), closely followed by T_2 (Morus-Almond-Wheat), though the total cost incurred was also more in these combinations. Additional income from almond fruits accounts for the high net returns. The results are in agreement with the work of Kumar (1996), who reported higher gross and net returns from agrihortisilviculture system over sole crop system.

T_1 (Morus-Wheat) and T_4 (Grewia-Wheat) resulted in less net returns than T_5 when the cost incurred for maintenance and harvesting of the fodder trees was deducted from the gross returns.

SUMMARY & CONCLUSIONS

SUMMARY AND CONCLUSIONS

The present investigations entitled "Tree-crop interaction studies in agrihortisilviculture system" were carried out at Experimental Farm of the Department of Silviculture and Agroforestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, India, during December, 1997 to June, 1998.

The experiment was laid in randomized block design using five tree-crop combinations namely Morus-Wheat(T_1), Morus-Almond-Wheat(T_2), Grewia-Almond-Wheat(T_3), Grewia-Wheat(T_4) and Sole Wheat(T_5), each replicated thrice. In all of the combinations wheat was supplied with two nitrogen doses: (i) recommended N level (80 kg ha⁻¹) and (ii) 25 per cent more than the recommended level i.e., 100 kg ha⁻¹.

Growth and yield of wheat

Different tree-crop combinations had significant and adverse effect on the growth and yield attributes of wheat viz. germination percentage, number of tillers plant⁻¹, number of plants m⁻², plant height, number of grain per ear, number of ear plant⁻¹, ear length, thousand grain weight, grain yield, straw yield and harvest index.

Comparing the various tree-crop combinations for their relative effect on the reduction in wheat grain yield over sole cropping, it was 17.9 per cent with grewia-almond, 21.3% with morus-almond, 25.2% with grewia and 28.2% with morus. Thus, combinations grewia-almond-wheat and grewia-wheat had lesser

adverse influence on wheat yield than morus-almond-wheat and morus-wheat, respectively.

Increase in the recommended N level by 25 per cent enhanced all the above growth and yield parameters except germination percentage, significantly. It helped in producing the grain as well as straw yield below the tree canopy equal or even more in magnitude to that obtained outside the tree canopy i.e. at distance D_2 . Direction DR_2 showed significantly higher yield over DR_1 .

Nutrient concentration and uptake

The N, P and K concentration in wheat plants at tillering stage was maximum in the combinations involving almond trees as a component, and minimum values were observed in sole wheat. However, at the later growth stages of the wheat higher N, P and K concentration was found in sole wheat over other tree-crop combinations.

In general, a steady decrease in N, P and K concentration has been observed with the advancement in growth period. Concentration of N and P was higher in grain, whereas K concentration was higher in straw. N_2 level of fertilization increased the N, P and K concentration in the wheat plants significantly. N, P and K concentration was higher at distance D_1 over D_2 at tillering stage. This trend was reversed during the later stages in consequence of growth initiation in trees. Direction DR_2 was seen favouring the wheat plants with higher nutrient concentration at all the stages studied. Concentration of P from milking stage onwards was higher at N_1 level of fertilization, distance D_1 and direction DR_1 over their counter-treatments N_2 , D_2 and DR_2 , respectively.

Uptake of N, P and K in grain and straw reflected a pattern similar to their concentration due to tree crop combinations, nitrogen levels, distance and direction.

Tree species

Harvested biomass of loppings was more in morus-wheat, and grewia-wheat tree-crop combinations over morus-almond-wheat and grewia-almond-wheat, respectively. The crown spread of grewia was 60 per cent and 68 per cent of morus in north-south and east-west directions. Almond possessed the highest crown spread. Non-significant changes in N, P and K concentrations in almond leaves and pruned branches were observed. On the other hand, significant changes in nutrient concentration of fodder tree leaves and branches were found for some of the elements.

The root architecture and distribution of grewia and morus was more or less similar. Horizontally spreading, shallow roots without tap root, mainly spreaded either in south-west or in north-east directions were the specific features of these tree species. Nevertheless, considerable difference was recognized in almond root system which exhibited well defined tap root, penetrating deeper, lesser angle of secondary and tertiary roots with respect to the vertical axis and lesser number of total roots. Almond appeared to be more suitable to intercrop in agroforestry systems for its less spreading deep-rooted feature.

Soil studies

Soil moisture was high when wheat was grown in association with grewia-almond except at harvesting stage, among all the tree-crop combinations. Application of nitrogen helped in maintaining the soil moisture at significantly higher level during all the active growth stages. Significantly

higher soil moisture was observed at distance D_2 (outside the canopy) at all the stages except tillering.

Organic carbon content in the soil was slightly higher in combinations involving almond (T_2 and T_3) throughout the growth period. Distance D_1 had significantly higher organic carbon content over D_2 . Nitrogen level and direction effects were non-significant. Concentration of available N, P and K in the soil followed the trend similar to organic carbon content of the soil. Soil pH and E.C. also showed slight increase where organic matter was higher.

Relative illumination (R.I.)

The tree-crop combination T_2 (Morus-Almond-Wheat) followed by T_1 (Morus-Wheat) showed the least RI from panicle initiation stage onwards. The R.I. value decreased to the level of 50-67 per cent in different tree-crop combinations at harvesting stage.

Nutrient balance

Addition as well as removal of N, P and K was more in the combinations which included almond (T_2 and T_3) as a component. N and P showed depletion in all the cases while K was depleted only in T_2 and T_3 .

Economic returns

The total cost incurred, gross returns as well as net returns were high in tree-crop combinations involving almond.

CONCLUSIONS

Comparing the tree-crop combinations with respect to nutrient availability, soil moisture and sharing of radiant energy while intergrating *Grewia optiva*, *Morus alba* and almond (*Prunus amygdalus*) with wheat in agroforestry systems, the following inferences can be made.

Wheat yield reduction was maximum (28.2%) in the tree-crop combination : Morus-Wheat whereas, Grewia-Almond-Wheat had minimum (17.9%) reduction in yield. The association of morus with wheat has reduced N, P and K concentration in wheat plants more than grewia. Collating the tree-crop phenophases i.e. grewia and morus, grewia showed more temporal and spatial compatibility with wheat crop than morus, however belowground spatial distribution of grewia and morus roots was almost alike. Morus and grewia both had shallow and spreading root system.

Availability of soil moisture was more in combinations involving almond and grewia. Similarly, N, P and K addition as well as removal was also more in these combinations.

It can be inferred from the present studies that grewia forms a better option than morus to be intercropped with wheat in agrisilviculture system. Similarly, grewia-almond-wheat constitutes a better agrihortisilviculture system than morus-almond-wheat. In this system wheat crop should be supplemented with 25 per cent extra nitrogen than the recommended dose.

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APPENDICES

**APPENDIX-1: METEOROLOGICAL DATA FOR THE EXPERIMENTAL SITE
DURING THE PERIOD OF FIELD STUDIES**

Month	Temperature (°C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
1997				
December	17.00	2.90	67.00	85.20
1998				
January	17.50	2.10	60.00	15.10
February	18.70	4.70	89.50	87.10
March	20.80	6.10	56.30	125.50
April	28.20	11.20	50.90	46.60
May	32.20	15.40	46.30	63.00
June	31.50	17.90	57.50	185.10
July	29.30	20.30	80.00	206.40
August	28.20	20.20	79.00	100.80
September	27.30	17.80	81.00	193.70
October	26.30	12.50	69.00	264.00
November	24.30	6.30	56.20	-

Source : *Meteorological Section, Department of Soil Science and Water Management, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) – 173 230*

**APPENDIX-II: INTERACTION EFFECT OF TREE-CROP COMBINATION X NITROGEN LEVEL ON GROWTH AND YIELD
ATTRIBUTES OF WHEAT**

Combi- nation	Growth								Yield													
	Germination (%)		No. of tillers plant ⁻¹		No. of plants m ⁻²		Plant height (cm)		No. of grain per ear		No. of ear plant ⁻¹		1000 grain weight (g)		Ear length (cm)		Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)		Harvest index (%)	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	77.46	78.00	3.81	4.60	71.08	77.08	66.40	73.87	25.50	28.58	3.05	3.21	34.71	36.27	7.20	7.41	13.79	17.42	31.37	35.43	30.40	32.89
T ₂	76.50	76.12	3.93	4.68	74.83	82.00	66.97	74.43	26.83	29.67	3.29	3.42	36.90	38.35	7.61	7.85	15.22	18.97	36.27	38.81	29.49	32.76
T ₃	77.50	78.50	4.18	4.95	84.08	89.08	66.55	74.05	27.67	30.25	3.42	3.55	38.27	39.79	7.81	8.10	16.07	19.63	38.10	39.99	29.59	32.88
T ₄	81.00	81.75	3.96	4.76	79.92	83.42	64.67	73.14	26.00	28.83	3.16	3.29	36.01	37.30	7.40	7.60	14.37	18.15	34.37	37.36	29.41	32.60
T ₅	83.83	84.08	4.68	5.37	86.50	98.25	71.87	77.76	32.50	34.67	3.78	3.98	41.04	42.96	8.24	8.89	20.29	23.17	41.72	45.00	32.71	33.98
S.E.(diff.)	0.81		0.02		0.52		0.21		0.36		0.016		0.12		0.05		0.15		0.32		0.26	
C.D. _{0.05}	NS		0.04		1.04		0.41		NS		0.032		0.24		0.10		0.30		0.63		0.51	

**APPENDIX-III: INTERACTION EFFECT OF TREE-CROP COMBINATION X DISTANCE ON GROWTH AND YIELD
ATTRIBUTES OF WHEAT**

Combi- nation	Growth								Yield													
	Germination (%)		No. of tillers plant ⁻¹		No. of plants m ⁻²		Plant height (cm)		No. of grain per ear		No. of ear plant ⁻¹		1000 grain weight (g)		Ear length (cm)		Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)		Harvest index (%)	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	76.33	79.12	4.03	4.38	72.42	75.75	69.40	78.87	25.92	28.17	3.02	3.24	34.81	36.17	7.15	7.46	14.01	17.20	31.27	35.53	30.82	32.48
T ₂	75.12	77.50	4.15	4.46	75.33	81.50	70.22	71.18	26.83	29.67	3.25	3.45	37.02	38.22	7.56	7.90	15.50	18.70	35.60	39.48	30.22	32.02
T ₃	77.25	78.75	4.44	4.69	83.17	90.00	69.75	70.85	27.33	30.58	3.38	3.59	38.54	39.52	7.79	8.12	16.21	19.49	37.75	40.34	29.95	32.52
T ₄	80.50	82.25	4.19	4.53	80.67	82.67	68.05	69.77	26.33	28.50	3.13	3.32	36.22	37.09	7.34	7.66	14.62	17.90	33.64	38.09	30.17	31.84
T ₅	83.75	84.17	4.99	5.06	92.50	92.25	74.70	74.93	33.33	33.83	3.87	3.88	41.99	42.01	8.56	8.57	21.75	21.71	43.46	43.27	33.33	33.36
S.E.(diff.)	0.81		0.02		0.52		0.21		0.36		0.02		0.12		0.05		0.15		0.32		0.26	
C.D. _{0.05}	NS		0.04		1.04		0.41		0.71		0.04		0.25		0.10		0.30		0.63		0.51	

APPENDIX-IV : INTERACTION EFFECT OF TREE-CROP COMBINATION X DIRECTION ON GROWTH AND YIELD ATTRIBUTES OF WHEAT

Combi- nation	Growth								Yield													
	Germination (%)		No. of tillers plant ⁻¹		No. of plants m ⁻²		Plant height (cm)		No. of grain per ear		No. of ear plant ⁻¹		1000 grain weight (g)		Ear length (cm)		Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)		Harvest index (%)	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	76.83	78.62	4.06	4.35	71.08	77.08	69.51	70.76	26.25	27.83	3.12	3.14	35.30	35.69	7.23	7.39	14.25	16.96	31.46	35.35	31.04	32.25
T ₂	74.37	78.25	4.15	4.46	75.33	81.50	70.24	71.17	27.50	29.00	3.31	3.39	37.22	38.02	7.63	7.84	16.07	18.12	36.21	38.87	30.62	31.62
T ₃	76.75	79.25	4.39	4.73	83.42	89.75	69.60	71.00	28.17	29.75	3.45	3.52	38.70	39.36	7.88	8.03	16.88	18.82	37.87	40.21	30.73	31.74
T ₄	80.50	82.25	4.23	4.49	78.42	84.92	68.31	69.50	26.50	28.33	3.20	3.24	36.40	36.91	7.43	7.57	15.07	17.45	34.08	37.65	30.54	31.47
T ₅	83.58	84.33	4.98	5.07	91.25	93.50	74.55	75.08	33.50	33.67	3.88	3.88	41.98	42.01	8.54	8.58	21.41	22.05	43.17	43.55	33.10	33.59
S.E.(diff.)	0.81		0.02		0.52		0.21		0.36		0.02		0.12		0.05		0.15		0.32		0.26	
C.D. _{0.05}	NS		0.04		1.04		0.41		0.71		0.04		0.24		NS		0.30		0.63		NS	

APPENDIX-V: INTERACTION EFFECT OF TREE-CROP COMBINATION X NITROGEN LEVEL ON NITROGEN CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	2.90	2.99	2.40	2.55	1.30	1.38	1.59	1.67	0.27	0.31
T ₂	2.92	3.04	2.45	2.62	1.33	1.42	1.65	1.72	0.29	0.33
T ₃	2.94	3.10	2.55	2.68	1.38	1.46	1.69	1.79	0.30	0.34
T ₄	2.92	3.02	2.60	2.70	1.32	1.41	1.62	1.70	0.28	0.22
T ₅	2.90	3.00	2.63	2.70	1.41	1.50	1.72	1.83	0.32	0.37
S.E.(diff.)	0.01		0.02		0.01		0.01		0.01	
C.D. _{0.05}	0.02		0.04		NS		NS		0.02	

APPENDIX-VI: INTERACTION EFFECT OF TREE-CROP COMBINATION X DISTANCE ON NITROGEN CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	2.95	2.94	2.42	2.53	1.26	1.42	1.58	1.69	0.29	0.30
T ₂	3.01	2.96	2.50	2.58	1.32	1.44	1.66	1.72	0.31	0.32
T ₃	3.08	2.96	2.58	2.65	1.37	1.47	1.71	1.77	0.32	0.33
T ₄	2.98	2.96	2.63	2.67	1.31	1.43	1.61	1.71	0.25	0.26
T ₅	2.95	2.95	2.68	2.65	1.46	1.46	1.78	1.78	0.35	0.35
S.E.(diff.)	0.01		0.02		0.01		0.01		0.007	
C.D. _{0.05}	0.02		0.04		0.02		0.02		NS	

APPENDIX-VII: INTERACTION EFFECT OF TREE-CROP COMBINATION X DIRECTION ON NITROGEN CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	2.93	2.97	2.45	2.50	1.30	1.38	1.60	1.67	0.29	0.30
T ₂	2.97	3.00	2.49	2.59	1.34	1.42	1.65	1.73	0.31	0.32
T ₃	3.01	3.03	2.57	2.67	1.40	1.44	1.72	1.67	0.31	0.32
T ₄	2.96	2.98	2.63	2.67	1.36	1.38	1.62	1.70	0.25	0.26
T ₅	2.94	2.96	2.67	2.67	1.45	1.47	1.76	1.80	0.34	0.36
S.E.(diff.)	0.01		0.02		0.01		0.01		0.007	
C.D. _{0.05}	NS		0.04		0.02		0.02		NS	

APPENDIX-VIII: INTERACTION EFFECT OF TREE-CROP COMBINATION X NITROGEN LEVEL ON PHOSPHORUS CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	0.42	0.44	0.33	0.34	0.32	0.31	0.35	0.34	0.18	0.17
T ₂	0.45	0.46	0.34	0.35	0.28	0.27	0.33	0.32	0.14	0.13
T ₃	0.45	0.46	0.36	0.38	0.29	0.26	0.32	0.31	0.13	0.12
T ₄	0.43	0.44	0.37	0.39	0.29	0.28	0.34	0.33	0.16	0.15
T ₅	0.42	0.43	0.36	0.38	0.25	0.24	0.29	0.28	0.11	0.10
S.E.(diff.)	0.007		0.007		0.006		0.007		0.006	
C.D. _{0.05}	NS		NS		NS		NS		NS	

APPENDIX-IX: INTERACTION EFFECT OF TREE-CROP COMBINATION X DISTANCE ON PHOSPHORUS CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	0.45	0.41	0.33	0.35	0.33	0.30	0.36	0.34	0.19	0.17
T ₂	0.48	0.44	0.34	0.35	0.29	0.27	0.34	0.32	0.14	0.13
T ₃	0.47	0.45	0.36	0.38	0.28	0.26	0.33	0.31	0.13	0.12
T ₄	0.46	0.42	0.37	0.39	0.30	0.28	0.35	0.33	0.16	0.15
T ₅	0.43	0.42	0.36	0.38	0.25	0.24	0.29	0.28	0.10	0.10
S.E.(diff.)	0.007		0.007		0.006		0.007		0.006	
C.D. _{0.05}	0.014		NS		NS		NS		NS	

APPENDIX-X: INTERACTION EFFECT OF TREE-CROP COMBINATION X DIRECTION ON PHOSPHORUS CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	0.43	0.44	0.33	0.34	0.32	0.31	0.36	0.34	0.19	0.17
T ₂	0.45	0.47	0.34	0.36	0.29	0.27	0.34	0.32	0.14	0.13
T ₃	0.45	0.47	0.36	0.38	0.28	0.27	0.33	0.30	0.13	0.12
T ₄	0.43	0.45	0.37	0.39	0.30	0.38	0.35	0.33	0.16	0.14
T ₅	0.42	0.43	0.36	0.38	0.25	0.24	0.29	0.28	0.10	0.10
S.E.(diff.)	0.007		0.007		0.006		0.007		0.006	
C.D. _{0.05}	NS		NS		NS		NS		NS	

APPENDIX-XI: INTERACTION EFFECT OF TREE-CROP COMBINATION X NITROGEN LEVEL ON POTASSIUM CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	1.80	1.81	1.68	1.69	0.85	0.86	0.30	0.31	0.80	0.82
T ₂	1.90	1.90	1.75	1.76	0.89	0.91	0.34	0.35	0.90	0.92
T ₃	1.91	1.92	1.77	1.78	0.90	0.92	0.36	0.37	0.95	0.97
T ₄	1.82	1.82	1.72	1.74	0.87	0.88	0.32	0.33	0.85	0.87
T ₅	1.78	1.79	1.77	1.78	0.92	0.93	0.38	0.39	0.10	1.03
S.E.(diff.)	0.006		0.007		0.007		0.007		0.009	
C.D. _{0.05}	0.011		NS		NS		NS		NS	

APPENDIX-XII: INTERACTION EFFECT OF TREE-CROP COMBINATION X DISTANCE ON POTASSIUM CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	1.83	1.79	1.64	1.74	0.82	0.90	0.30	0.32	0.77	0.85
T ₂	1.95	1.85	1.73	1.79	0.86	0.94	0.34	0.36	0.87	0.95
T ₃	1.95	1.87	1.77	1.79	0.87	0.95	0.36	0.38	0.92	0.10
T ₄	1.86	1.78	1.69	1.77	0.84	0.91	0.32	0.34	0.82	0.90
T ₅	1.78	1.79	1.77	1.78	0.92	0.93	0.38	0.40	1.01	1.02
S.E.(diff.)	0.006		0.007		0.007		0.007		0.009	
C.D. _{0.05}	0.011		0.013		0.013		NS		0.018	

APPENDIX-XIII: INTERACTION EFFECT OF TREE-CROP COMBINATION X DIRECTION ON POTASSIUM CONCENTRATION (%) IN WHEAT AT VARIOUS STAGES OF GROWTH

Combinations	Tillering		Panicle initiation		Milking		Harvesting			
							Grain		Straw	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	1.80	1.82	1.68	1.70	0.85	0.87	0.30	0.32	0.79	0.83
T ₂	1.88	1.92	1.75	1.77	0.89	0.91	0.34	0.36	0.89	0.93
T ₃	1.91	1.92	1.77	1.79	0.90	0.92	0.36	0.38	0.94	0.98
T ₄	1.81	1.83	1.72	1.74	0.86	0.89	0.32	0.34	0.84	0.88
T ₅	1.78	1.79	1.77	1.78	0.93	0.92	0.38	0.40	1.01	1.02
S.E.(diff.)	0.006		0.007		0.007		0.007		0.009	
C.D. _{0.05}	0.011		NS		NS		NS		NS	

APPENDIX-XIV: NUTRIENT UPTAKE (kg ha⁻¹) IN WHEAT AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X NITROGEN LEVEL

Combinations	Grain						Straw					
	N		P		K		N		P		K	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	22.06	29.26	4.80	5.90	4.16	5.44	8.49	11.01	5.62	5.98	25.20	29.20
T ₂	25.21	32.80	5.00	6.04	5.20	6.67	10.54	12.83	5.06	5.12	32.75	35.81
T ₃	27.23	35.21	5.12	6.06	5.81	7.29	11.44	13.63	4.95	5.79	36.26	38.87
T ₄	23.40	31.03	4.86	5.96	4.62	6.02	9.64	8.24	5.30	5.59	29.34	32.63
T ₅	34.91	42.40	5.88	6.54	7.71	9.04	13.36	16.65	4.42	4.50	41.72	46.35
S.E.(diff.)	0.33		0.13		0.14		0.30		0.22		0.44	
C.D. _{0.05}	NS		NS		NS		0.60		NS		0.88	

APPENDIX-XV: NUTRIENT UPTAKE (kg ha⁻¹) IN WHEAT AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X DISTANCE

Combinations	Grain						Straw					
	N		P		K		N		P		K	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	22.18	29.15	4.96	5.74	4.15	5.45	8.96	10.54	5.76	5.84	24.14	30.26
T ₂	25.76	32.25	5.18	5.87	5.10	6.66	10.89	12.47	5.07	5.12	31.01	37.55
T ₃	27.82	34.62	5.25	5.92	5.78	7.33	11.92	13.13	4.90	4.84	34.76	40.37
T ₄	23.65	30.79	5.03	5.79	4.62	6.02	8.20	9.69	5.29	5.60	27.64	34.33
T ₅	38.68	38.63	6.2	6.15	8.17	8.58	15.04	14.97	4.49	4.43	43.92	44.16
S.E.(diff.)	0.33		0.13		0.14		0.30		0.22		0.44	
C.D. _{0.05}	0.65		0.27		0.28		0.60		NS		0.88	

APPENDIX-XVI: NUTRIENT UPTAKE (kg ha⁻¹) IN WHEAT AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X DIRECTION

Combinations	Grain						Straw					
	N		P		K		N		P		K	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	22.87	28.45	5.04	5.66	4.22	5.38	9.00	10.49	5.79	5.80	24.96	29.45
T ₂	26.57	31.43	5.36	5.68	5.41	6.46	11.07	12.29	5.15	5.04	32.31	36.26
T ₃	29.16	33.28	5.46	5.71	6.02	7.09	11.94	13.11	4.92	4.81	35.64	39.49
T ₄	24.59	29.85	5.18	5.65	4.77	5.87	8.33	9.56	5.44	5.45	28.72	33.25
T ₅	37.66	39.65	6.20	6.23	8.04	8.72	14.50	15.51	4.46	4.46	43.63	44.45
S.E.(diff.)	0.33		0.13		0.14		0.30		0.22		0.44	
C.D. _{0.05}	0.65		0.27		NS		NS		NS		0.88	

APPENDIX-XVII : NUTRIENT CONCENTRATION (%) AND UPTAKE (KG/ HA) IN FRUITS AS INFLUENCED BY TREE CROP COMBINATION AND NITROGEN LEVEL

A) Tree-crop combination

Combinations	N		P		K	
	Content	Uptake	Content	Uptake	Content	Uptake
T ₂	6.05	20.70	0.74	2.51	3.40	11.46
T ₃	6.23	21.42	0.76	2.63	3.45	12.05
S.E.(diff.)	0.02	1.63	0.01	0.22	0.012	0.93
CD _{0.05}	0.05	NS	NS	NS	0.029	NS

B) Nitrogen level

N ₁	6.09	20.61	0.75	2.63	3.44	12.16
N ₂	6.18	21.51	0.75	2.51	3.40	11.35
S.E.(diff.)	0.02	1.63	0.01	0.22	0.01	0.93
CD _{0.05}	0.05	NS	NS	NS	0.03	NS

APPENDIX-XVIII: PER CENT SOIL MOISTURE AT VARIOUS STAGES OF GROWTH AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X NITROGEN LEVEL

Combinations	Per cent soil moisture							
	Tillering		Panicle initiation		Milking		Harvesting	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
T ₁	6.14	6.41	14.86	15.22	9.19	9.50	4.45	4.70
T ₂	7.41	7.95	15.12	15.27	13.37	13.61	5.03	5.22
T ₃	7.56	8.16	18.87	19.22	16.91	17.28	5.77	5.95
T ₄	6.56	6.71	17.87	18.14	16.29	16.48	5.44	5.58
T ₅	6.65	6.70	17.60	17.63	16.53	16.51	6.44	6.53
S.E.(diff.)	0.07		0.08		0.08		0.06	
C.D. _{0.05}	0.14		0.15		0.16		NS	

APPENDIX-XIX: PER CENT SOIL MOISTURE AT VARIOUS STAGES OF GROWTH AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X CROP DISTANCE

Combinations	Per cent soil moisture							
	Tillering		Panicle initiation		Milking		Harvesting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
T ₁	6.12	6.43	14.04	16.04	8.39	10.30	3.53	5.62
T ₂	7.92	7.44	14.21	16.19	12.77	14.21	4.00	6.25
T ₃	8.04	7.68	20.17	17.92	16.42	17.77	4.87	6.85
T ₄	6.36	6.61	17.88	18.13	15.87	16.90	4.53	6.49
T ₅	6.64	6.71	17.60	17.63	16.52	16.52	4.47	6.50
S.E.(diff.)	0.07		0.08		0.08		0.06	
C.D. _{0.05}	0.14		0.15		0.16		0.12	

APPENDIX-XX: PER CENT SOIL MOISTURE AT VARIOUS STAGES OF GROWTH AS INFLUENCED BY INTERACTION BETWEEN TREE-CROP COMBINATION X DIRECTION

Combinations	Per cent soil moisture							
	Tillering		Panicle initiation		Milking		Harvesting	
	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂	DR ₁	DR ₂
T ₁	6.68	5.87	15.12	14.96	9.19	9.50	4.34	4.81
T ₂	8.24	7.12	15.24	15.16	13.20	13.77	5.00	5.25
T ₃	8.40	7.32	19.33	18.76	16.75	17.44	5.72	6.00
T ₄	7.32	5.65	18.07	17.95	16.00	16.77	5.36	5.67
T ₅	6.69	6.66	17.66	17.57	16.52	16.52	6.45	6.52
S.E.(diff.)	0.07		0.08		0.08		0.06	
C.D. _{0.05}	0.14		0.15		0.16		0.12	

APPENDIX-XXI: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON ORGANIC CARBON CONTENT (%) OF THE SOIL AT VARIOUS STAGES OF GROWTH

A) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	1.25	1.35	1.40	1.23	1.05
T ₂	1.26	1.36	1.41	1.26	1.08
T ₃	1.26	1.36	1.42	1.26	1.06
T ₄	1.25	1.35	1.40	1.23	1.05
T ₅	1.18	1.29	1.30	1.12	0.97
S.E.(diff.)	0.004	0.003	0.004	0.005	0.004
C.D. _{0.05}	0.009	0.007	0.008	0.010	0.009

B) Nitrogen level

N ₁	1.24	1.34	1.38	1.22	1.05
N ₂	1.24	1.34	1.39	1.22	1.04
S.E.(diff.)	0.003	0.002	0.003	0.003	0.003
C.D. _{0.05}	NS	NS	NS	NS	0.006

C) Distance

D ₁	1.29	1.39	1.47	1.30	1.10
D ₂	1.20	1.30	1.31	1.14	0.99
S.E.(diff.)	0.003	0.002	0.003	0.003	0.003
C.D. _{0.05}	0.005	0.004	0.005	0.006	0.006

D) Direction

DR ₁	1.24	1.34	1.38	1.22	1.05
DR ₂	1.24	1.34	1.39	1.22	1.04
S.E.(diff.)	0.003	0.002	0.003	0.003	0.003
C.D. _{0.05}	NS	NS	NS	NS	0.006

APPENDIX-XXII: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON AVAILABLE NITROGEN CONTENT (kg ha^{-1}) OF THE SOIL AT VARIOUS STAGES OF GROWTH

B) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	442.7	477.7	498.5	450.0	430.0
T ₂	452.5	487.7	515.7	467.7	449.2
T ₃	447.7	482.7	511.7	469.9	451.7
T ₄	433.0	467.1	501.1	462.6	447.7
T ₅	432.3	467.5	508.6	458.7	425.1
S.E.(diff.)	0.61	0.59	0.62	0.84	0.62
C.D. _{0.05}	1.21	1.18	1.24	1.67	1.23

B) Nitrogen level

N ₁	441.6	471.8	498.6	455.2	430.4
N ₂	441.6	481.3	515.6	468.2	451.0
S.E.(diff.)	0.38	0.37	0.39	0.53	0.39
C.D. _{0.05}	NS	0.75	0.78	1.06	0.78

C) Distance

D ₁	443.8	478.7	509.2	463.6	442.8
D ₂	439.5	474.4	505.0	459.9	438.6
S.E.(diff.)	0.38	0.37	0.39	0.53	0.39
C.D. _{0.05}	0.77	0.75	0.78	1.06	0.78

D) Direction

DR ₁	441.6	476.4	506.9	461.4	440.5
DR ₂	441.7	476.6	507.3	462.1	440.9
S.E.(diff.)	0.38	0.37	0.39	0.53	0.39
C.D. _{0.05}	NS	NS	NS	NS	NS

APPENDIX-XXIII: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON AVAILABLE PHOSPHORUS CONTENT (kg ha⁻¹) OF THE SOIL AT VARIOUS STAGES OF GROWTH

C) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	56.54	79.75	71.00	62.17	52.58
T ₂	57.54	80.12	71.42	62.54	53.71
T ₃	57.46	80.12	71.75	62.54	54.46
T ₄	56.71	79.29	71.04	62.50	54.58
T ₅	53.92	76.67	69.83	59.21	50.54
S.E.(diff.)	0.39	0.37	0.38	0.31	0.28
C.D. _{0.05}	0.78	0.73	0.76	0.61	0.55

B) Nitrogen level

N ₁	56.37	79.13	70.90	61.85	53.15
N ₂	56.50	79.25	71.12	61.73	53.20
S.E.(diff.)	0.25	0.23	0.24	0.19	0.17
C.D. _{0.05}	NS	NS	NS	NS	NS

C) Distance

D ₁	58.35	80.88	72.23	63.27	55.18
D ₂	54.52	77.50	69.78	60.32	51.17
S.E.(diff.)	0.25	0.23	0.24	0.19	0.17
C.D. _{0.05}	0.49	0.46	0.48	0.39	0.35

D) Direction

DR ₁	56.33	79.08	71.02	61.78	53.20
DR ₂	56.53	79.30	71.00	61.80	53.15
S.E.(diff.)	0.25	0.23	0.24	0.19	0.17
C.D. _{0.05}	NS	NS	NS	NS	NS

APPENDIX-XXIV: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON AVAILABLE POTASSIUM CONTENT (kg ha^{-1}) OF THE SOIL AT VARIOUS STAGES OF GROWTH

D) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	350.7	370.0	362.5	356.5	348.9
T ₂	351.6	371.5	363.8	358.8	350.2
T ₃	352.1	372.0	364.4	359.4	351.0
T ₄	351.8	371.4	363.3	357.2	349.5
T ₅	347.8	365.5	359.0	353.7	348.8
S.E.(diff.)	0.34	0.40	0.32	0.32	0.43
C.D. _{0.05}	0.67	0.80	0.65	0.64	0.86

B) Nitrogen level

N ₁	350.8	370.0	362.60	357.0	349.5
N ₂	350.8	370.1	362.60	357.3	349.8
S.E.(diff.)	0.21	0.25	0.21	0.20	0.27
C.D. _{0.05}	NS	NS	NS	NS	NS

C) Distance

D ₁	353.2	373.4	364.8	358.5	350.5
D ₂	348.5	366.8	360.4	355.8	348.8
S.E.(diff.)	0.21	0.25	0.21	0.20	0.27
C.D. _{0.05}	0.42	0.51	0.41	0.40	0.54

D) Direction

DR ₁	350.7	370.1	360.7	357.1	349.4
DR ₂	350.9	370.0	362.5	357.2	349.9
S.E.(diff.)	0.21	0.25	0.21	0.20	0.27
C.D. _{0.05}	NS	NS	NS	NS	NS

APPENDIX-XXV: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON pH OF THE SOIL AT VARIOUS STAGES OF GROWTH

E) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	6.94	6.99	6.92	6.87	6.83
T ₂	6.97	7.00	6.94	6.89	6.85
T ₃	6.97	7.00	6.94	6.86	6.85
T ₄	6.94	6.98	6.92	6.88	6.83
T ₅	6.90	6.93	6.89	6.83	6.80
S.E.(diff.)	0.003	0.004	0.005	0.022	0.004
C.D. _{0.05}	0.006	0.008	0.009	NS	0.008

B) Nitrogen level

N ₁	6.94	6.98	6.92	6.88	6.83
N ₂	6.94	6.98	6.92	6.86	6.84
S.E.(diff.)	0.002	0.003	0.003	0.014	0.002
C.D. _{0.05}	NS	NS	NS	NS	NS

C) Distance

D ₁	6.96	7.00	6.94	6.88	6.86
D ₂	6.92	6.95	6.90	6.85	6.81
S.E.(diff.)	0.002	0.003	0.003	0.014	0.002
C.D. _{0.05}	0.004	0.005	0.006	0.027	0.005

D) Direction

DR ₁	6.94	6.98	6.92	6.87	6.84
DR ₂	6.95	6.98	6.92	6.86	6.83
S.E.(diff.)	0.002	0.003	0.003	0.014	0.002
C.D. _{0.05}	NS	NS	NS	NS	NS

APPENDIX-XXVI: INFLUENCE OF TREE-CROP COMBINATION, NITROGEN LEVEL, DISTANCE AND DIRECTION ON E.C. (dsm^{-1}) OF THE SOIL AT VARIOUS STAGES OF GROWTH

F) Tree-crop combination

Combinations	Before sowing	Tillering	Panicle initiation	Milking	Harvesting
T ₁	0.204	0.212	0.198	0.178	0.168
T ₂	0.213	0.217	0.205	0.188	0.178
T ₃	0.213	0.216	0.205	0.188	0.178
T ₄	0.203	0.216	0.205	0.178	0.168
T ₅	0.195	0.208	0.190	0.172	0.164
S.E.(diff.)	0.002	0.003	0.002	0.003	0.002
C.D. _{0.05}	0.003	NS	0.005	0.005	0.005

B) Nitrogen level

N ₁	0.206	0.214	0.200	0.181	0.171
N ₂	0.205	0.213	0.200	0.181	0.171
S.E.(diff.)	0.001	0.002	0.002	0.002	0.002
C.D. _{0.05}	NS	NS	NS	NS	NS

C) Distance

D ₁	0.213	0.222	0.207	0.185	0.175
D ₂	0.198	0.205	0.194	0.177	0.167
S.E.(diff.)	0.001	0.002	0.002	0.002	0.002
C.D. _{0.05}	0.002	0.004	0.003	0.003	0.003

D) Direction

DR ₁	0.205	0.214	0.200	0.181	0.171
DR ₂	0.206	0.213	0.200	0.181	0.172
S.E.(diff.)	0.001	0.002	0.002	0.002	0.002
C.D. _{0.05}	NS	NS	NS	NS	NS

APPENDIX-XXVII: TOTAL AMOUNT OF NUTRIENTS ADDED (kg ha^{-1}) ANNUALLY TO THE SOIL DUE TO TREE-CROP COMBINATION

Combinations	Components	N				P				K			
		Fertilizer	FYM	Litterfall	Total	Fertilizer	FYM	Litterfall	Total	Fertilizer	FYM	Litterfall	Total
T ₁	Wheat	80	-	-	80	40	-	-	40	40	-	-	40
	Morus	-	-	-	-	-	-	-	-	-	-	-	-
	Total	80	-	-	80	40	-	-	40	40	-	-	40
T ₂	Wheat	80	-	-	80	40	-	-	40	40	-	-	40
	Morus	-	-	-	-	-	-	-	-	-	-	-	-
	Almond	63.89	3.20	12.63	79.72	25.03	3.60	0.96	29.56	60	7.68	15.53	83.21
	Total	173.89	3.20	12.63	159.72	65.03	3.60	0.94	69.56	100.00	7.68	15.53	123.21
T ₃	Wheat	80	-	-	80	40	-	-	40	40	-	-	40
	Grewia	-	-	-	-	-	-	-	-	-	-	-	-
	Almond	63.89	3.20	10.54	77.63	25.03	3.60	0.78	29.41	60.00	7.68	12.68	80.36
	Total	143.89	3.20	10.54	157.63	65.03	3.60	0.78	69.41	100.00	7.68	12.68	120.36
T ₄	Wheat	80	-	-	80	40	-	-	40	40	-	-	40
	Grewia	-	-	-	-	-	-	-	-	-	-	-	-
	Total	80	-	-	80	40	-	-	40	40	-	-	40
T ₅	Wheat	80	-	-	80	40	-	-	40	40	-	-	40

APPENDIX-XXVIII: TOTAL AMOUNT OF NUTRIENTS REMOVED (kg ha⁻¹)
ANNUALLY FROM THE SOIL DUE TO TREE-CROP
COMBINATIONS

Combination	N	P	K
T ₁			
Grain	25.66	5.35	4.80
Straw	9.75	5.80	27.20
Morus leaves	10.10	0.65	7.62
Morus branches	8.62	0.75	9.54
Total	54.13	12.56	49.16
T ₂			
Grain	29.00	5.52	5.94
Straw	11.68	5.09	34.28
Morus leaves	4.86	0.30	3.57
Morus branches	3.77	0.35	3.91
Almond fruits	20.70	2.51	11.46
Total	70.01	13.77	59.16
T ₃			
Grain	31.22	5.59	6.55
Straw	12.53	4.87	37.56
Grewia leaves	4.41	0.28	4.22
Grewia branches	11.64	0.65	10.86
Almond fruits	21.42	2.63	12.05
Total	81.22	14.02	71.24
T ₄			
Grain	27.22	5.41	5.32
Straw	8.94	5.44	30.98
Grewia leaves	8.23	0.53	8.07
Grewia branches	22.03	1.25	21.96
Total	66.42	12.63	66.33
T ₅			
Grain	38.65	6.21	8.37
Straw	15.00	4.46	44.04
Total	53.65	10.67	52.41

APPENDIX-XXIX: PRICES OF VARIOUS INPUTS AND OUTPUTS DURING 1997-98

Sr. No.	Variable	Rate (Rs.)
Inputs		
1.	Tractor charges	155/hr
2.	Thresher charges	9/hr
3.	Labour charges	45.75/ manday
4.	Seed cost	8.30/kg
5.	Fertilizer and minerals	
	CAN	422/q
	Urea	266/q
	SSP	260/q
	MoP	270/q
	FYM	30/q
6.	Chemicals	
	2,4-D	180/kg
	TSO	40/l
	Metasystox	186/l
Outputs		
1.	Wheat grain	5/kg
2.	Wheat straw	2.5/kg
3.	Morus leaf fodder	45/q
4.	Grewia leaf fodder	55/q
5.	Morus fuelwood*	132/q
6.	Grewia fuelwood*	124/q
7.	Almond fruits	30/kg

* Computed values in terms of calorific value

Kerosene oil	= Rs. 2.80/l
1 l kerosene oil	= 9259k cal/l
1 kg Morus branch wood	= 4363 k cal/kg
1 kg Grewia branch wood	= 6090 k cal/kg

APPENDIX-XXX: COST OF CULTIVATION OF WHEAT

Particulars	Operational inputs (ha ⁻¹)	T ₁ -T ₄ (Rs.)*	T ₅ (Rs.)*
Seed	120 kg	896.40	996.00
CAN	160 kg	607.68	675.52
Urea	87.50 kg	209.47	232.75
SSP	250 kg	585.00	650.00
MoP	65 kg	157.95	175.50
2,4-D	1 kg	162.00	180.00
Three ploughings	10 hrs	411.75	457.50
Two harrowings and plankings	7 hrs	288.22	320.25
Sowing	15 mandays	617.62	686.25
Weedicide application	6 mandays	247.05	274.50
Hand weeding	15 mandays	617.62	686.25
Harvesting	20 mandays	823.50	915.00
Threshing	25 mandays	1029.37	1143.75
Total	-	6653.63	7393.27

1 manday = 8 hours of single labour unit

Net cropped area - T₁-T₄ = 9,000 m²
 T₅ = 10,000 m²

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

APPENDIX-XXXI: COST OF MAINTENANCE OF MORUS, GREWIA AND ALMOND TREES AND HARVEST OF THEIR PRODUCES

Component	Operational inputs	T ₁	T ₂	T ₃	T ₄
Morus*					
Lopping	4 mandays	1372.50	915.00	-	-
Separation of leaves and branches	6 mandays	2058.75	1372.50	-	-
Grewia*					
Lopping	4 mandays	-	-	915.00	1372.50
Separation of leaves and branches	6 mandays	-	-	1372.50	2058.75
Almond**					
CAN	222 kg	-	1055.00	1055.00	-
SSP	177.6 kg	-	532.00	532.00	-
MoP	111 kg	-	337.50	337.50	-
FYM	6.6 ton	-	2229.73	2229.73	-
TSO	500 ml	-	22.52	22.52	-
Fertilizer application	4 mandays	-	206.00	206.00	-
FYM application	10 mandays	-	515.20	515.20	-
TSO spray	6 mandays	-	309.12	309.12	-
Basin preparation	18 mandays	-	927.36	927.36	-
Pruning	16 mandays	-	824.32	824.32	-
Fruit harvesting	27.75 mandays	-	1429.69	1429.69	-
Total		34.31.25	10675.94	10675.94	3431.25

* Operational input for 100 trees

** Operational input for 222 trees

APPENDIX-XXXII: VARIATION IN BIOMASS YIELD (q ha⁻¹) DUR TO TREE-CROP COMBINATION AND NITROGEN LEVEL

Components	T ₁		T ₂		T ₃		T ₄		T ₅	
	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂	N ₁	N ₂
Wheat										
Grain	13.79	17.42	15.22	18.97	16.07	19.63	14.37	18.15	20.29	23.17
Straw	31.37	35.43	36.27	38.81	38.10	39.99	34.37	37.36	41.72	45.00
Sub-total	45.16	52.85	51.49	57.78	54.17	59.62	48.74	55.51	62.01	68.17
Morus*										
Leaf	18.61	18.61	8.77	8.77	-	-	-	-	-	-
Branch	30.99	30.99	13.28	13.28	-	-	-	-	-	-
Sub-total	49.60	49.60	22.05	22.05	-	-	-	-	-	-
Grewia*										
Leaf	-	-	-	-	2.77	2.77	5.12	5.12	-	-
Branch	-	-	-	-	9.23	9.23	17.09	17.09	-	-
Sub-total	-	-	-	-	12.00	12.00	22.21	22.21	-	-
Almond*										
Fruit	-	-	12.56	12.56	12.65	12.65	-	-	-	-
Total	94.76	102.45	86.10	92.39	78.82	84.27	70.95	77.72	62.01	68.17

* The biomass yield irrespective of N level is taken

CURRICULUM VITAE

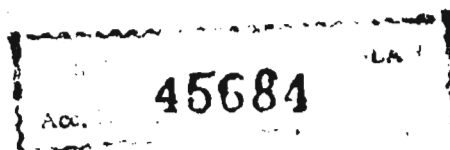
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THESIS ABSTRACT

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Year of award of degree : 1999
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ii) Soil and Water Management
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ABSTRACT

The investigation entitled "Tree-crop interaction studies in agrihortisilviculture system" was conducted during December, 1997 – June, 1998 with treatments involving 5 tree-crop combinations viz., Morus-Wheat (T_1), Morus-Almond-Wheat (T_2), Grewia-Almond-Wheat (T_3), Grewia-Wheat (T_4) and sole Wheat (T_5). In all the combinations, wheat was supplied with two nitrogen levels: i) recommended N level (80 kg/ha) and ii) 25 % more than the recommended level (100 kg/ha). The aboveground and underground resource use characteristics and the nature of tree-crop association were studied based on soil moisture availability, available N, P and K; organic matter content of the soil, pH, EC; relative illumination; nutrient concentration in plant parts; and ultimately growth and yield of the plant components.

Different tree-crop combinations had significant suppressing effect on growth and yield attributes of wheat. The reduction in wheat yield over sole cropping was 17.9, 21.3, 25.2 and 28.2% at tree-crop combinations T_3 , T_2 , T_4 and T_1 , respectively. Increase in N level by 25% more than the recommended level enhanced grain and straw yield below the tree crown in equal or even more magnitude to that obtained outside the crown at recommended level of N. Higher concentration of N, P and K was found in sole wheat over the tree-crop combinations except at tillering stage. Similar trend was reflected with uptake of the nutrients by grain and straw.

The crown spread of grewia was 60% and 68% of morus (2.32 and 1.87m) in north-south and east-west directions. Almond possessed the highest (2.96 and 2.35m) crown spread. Harvested biomass of loppings was more in T_1 and T_4 over T_2 and T_3 , respectively. The root architecture and their distribution in grewia and morus was horizontal, spreading and shallow without tap root. Almond had well defined tap root, penetrating deeper, with lesser root angle.

Soil moisture was higher when wheat was grown in association with grewia-almond at all the critical growth stages of wheat. Organic carbon, available N, P and K; pH and EC were slightly higher in combinations involving almond. Addition as well as removal of nutrients was more in this combinations. N and P showed depletion in all the cases while K was depleted only in T_2 and T_3 . The tree-crop combination T_2 followed by T_1 showed the least (50.04%) relative illumination at crop level during crop harvest.

The net financial returns were highest in T_3 and T_2 where almond is a component. Sole crop generated a net income more than T_1 and T_4 . Therefore, the findings evinced that grewia can be a better option to be grown with wheat than morus both in agrisilviculture and agrihortisilviculture systems. Wheat crop should be supplemented with 25% more N than the recommended dose in this system.

Signature of the Major Advisor

Signature of the student

Countersigned

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