

**Evaluation of Water Productivity under
Different Pruning Intensities in *Dalbergia
sissoo* - Paddy - Wheat based
Agrisilviculture System**

THESIS

Submitted to the

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

**In partial fulfilment of the requirements
for the Degree of**

MASTER OF SCIENCE

In

FORESTRY

(Agroforestry)

By

GANESHA B.H.

Department of Forestry

College of Agriculture, Jabalpur 482004

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, MP

2017

CERTIFICATE- I

*This is to certify that the thesis entitled “Evaluation of water productivity under different pruning intensities in Dalbergia sissoo - Paddy - Wheat based Agrisilviculture system.” submitted in partial fulfilment of the requirement for degree of **MASTER OF SCIENCE in FORESTRY (AGROFORESTRY)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of bonafide research work carried out by Mr. Ganesh B.H. under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.*

All the assistance and help received during the course of the investigation has been acknowledged by him.

Place: Jabalpur

Date:

Dr. M.L. Sahu

Chairman of the Advisory Committee

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. M.L. Sahu	-----
Member	Dr. K.K. Jain	-----
Member	Dr. K.S. Kushwaha	-----

CERTIFICATE - II

This is to certify that the thesis entitled "Evaluation of water productivity under different pruning intensities in Dalbergia sissoo - Paddy - Wheat based Agrisilviculture system." submitted by Mr. Ganesh B.H. to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN FORESTRY (AGROFORESTRY) in the Department of Forestry has been, after evaluation, approved by the External Examiner and by the Student's Advisory Committee after an oral examination of the same.

Place: Jabalpur

Date :

(Dr. M.L. Sahu)

Chairman of the Advisory Committee

MEMBERS OF THE ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. M.L. Sahu	-----
Member	Dr. K.K.Jain	-----
Member	Dr. K.S. Kushwaha	-----
Head of the Department	Dr. L.D. Koshta	-----
Director Instructions	Dr. D. Khare	-----

Declaration and Undertaking by the Candidate

I, Mr. Ganesha B.H. S/o Haleshappa B.C. Certify the work embodied in thesis entitled “Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system.” is my own first hand bonafide work carried out by me under the guidance of Dr. M.L. Sahu at Department of Forestry, college of Agriculture, Jabalpur during 2015-16

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes and errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given, thereof.

Place: Jabalpur

Date:

Mr. Ganesha B.H.

**Copyright © Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur
Madhya Pradesh 2017**

Copyright Transfer Certificate

Title of the Thesis- "Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system."

Name of the candidate : Mr. Ganesha B.H.

Subject : Agroforestry

Department : Department of Forestry

College : College of Agriculture

Year of thesis submission : 2017

Copyright Transfer

The undersigned Mr. Ganesha B.H. assigns to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, all rights under Copyright Act, that may exist in and for the thesis entitled "Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system " submitted for the award of M.Sc.(Forestry) degree.

Date:

Place: Jabalpur

Dr. M.L. Sahu
Major Advisor

Mr. Ganesha B.H.
Student

LIST OF CONTENTS

Number	Title	Page
1	Introduction	1-3
2	Review of Literature	4-15
3	Material and Methods	16-31
4	Results	32-49
5	Discussion	50-54
6	Summary, Conclusions and Suggestions for further work	55-60
	6.1 Summary	56
	6.2 Conclusion	60
	6.3 Suggestions for further work	60
7	Bibliography	61-65
8	Appendices	I-VI

LIST OF TABLES

Number	Title	Page
3.1	Weekly meteorological parameters during the Kharif crop season (June 2015 to November 2015)	18
3.2	Weekly meteorological parameters during the Rabi crop season (November 2015 to May 2016)	19
3.3	Physico-Chemical properties of the soil of experimental field	20
3.4	Past history of the experimental field	21
3.5	To determine the water productivity of Agroforestry in different pruning intensity	30
4.1	Seasonal increment of dbh under different pruning intensity	32
4.2	Effect of different pruning and package of practice on grain and straw yield.	33
4.3	Seasonal increment of LST, SST and FW under different pruning intensity	34
4.4	Effect of different pruning and package of practice on paddy equivalent yield of crop component	35
4.5	Effect of different pruning intensity on paddy equivalent yield of tree component	36
4.6	Effect of different pruning intensity on paddy equivalent yield of Agroforestry	37
4.7	Influence of different pruning intensity on quantity of green, blue, total water used by agroforestry	37
4.8	Effect of different pruning intensity on Kharif water productivity of agroforestry	38
4.9	Seasonal increment of dbh on effect of different pruning intensity	39
4.10	Effect of different pruning and package of practices on wheat grain and straw yield.	40
4.11	Seasonal increment of LST, SST and FW in different pruning intensity.	41
4.12	Effect of pruning and package of practices on wheat equivalent yield of crop component	42
4.13	Effect of different pruning intensity on wheat equivalent yield of tree component	43

Number	Title	Page
4.14	Effect of different pruning intensity on wheat equivalent yield of Agroforestry	43
4.15	Influence of different pruning intensity on quantity of green, blue, total water used by agroforestry	44
4.16	Effect of different pruning intensity on water productivity of agroforestry	45
4.17	Paddy equivalent yield in different farming practice	45
4.18	Green, blue and total water used in different farming practice during Kharif season	46
4.19	Paddy equivalent water productivity in different farming practice during Kharif season	47
4.20	Wheat equivalent yield in different farming practice	47
4.21	Green, blue and total water used in different farming practice during Rabi season	48
4.22	Wheat equivalent water productivity in different farming practice during Rabi season	49

LIST OF FIGURES

Number	Title	Page (in between)
1	Weekly meteorological parameters during the Kharif crop season (June 2015 to November 2015)	19-20
2	Weekly meteorological parameters during the Rabi crop season (November 2015 to May 2016)	19-20
3	Layout Plan of experimental field	21-22
4	Seasonal increment of dbh under different pruning intensity	33-34
5	Effect of different pruning and package of practice on paddy grain and straw yield	33-34
6	Effect of different pruning intensity on paddy equivalent yield of large size timber of tree component	37-38
7	Effect of different pruning intensity on paddy equivalent yield of SST of tree component	37-38
8	Effect of different pruning intensity on paddy equivalent yield of fuel wood component	37-38
9	Effect of different pruning intensity on paddy equivalent yield of agroforestry (crop + tree)	37-38
10	Effect of different pruning intensity on Kharif water productivity of agroforestry	39-40
11	Seasonal increment of dbh on effect of different pruning intensity	39-40
12	Effect of different pruning and package of practices on wheat grain and straw yield	43-44
13	Effect of different pruning intensity on wheat equivalent yield of large size timber component	43-44
14	Effect of different pruning intensity on wheat equivalent yield on Small size timber component	43-44
15	Effect of different pruning intensity on wheat equivalent yield on Fuel wood component	43-44
16	Effect of different pruning intensity on wheat equivalent yield of agroforestry (crop + tree)	45-46
17	Effect of different pruning intensity on Rabi water productivity of agroforestry	45-46

Number	Title	Page (in between)
18	Paddy equivalent yield in different farming practice	47-48
19	Paddy equivalent water productivity in different farming practice during Kharif season	47-48
20	Wheat equivalent yield in different farming practice	49-50
21	Wheat equivalent water productivity in different farming practice during Rabi season	49-50

LIST OF PLATES

Number	Title	Page (In between)
1	dbh measurement using tree calliper	26-27
2	Lifesaving irrigation in wheat experimental plots	27-28
3	View of wheat experimental plot	27-28

LIST OF SYMBOLS

Abbreviation & Symbol	Stand for
F	Analysis of variance
et al.	And others
etc.	And the rest
@	At the rate of
cm	Centimetre
©	Copyright
CD	Critical difference
°C	Degree centigrade
df	Degree of freedom
Fig	Figure
FAO	Food and Agriculture Organization
g	Gram
Kg	kilogram
hr	Hour
Max	Maximum
m	Metre
mm	Millimetre
Min	Minimum
viz.	Namely
%	Percentage
cm^{-1}	Per centimetre
m^{-3}	Per cubic metre
ha^{-1}	Per hectare
$\sqrt{\quad}$	Square root
SEI	Stockholm Environment Institute
$\text{SEm} \pm$	Standard error of mean
i.e.,	That is

CONNOTATION

F ₁	100 kg N, 60 kg P and 40 kg K + 100 kg seed @ ha ⁻¹
F ₂	125 kg N, 60 kg P and 40 kg K + 100 kg seed @ ha ⁻¹
F ₃	100 kg N, 60 kg P and 40 kg K + 125 kg seed @ ha ⁻¹
P ₀	0% pruning, no pruning
P ₂₅	25% pruning of total tree height
P ₅₀	50% pruning of total tree height
P ₇₅	75% pruning of total tree height
dbh	Diameter at breast height
FD	Fertilizer dose
N	Nitrogen
P	Phosphorus
K	Potassium
RD	Recommended dose
RFD	Recommended fertilizer dose
RSR	Recommended seed rate
SR	Seed rate
LST	Large size timber
SST	Small size timber
FW	Fuel wood
PEY	Paddy Equivalent Yield
WEY	Wheat Equivalent Yield
WP	Water productivity
WUE	Water use efficiency

ACKNOWLEDGEMENT

I would like to express my deepest sense of gratitude and reverence to my major guide and chairman of my advisory committee Dr. M.L. Sahu, Senior Scientist, Department of Forestry, J.N.K.V.V., Jabalpur, for his able guidance, keen interest, critical analysis and valuable suggestions during the course of investigation and preparation of the manuscript.

I extend my heartiest thanks to Professor and Head, Department of Forestry Dr. L.D. Koshta and worthy members of my advisory committee Dr. K.K. Jain and Dr. K.S. Kushwaha for their suggestions to carry out the research successfully. With profound respect, I am thankful to all my respected teachers Dr. R. Bajpai, Dr. K.K. Jain, Shri Yashpal Singh, Shri R.P. Dongre, Shri Rahul Dongre and all staff members of Department of Forestry, for their encouragement and support during the experiment and course work.

I feel myself duty bound to express my deep sense of gratitude and thanks to Prof. V. S. Tomar, Hon'ble Vice Chancellor, JNKVV, Jabalpur, Dr. P.K. Mishra, Dean Faculty, JNKVV, Jabalpur, Dr. S.K. Rao, Ex Director of Research Services, JNKVV, Jabalpur, Dr. Om Gupta, Dean, College of Agriculture, Dr. Dharendra Khare, Director of Instructions and Director of Research Services, Dr. V.K. Pyasi, Dean Students Welfare, JNKVV Jabalpur for providing all necessary facilities during conduct of the research work. I wish to extend my sincere thanks to all faculty & staff members of central library for providing valuable literatures for research work.

It is with the personal touch of emotions that I seize the opportunity to acknowledge the moral support, ever caring nature of my seniors like C.P. Rahangdale, Vinod, Amitesh Ranjan Yogesh Rajput, Vijay bhagare, Gajendra, Raghavendra Singh Meena, Indulata, Pratima Tiwari, Priyanshu Jain and juniors Shubra Suchismita Mohapatra, Vikas Seth, Allana, InkumNaro and Ankit Pandey.

I also thank field extension officer Shri Manoj Pathak and field workers Shri Shivu, Shri Tulasi, Munni bai, Manoj Patel Harsh Computers, Yadav Brothers and all my loved ones who supported directly and indirectly during course of my investigation.

I wish to express, my unbounded love and respect towards my father Mr. Haleshappa B.C., mother Mrs. Prameelamma, and my sister, for moulding my life with their love, affection, care and sacrifices, which has made me complete human being. Lastly I would like to convey my cordial thanks to all those unmentioned persons who helped me to fulfill my dream, come true.

Place: Jabalpur

Date:

(Ganesha B. H.)

INTRODUCTION

Water is essential for survival of all living beings including from small tiny organisms to big trees and animals. But today, fresh water resources are stretched thin due to the rapid growth in world population, the pressure on water resources is increasing (Rijsberman 2006). In systems where water is becoming the limiting factor, agricultural production should be expressed per unit of water consumed instead of production expressed per unit land. It is inevitable that the production per unit water consumed, water productivity must be increased to meet the challenge water scarcity (Kijne et al., 2003). Need to increase water productivity is a growing global concern as the World Commission on Water has estimated that demand for water will increase tremendously for the next 30 years and approximately half of the world's population will experience conditions of severe water stress by 2025 (Ong et al., 2006). Higher water productivity reduces the need for additional water and land resources in irrigated and rain fed systems. Total eradication of hunger in India requires around $1,860 \text{ km}^3 \text{ year}^{-1}$ of water by 2030 and more than $2,000 \text{ km}^3 \text{ year}^{-1}$ by 2050, increases by 160 & 180 percent compared to the current consumption of water (SEI, 2005). India is a land of small farm holdings, there are now 106 million operational holdings and about 75% of which are one hectare (ha) or less in size. Along with this per capita availability of land has declined from 0.48 ha in 1950 to 0.12 ha in 2004 (Sahu 2006). The operational holdings are shrinking continuously due to increase in population. This is leading to problems like food crisis, shortage of fodder, fuel wood, employment opportunities, global warming, soil erosion etc. It is a challenging task to produce more biomass per drop and to increase productivity of land. Together, the increasing food demand and decreasing water allocation suggest that the agriculture sector has to produce more food with less water (Cai et al., 2010).

Water productivity is a measure of economic livelihood or biophysical output derived from the use of unit water. It is expressed in terms of equivalent grain production per m^3 or per cm of water used. Its unit is kg m^{-3} or $\text{Kg ha}^{-1} \text{ cm}^{-1}$, ($1\text{kg ha}^{-1} \text{ cm}^{-1} = 100 \text{ kg m}^{-3}$). Higher water productivity

reduces the need for additional water and land resources in irrigated and rain fed systems. Raising water productivity is the cornerstone of any demand management strategy (Molden et al., 2001).

Agroforestry can improve soil fertility, provide fodder, produce tree fruits, expand fuel wood supplies and produce a variety of wood products for farmer's own use and sale without demanding additional land (Kumar 2016). Agroforestry may improve productivity by increasing the proportion of annual rainfall capture and it is the most effective in utilizing available soil moisture (Ong et al., 1992). One of the principal biophysical premises of agroforestry in dry land systems is to conserve and maximize the use of limited water supplies (Broadhead et al., 2003). Water conservation and more productive use of water is one of the key benefits of agroforestry (Ong and Swallow 2003). In total agroforestry has potential to maintain higher levels of biodiversity and greater biomass than mono crop or pasture system (Seeta et al., 2016).

The unmanaged tree canopy not only reduces the productivity of agricultural crops, but in most cases deteriorates the quality of the produce as well (Duguma et al., 1988). Pruning is a tending operation where lower branches of the trees are removed. The main reason of pruning is to shaping of form (by controlling or directing growth), improving or maintaining health, reducing risk from falling branches, increasing the yield or quality of timber, increase the intensity of light penetration etc. Tree pruning is a common management practice in agroforestry for mulching and reducing competition between the annual and perennial crop (Peter and Lehmann 2000). Generally canopy management will often have direct bearing on root characteristics as well as growth, vigor and biomass of tree itself (Thakur and Singh 2000). Considering the above problem the present study entitled as "Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system", has been undertaken with the following objectives

1. Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat Agrisilviculture system.
2. Evaluation of water productivity under different farming practices in *Dalbergia sissoo* - Paddy - Wheat Agrisilviculture system.

REVIEW OF LITERATURE

The present investigations deal with the water productivity of agroforestry, tree and crop.). For the present study entitled “**Evaluation of water productivity under different pruning intensities in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system**” an attempt has been made to collect the available literature and is reviewed in this chapter under the following heads:

2.1 Water productivity of crop alone (Agriculture)

2.1.1 Water productivity of paddy

2.1.2 Water productivity of wheat

2.2 Water productivity of tree alone (Silviculture)

2.3 Water productivity of crop + tree (Agroforestry)

2.3.1 Effect of pruning intensity on tree growth

2.3.2 Effect of pruning intensity on lower crop

2.1 Water productivity of crop alone (Agriculture)

2.1.1 Water productivity of paddy

Iskandar and Molden (2004) conducted the experiment in central Asia and reported that the spatial water productivity of rice and cotton for Private-peasant farms (PPFs) and Collective-cooperative farms (CCFs). Results revealed that both the highest water productivity ($26 \text{ kg ha}^{-1} \text{ cm}^{-1}$) and the lowest water productivity ($15 \text{ kg ha}^{-1} \text{ cm}^{-1}$) for rice were observed for PPFs, while in case of cotton, the highest water productivity ($60 \text{ kg ha}^{-1} \text{ cm}^{-1}$) and the lowest water productivity ($31 \text{ kg ha}^{-1} \text{ cm}^{-1}$) were observed for PPFs and CCFs respectively.

Bouman et al. (2005) conducted the research in Phillipines on yield and water use of irrigated tropical aerobic rice systems and he reported that total water input 1240-1880 mm in flooded and 790-1430 mm in aerobic fields and aerobic fields used 190 mm less water in land preparation and had 250–300 mm less seepage and percolation, 80 mm less evaporation, and 25

mm less transpiration than flooded fields. Without plastic sheets to prevent seepage in flooded fields, the water productivity of rice (with respect to rainfall and irrigation water input) under aerobic conditions was 32-88% higher than under flooded conditions.

Ganiyu et al. (2012) did experiment in Ghana on water use efficiency and productivity for rice and reported that 939.9 mm of water was required for growth, development and maturity of paddy in dry season of northern region of Ghana. The average yield of paddy rice was 3.6 tons ha⁻¹ and the average water productivity was 43 kg ha⁻¹ cm⁻¹.

Kaur et al. (2012) conducted experiment in Punjab region on water productivity enhancement and reported that the laser leveling farmers could save irrigation water and energy by 24.00 and 4.25% respectively. The irrigation cost reduced by 44% over the conventional practice, and water productivity improved by 39%, the ha⁻¹ water productivity of paddy on laser-leveled fields was 102.89 kg ha⁻¹ cm⁻¹.

Alauddin and Sharma (2013) did experiment in Bangladesh on differences in rice water productivity and reported that, the rice water productivity for 21 Bangladesh districts for 37 years. They observed that water productivity of rice varied significantly among districts and Overall rice water productivity in Bangladesh was relatively low (30.6-45.9 kg ha⁻¹ cm⁻¹) both by South Asian and International standards.

2.1.2 Water productivity of wheat

Ahmad et al. (2004) conducted the experiment in Pakistan on crop water productivity of rice and wheat and they reported that, the water productivity of rice and wheat in a rice-wheat cropping system. The study indicated that water productivity per unit of gross inflow ranged from 17 to 38 kg ha⁻¹ cm⁻¹ for rice and 78 to 203 kg ha⁻¹ cm⁻¹ for wheat. The economic water productivity measured in terms of gross margins per unit of gross inflow for rice, wheat and rice-wheat rotation ranged from 5-51 \$ m⁻³, 50-150 \$ m⁻³ and 26 to 76 \$ m⁻³, respectively.

Zwart and Bastiaanssen (2004) measured average CWP (crop water productivity) values per unit water depletion are 1.09, 1.09, 0.65, 0.23 and 1.80 kg m⁻³ for wheat, rice, cotton_{seed}, cotton_{lint} and maize, respectively. The range of CWP was very large (wheat, 0.6-1.7 kgm⁻³; rice, 0.6-1.6 kg m⁻³; cotton_{seed}, 0.41–0.95 kg m⁻³; cotton_{lint}, 0.14-0.33 kg m⁻³ and maize, 1.1-2.7 kg m⁻³) and thus offers tremendous opportunities for maintaining or increasing agricultural production with 20-40% less water resources. They finally concluded that CWP can be increased significantly if irrigation is reduced and crop water deficit is intentionally induced.

Ilbeyi et al. (2006) conducted the experiment in central Turkey to assess the impact of early sowing with supplemental irrigation (SI) and management options during other dry spells on the productivity of a bread wheat cultivar, “Bezostia”. Treatments included early sowing with 50 mm irrigation and normal sowing with no irrigation as main plots. Four spring (SI) levels occupied the sub-plots. These are rainfed (no-irrigation), full irrigation to satiate crop water requirements and two deficit irrigation levels of 1/3 and 2/3 at the full irrigation treatments. Grain yields of 5120, 5170 and 5350 kg ha⁻¹ were obtained by applying 1/3, 2/3 and full SI, respectively. The mean productivity of irrigation water given at sowing was 3.70 kg⁻¹ m³ with maximum value of 4.5 kg⁻¹ m³. Water productivity of 1/3, 2/3 and full SI were 2.39, 1.46 and 1.27 kg⁻¹ m³, respectively, compared to rainwater productivity of 0.96 kg⁻¹ m³.

Ali et al. (2007) conducted a field experiment to study the effects of water deficit on yield and water productivity of wheat in Bangladesh. Yield attributes were affected by deficit irrigation treatments although they are not statistically different in all cases. The grain and straw yields were significantly affected by treatments. The highest grain yield was obtained with the no-deficit treatment. The highest water productivity and productivity of irrigation water were obtained in the alternate deficit treatment.

Chahal et al. (2007) conducted experiment on effects of different date of transplanting and weather parameters on yield, evapotranspiration and water productivity of rice and subsequent wheat in rice–wheat cropping

system in Punjab region. Shifting of transplanting dates resulted into a saving of 192 mm as wet (evapotranspiration) and 590 mm as dry (irrigation) water. Real and apparent crop water productivities (grain yield per unit of water consumed by the crop as ET and irrigation water applied, respectively) were more (>70%) in rice transplanted under lower (end of June onwards) than higher evaporative demand (mid May).

Liu et al. (2007) did work in China on role of irrigation in winter wheat yield, crop water productivity, and production where GIS-based EPIC model (GEPIC) was applied to simulate crop yield and crop water productivity for winter wheat (*Triticum aestivum* L.) at a grid resolution of 5 arc-minutes and to analyze the impacts of reducing irrigation water on wheat production. They show that irrigation is especially important in improving crop water productivity of winter wheat. On average, the provincial aggregate crop water productivity was 56% higher under the irrigated than that under the rainfed conditions. The intensification of water stress and the associated increase in environmental problems in much of the north China plain require critical thoughts about reducing water allocation for irrigated winter wheat. Two scenarios for irrigation reduction in the NCP provinces are presented: reducing irrigation depth (S1), and replacing irrigated winter wheat by rainfed winter wheat (S2). The simulation results show that S1 and S2 have similar effects on wheat production when the reduction in irrigation water supply is below 20% of the current level. Above this percentage, S2 appears to be a better scenario since it leads to less reduction in wheat production with the same amount of water saving.

Li et al. (2008) conducted the investigation in north China to determine an accurate estimate of the evapotranspiration (ET) and crop water productivity (CWP) at regional scale is therefore key to the practice of water-saving. The calculated average and maximum water consumption of winter wheat in these 83 counties were 424 and 475 mm, respectively. The error of ET estimation over the entire growing stage of winter wheat was approximately 4.3%. The highest CWP across this region was 1.67 kg m^{-3} , and the lowest was less than 0.5 kg m^{-3} . They observed a close linear relationship between CWP and yield and also observed that the continuing

increase of ET leads to a peaking and subsequent decline of CWP, which suggests that the higher water consumption does not necessarily lead to a higher yield.

Gowing et al. (2009) conducted a field experiments on a wheat crop grown in a sandy loam soil and show that increased salinity decreased total water uptake by the crop, but in most treatments wheat still extracted 40% of its requirement from the groundwater, similar to the proportion reported for non-saline conditions. Yield depression was limited to 30% of maximum when the irrigation water was of relatively good quality (1 and 2 dS/m) even with saline groundwater (up to 6 dS/m). Crop water productivity (grain yield basis) was around 0.35 kg/m³ over a wide range of salinity conditions when calculated conventionally on the basis of total water use, but was generally above 1.0 kg/m³ if calculated on the basis of irrigation input only.

Zwart et al. (2010) using a WATPRO water productivity model for wheat, using remote sensing data products as input, was applied at a global scale with global data sets of the normalized difference vegetation index (NDVI) and surface albedo to benchmark water productivity of wheat for the beginning of this millennium. It was found that water productivity varies from approximately 0.2 to 1.8 kg of harvestable wheat per cubic meter of water consumed.

Mojid et al. (2012) did experiment in Bangladesh on growth performance and water use efficiency of wheat in loamy sand and reported growth performance and water use efficiency of wheat in loamy sand that the treated with various proportions of silt loam. Results showed that, the water use efficiency increased progressively with increasing quantity of clay in the treatments; the amendment saved 30 to 60% irrigation water compared to control (loamy sand, 6.04% clay). Loam (10% clay) appeared to be the best soil texture for wheat cultivation.

Montazar and Azadegan (2012) conducted study in Iran on effects of seasonal water use and applied N fertilizer on grain yield and water productivity indices of wheat in an arid region . The results revealed that, the yield responses to N was associated with water application levels and the

maximum water productivity ($272 \text{ kg ha}^{-1} \text{ cm}^{-1}$) would be achieved when 98 kg N ha^{-1} is combined with 156 mm of supplemental irrigation.

Tadayon et al. (2012) conducted an experiment to evaluate the effects of different amounts of supplemental irrigation at different growth stage and application of different rate of nitrogen fertilizer on grain yield and water productivity of wheat in Iran. Additional application nitrogen fertilizers also increased seed yield and water productivity. Generally, the combination of supplemental irrigation at jointing stage and application of $100 \text{ kg nitrogen ha}^{-1}$ have important roles in the improvement of seed yield and water productivity of Sardari wheat under semi-arid region.

Yan et al. (2014) analyzed the crop water productivity (CWP) of winter wheat in northern China. The results showed that, the average CWP of winter wheat (*Triticum aestivum* L.) in the basin for 2003-2009 was $104.9 \text{ kg ha}^{-1} \text{ cm}^{-1}$, with CWP values across the basin ranging between 70 and $140 \text{ kg ha}^{-1} \text{ cm}^{-1}$.

2.2 Water productivity of tree alone (Silviculture)

Keguin and Binrui (2000) conducted study in China and found that the water harvesting potential of stands (silviculture) has the ability to increase the water productivity, due to increase collection of run-off volume in the planting strip. The relationships between improvement in water environment and forest production were investigated for 5 and 10-year-old stands of black locust (*Robinia pseudoacacia*). The highest value of water productivity ($216.64 \text{ kg ha}^{-1} \text{ cm}^{-1}$) was observed for tree density 1840 hm^{-2} (in the 10-year-old plantation) followed by $84.10 \text{ kg ha}^{-1} \text{ cm}^{-1}$ for tree density 1000 hm^{-2} (in the 5-year-old plantation).

Singh and Singh (2009) tested the effect of varying soil water stress regimes on water productivity and nutrient uptake in *Dalbergia sissoo* seedling in Indian desert. The results showed that, the seedlings in level 26.5 mm had highest biomass per liter of water use (i.e., water productivity) and it was the best for growth and biomass production in which water use efficiency was highest.

Egea et al. (2010) investigated the long term effects of different deficit irrigation on water productivity, tree growth and yield determinants of almond trees grown in a semi-arid climate in Spain. They observed a highly significant correlation between the trunk growth rate and volume of water applied. Similarly a significant relationship was found between water applied and the increase in crown volume. They also recorded a linear decrease in kernel yield with decreasing water applied, which implies that 1% decrease in water application would lead to a reduction of 0.43% in yield.

Attalla et al. (2011) carried out an experiment on olive trees water productivity in response to varies irrigation regimes. The result revealed that the higher level of irrigation water (60 mm twice/month) during May to September was more effective in increasing the water productivity and fruit quality of olive in both seasons.

Ghrab et al. (2013) did study in semi-arid climate of northern Tunisia and reported that continuous deficit irrigation is a valuable tool for improving water productivity in peach orchard, as it saves a significant amount of water and maintains sustainable production levels. They recorded higher water productivity ($62 \text{ kg ha}^{-1} \text{ cm}^{-1}$) for the deficit irrigation as compared to control ($54 \text{ kg ha}^{-1} \text{ cm}^{-1}$).

2.3 Water productivity of crop + tree (Agroforestry)

Droppelmonn et al. (2000) reported that higher water use efficiency in agroforestry (tree + crop) as compare to agriculture (only crop) in northern Kenya. They observed higher water use efficiency in pruned trees as compare to no pruned trees. They also recorded higher water use efficiency in high density tree ($2500 \text{ trees ha}^{-1}$) as compare to low density ($833 \text{ trees ha}^{-1}$) trees. Highest value of water use efficiency was recorded in agroforestry of *Acacia saligna* + sorghum ($159 \text{ kg ha}^{-1} \text{ cm}^{-1}$), followed by *Acacia saligna* + cowpea ($121 \text{ kg ha}^{-1} \text{ cm}^{-1}$). They described the improved water use efficiency is due to the reduction of unproductive water loss.

Jackson et al. (2000) conducted an investigation in Kenya on water use by a hill slope agroforestry system by incorporating *Grevillea robusta*, a fast growing tree species, and maize. Agroforestry system had the highest

water use, the trees grown alone used slightly less water and a conventional maize crop used significantly less water. It was demonstrated that moderate pruning of the tree canopy, although reducing competition for light between the trees and crops, did little to limit the water demand of the tree component, resulting in little or no recharge to the soil profile. When the tree canopy was more heavily pruned, following the example of local farm management practices, the water requirement of the tree component was reduced and the soil profile water storage was able to recharge following rainfall.

Ong et al. (2002) reported that agroforestry has potential for improving water use efficiency by reducing the unproductive components of the water balance, i.e. run-off, soil evaporation and drainage. They cited the examples of India and Kenya that showed that agroforestry systems could double rainfall utilization as compare to agriculture.

Lott et al. (2003) conducted an experiment by involving a combination of sap flow measurements of transpiration and allometric estimates of biomass production to determine seasonal water use by trees and crops in agroforestry systems in semi-arid regions of Kenya region. They reported that agroforestry system is more efficient in water use as compared to sole tree (silviculture). Cumulative water use by *Grevillea* over the 4.5 year observation period was comparable in the sole tree (silviculture) and agroforestry, reaching a maximum utilization of annual rainfall of 64-68% 3-4 years after planting. These results confirm that agroforestry systems may greatly increase rainfall utilization compared to annual cropping systems.

Cui et al. (2006) carried out an experiment to study the water use efficiency in poplar agroforestry system under water stressed plain area of China. Results indicated that in 2-5 years old tree system, the water use efficiency of poplar agroforestry system was higher than in sole wheat-maize crop (agriculture).

Ong et al. (2006) reported that in semi-arid areas of India and Kenya has the greater productivity of agroforestry systems is primarily due to the greater quantity of water used. Then he described that some of the technical

approaches, which may be used to improve water productivity under agroforestry systems. As per their findings, agroforestry has the potential to improve water productivity in two ways. Trees can increase the quantity of water used on farm for tree or crop transpiration and may also improve the productivity of water that is used by increasing the biomass of trees or crops produced per unit of water used.

Ong et al. (2007) reported that the water use and water productivity of agroforestry system can be optimized in semi-arid tropics by adopting a right species combinations and management systems. They concluded that agroforestry is efficient in utilizing rainfall and thus more suitable for subsistence farmers particularly in semi-arid tropics.

Wongprom et al. (2010) carried out a study on water use efficiency of different spacing of *Eucalyptus* planted on paddy field bunds (agroforestry). He reported that annual water use is tended to increase with tree growth and generally spacing 2 m is tended to use the highest rate of water (5614.13 liter year⁻¹). They also observed that the water use efficiency of agroforestry with 2 m plant was highest (6.75 g liter⁻¹).

Ranjan and Sahu (2016) carried out an experiment in central India region and reported that the paddy equivalent yield of water productivity of agroforestry (141.8 kg ha⁻¹ cm⁻¹) and silviculture (159.6 kg ha⁻¹ cm⁻¹) were much higher than the agricultural (37.3 kg ha⁻¹ cm⁻¹). Among pruning intensities, the light pruning of 25% gave significantly higher mean water productivity (194.8 kg ha⁻¹ cm⁻¹) than no pruning (0%) and heavy pruning (75%). Agroforestry practices with 25% tree pruning, recommended dose of nitrogen and seed rate may be preferred in view of Kharif water productivity.

2.3.1 Effect of pruning intensity on tree growth

Miah et al. (1997) growth and yield components were significantly better in the pruned than unpruned plots, with yields in the pruned plots similar to those in sole crop plots (when actual ground area occupied was considered). Crop yield reductions in the unpruned plots were 61 and 78%, respectively.

Bandara et al. (1999) carried out an experiment on effects of pruning and understorey vegetation on crown development, biomass increment and above-ground carbon partitioning in *Pinus radiata* in New Zealand and observed that in 5 year old *Pinus radiata* trees, pruning reduced the tree growth by 27% when grown alone and by 16% when lucerne intercrop was taken under trees.

Pinkard et al. (1999) did experiment on responses to green pruning on net biomass production of *Eucalyptus nitens* in southern Australia and found that in 3- year old *Eucalyptus nitens* plantation, the removal of 0, 50 or 70% of the length of green crown, the total biomass production was reduced by 20 and 77% in 50 and 70% pruning respectively.

Frank and Eduardo (2003) did experiment on biomass dynamics of *Erythrina lanceolata* which is influenced by shoot pruning in Costa Rica and reported that higher biomass production of *Erythrina lanceolata* under total and partial pruning regime was measured in unpruned control, followed by tree with 50% of leaf pruned every month, while total pruning every six month resulted in lowest biomass production.

Zeng (2003) carried out a study in sub-tropical region of china on effect of pruning on above ground biomass partitioning of trees with four pruning intensities (0, 20, 50 and 70%) and found that pruning reduced the above ground biomass leaf fraction of tree instantaneously. The increased partitioning of above ground biomass to leaves following pruning, would benefit pruned trees to alleviate adverse effects of pruning and recover from the damage.

Noda et al. (2007) conducted a field experiment in Cuba on *Morus alba* with two pruning height 50 and 100 cm and two cutting frequencies 45 and 90 days. They observed that the cutting height showed a significant effect on total biomass in dry season and leaf biomass in both period. The highest plant biomass production was obtained with lowest pruning height. It was concluded that with 90 days and 50 cm of pruning height, acceptable dry matter yields were achieved.

Newaj et al. (2007) carried out an experiment in Uttar Pradesh on performances of intercrops under *Eucalyptus* based agriculture system and reported that in *Albizia procera* based agrisilviculture system, trees which were allowed to grow naturally (unpruned) attained maximum height, dbh and crown diameter than trees pruned upto 70% plant height and the growth of pure trees (without crop) was significantly ($P \leq 0.05$) less than trees in the agrisilviculture system.

Alvarez et al. (2013) did study in Argentina on effect pruning intensity and tree size on multi-stemmed *Prosopis flexuosa* trees and reported that pruning practices could be potentially used to obtain poles and firewood without a decrease in wood productivity. Results revealed that pruning could improve the shape in short run and increase stem diameter in long run.

2.3.2 Effect of pruning intensity on lower crop

Miah et al. (1997) conducted experiment on growth, biomass production and distribution pattern of three multipurpose tree species (*Acacia mangium*, *Acacia auriculiformis* and *Gliricidia sepium*) grown alone and in association with rice and mungbean under pruned and unpruned conditions. He found that *Acacia mangium*, *A. auriculiformis* and *Gliricidia sepium* were grown in association with upland rice (*Oryza sativa*) and mungbean (*Vigna radiata*) under pruned and un-pruned conditions. Growth, yield attributes and yield of both intercrops were significantly better in the pruned than un-pruned plots, with yields in the pruned plots similar to those in sole crop plots.

Samsuzzaman et al. (2002) carried out experiment in Bangladesh on Tree-crop interaction which are affected by tree spacing and pruning management. They reported that, the shoot pruning of *Acacia nilotica* trees thrice a year had the highest significant positive effect on crops yield. The yield of vegetable radish was increased by 71 per cent with *Acacia nilotica*, while with *Albizia lebbek*, rice and radish yields increased by 50 and 55 per cent, respectively due to pruning over un-pruned treatment.

Droppelmann and Berliner (2003) did work in the semi-arid and arid regions of Northern Africa and reported that in *Acacia saligna* based tree-

crop system, biomass yields and productivity of *Sorghum bicolor* per unit of land were highest when tree were pruned and intercropped.

Upadhyaya and Nema (2003) did study in India on tree-crop interaction in *Acacia* based agrisilviculture system. They observed that in *Acacia* based agrisilviculture system, different pruning intensity (20, 40, 60 and 80%) improved light penetration and significantly increased the yield of intercrops wheat and rice. The optimum yield of wheat (19.89 q ha⁻¹) was obtained under 40% canopy pruning whereas in case of rice, the maximum grain yield of 25.02 q ha⁻¹ was obtained in 80% pruning intensity.

Islam et al. (2006) conducted experiment to investigate the effect of levels of pruning on the yield and yield contributing characters of rice under eight years old *Dalbergia sissoo* tree in Bangladesh. The level of pruning of *Dalbergia sissoo* trees were designed as severely, moderately, medium and light pruned. Out of four tree rice associations, severely pruned tree produced significantly highest yield (3.63 t ha⁻¹) and lowest yield (2.70 t ha⁻¹) was produced by light pruned tree.

Handa et al. (2007) conducted a field experiment under rain fed condition with four levels (10, 25, 50 and 75%) pruning intensity with 10% pruning as control, to determine the effect on growth performances of tree species (*Hardwickia binata*, *Anogeissus pendula* and *A. latifolia*) and yield of Black gram. Maximum Black gram (141.80 kg/ha) and straw yield (233.20 kg/ha) were recorded with *H. binata* at 75% pruning intensity. No adverse effect was observed with 75% pruning on tree growth while intercrop yield was maximum.

Newaj et al. (2007) studied the influence of canopy pruning on biomass production in *Albizia procera* based agrisilvicultural system in Uttar Pradesh and found that growth and biomass production accumulation in *Albizia* was higher in control (Unpruned trees) than 50 and 70% canopy pruning. The biomass of herbaceous layer was significantly higher in 70% canopy pruning than 50% canopy pruning and control. The biomass of herbaceous layer in 70% pruning was about 2 times higher than control.

MATERIAL AND METHODS

The details of material used and the methods adopted during the course of investigation entitled “**Evaluation of Water productivity under different pruning intensity in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system**” are described in this chapter.

3.1 Research Area

The field experiment was conducted at Dusty Acre Research Farm, Department of Forestry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). The present investigation was carried out during Kharif and Rabi season 2015-16.

3.2 Location and extent

Study area lies at 23°12'50" North latitude and 79°57'56" East longitude. Study area belongs to Kymore Plateau and Satpura Hills Agro-climatic Zone as per classification of National Agricultural Research Project. Recently, this area has been classified as agro-ecological sub-region number 10.1 (Vindhyan Scarplands, Bundelkhand, and Narmada Valley, hot dry sub-humid ecological sub region with medium deep black soil).

3.3 Topography

The topography of the area is plain to gently sloping. Slope of the land vary from 0 to 1%.

3.4 Climate and weather conditions of Jabalpur

Study area enjoys a typical subtropical climate with hot dry summer and cool dry winter. Temperature extremes vary between minimum temperatures of 2.4⁰c in December- January month to maximum temperature of 46⁰c in May–June months. Based on 20 years mean meteorological data, the average annual rainfall of the locality is 1350 mm, which mostly received between mid-June to end of September with an occasional winter showers during December and January months. The mean monthly minimum temperature varies between 5.3 to 6.1 in December and January, and maximum temperature varies between 40 to 42°C during May and June, respectively January is the coldest month of the year with minimum

temperature being 5°C. Generally relative humidity remains very low during summer (20 to 23%), moderate (60 to 75%) during winter and it attains high value (80 to 95%) during rainy season.

3.4.1 Weather conditions during crop season

Seasonal variations prevailing during the crop growth period play an important role in the growth and development of the crop which ultimately influence the final yield of crop. The weekly meteorological data during the course of investigation recorded during crop season at Meteorological observatory, College of Agricultural Engineering, JNKVV, Jabalpur are presented in Table 3.1 and Table 3.2 and graphically illustrated in Fig.1 and Fig. 2

Kharif season (2015)

It is evident from the data that weather conditions were almost favorable for the growth and development of paddy. The monsoon commenced in the second week of June and terminated in the last week of September. During the growing season of the Paddy (June to November 2015), the maximum temperature (43°C) was recorded in June and minimum temperature (12.7°C) in November. The total rainfall received during the six month was 1029.2 mm with 44 rainy days. Relative humidity ranged between 40 to 93 % in morning and 17-76 % in evening. The wind velocity varied between 1.6 to 8.3 km per hour and mean sunshine hour ranged between 2.8 to 9.5 hours per day during growing season.

Rabi season (2015-16)

Crop season was almost favorable for crop. Minimum temperature was recorded in (4.2°C) in January. Relative humidity ranged between 36 to 94 % in morning and 11 to 65 % in evening. The total rainfall received during the six month was 86.5 mm with only 9 rainy days. The wind velocity varied between 1.5 to 6.9 km per hour and mean sunshine hour ranged between 5.4 to 10.5 hours per day during growing season.

Table 3.1: Weekly meteorological parameters during the Kharif crop season (June 2015 to November 2015)

Month	Meteo. Week	Temperature (°C)		Relative humidity (%)		Wind vel. (Km/hr)	Sun shine hrs	Rainfall (mm)	No. of Rainy days
		Max.	Min.	M	E				
June	22	43	27	40	17	5.4	8.9	0	0
	23	41.6	28.7	46	20	6.2	8.3	0	0
	24	36.5	25.8	72	49	5.6	4.2	16.6	3
	25	37.8	26.3	73	52	7.2	7	1.6	0
July	26	32.8	23.6	84	61	7.7	4.6	83.3	5
	27	33.8	24.7	78	55	8.3	5.9	51	3
	28	30.4	24.2	91	74	7.3	6.8	203.2	6
	29	31.5	24.2	89	70	5.1	2.8	72.8	5
	30	30.6	23.5	87	67	5.4	4.5	84.7	2
Aug	31	29.8	23.6	90	70	8.3	4.7	149.4	2
	32	31.2	24.2	91	69	3.7	4.6	14	2
	33	31.2	24.5	91	73	6.1	3	116.8	4
	34	31.3	23.6	88	64	6.5	7.4	9.4	1
Sept	35	30.4	22.9	93	76	4.9	3	104.6	5
	36	32.2	24.2	87	57	3.5	6.7	8.2	1
	37	33.5	23.1	91	55	3.1	8.4	3.4	1
	38	32	23.7	92	64	5.5	5.4	70.2	3
	39	32.6	21.1	84	45	4.2	9.2	0	0
Oct	40	33.1	19.5	88	35	2.1	9.3	0	0
	41	35.1	17.9	88	31	2.2	9.5	0	0
	42	34	19	86	36	2.4	9.2	0	0
	43	33.3	18.4	87	47	2.6	6.9	0	0
Nov	44	28	17	92	58	4.1	5.8	40	1
	45	31.4	17.9	88	40	1.8	5.8	00	00
	46	30.9	14.1	89	35	1.6	7.6	00	00
							Total	1029.2	44

Table 3.2: Weekly meteorological parameters during the Rabi crop season (November 2015 to May 2016)

Month	Meteo. Week	Temperature (°C)		Relative humidity (%)		Wind vel. (Km/hr)	Sun shine hrs	Rainfall (mm)	No. of Rainy days
		Max.	Min.	M	E				
Nov.	47	29.0	12.7	89	36	1.7	6.7	00	00
Dec.	48	30.8	14.5	88	34	2.3	7.2	00	00
	49	28.1	9.2	92	30	2.0	7.8	00	00
	50	26.6	9.2	82	32	3.0	7.6	00	00
	51	24.1	7.0	86	37	2.8	7.0	00	00
	52	24.2	5.4	91	25	1.5	8.6	00	00
Jan.	1	27.5	7.9	88	27	1.8	8.5	00	00
	2	26.7	8.0	81	32	1.7	7.7	00	00
	3	22.2	11.5	92	65	3.5	5.4	12.2	2
	4	23.3	4.2	94	29	2.3	9.6	00	00
Feb.	5	27.7	9.1	92	35	2.8	9.3	00	00
	6	26.4	8.4	84	34	3.2	8.3	00	00
	7	28.5	11.3	88	40	3.3	6.9	00	00
	8	30.2	11.8	90	32	2.7	7.4	00	00
March	9	30.5	13.4	85	34	3.3	8.5	00	00
	10	31.9	17.0	88	47	3.5	8.0	29.6	2
	11	30.9	15.9	85	37	4.1	8.7	6.5	2
	12	34.5	14.1	67	18	3.3	10.2	00	00
April	13	35.8	16.4	78	17	2.3	10.0	8.0	1
	14	39.1	20.1	62	18	3.0	9.1	00	0
	15	38.9	19.6	56	12	3.8	10.2	00	0
	16	41.1	21.9	48	12	5.0	10.5	00	0
May	17	40.2	20.9	46	11	5.1	10.4	00	0
	18	41.5	22.7	38	14	6.9	9.8	3.2	1
	19	39.7	24	44	19	4.4	8.8	0	0
	20	43.9	27.6	36	15	5.6	9.5	0	0
	21	41.1	26.8	54	38	9.1	8.1	26.8	1
								86.3	9

3.5 Edaphic factors

In order to find out the physico-chemical properties of soil of the experimental field, soil samples were taken randomly from different spots at a depth of 0 to 30 cm with the help of screw auger before sowing of the experiment. The soil samples were well mixed together for making representative samples. The composite samples were analyzed for physico-chemical properties of the soil in the laboratory, Department of Soil Science

and Agricultural Chemistry as per standard methods. The analytical values of soil were presented in Table 3.3.

Table 3.3: Physico-Chemical properties of the soil of experimental field

Sl. No.	Particulars	Analytical values	Category	Methodology
A. Mechanical composition				
1.	Sand %	24.02	Clay Sandy loam	International pipette method (Piper 1967)
2.	Silt %	19.83		
3.	Clay %	56.15		
B. Chemical composition				
1.	Organic carbon %	0.81	High	Walkey and Black method (Black 1965)
2.	Available N (Kg/ha)	288.1	Medium	Alkaline Permanganate method (Jackson 1966)
3.	Available P (Kg/ha)	20.38	High	Olsen method
4.	Available K (Kg/ha)	170.45	Very low	Flame photometer method (Jackson 1967)
5.	Soil PH	5.93	Acidic	pH meter (Piper 1967)
6.	Electrical conductivity (ds/m ² at 25°C)	0.26	Normal	Conductivity metre solu bridge method (Black 1965)

3.4 Cropping history of the experimental field

The following crops were grown during past eight years (Table 3.4).

Table 3.4: Past history of the experimental field

Year	Crop (Kharif)	Crop (Rabi)
2005-06	Fallow	Wheat
2006-07	Fallow	Wheat
2007-08	Fallow	Wheat
2008-09	Fallow	Wheat
2009-10	Paddy	Wheat
2010-2011	Paddy	Wheat
2011-2012	Paddy	Wheat
2012-2013	Paddy	Wheat
2013-2014	Paddy	Wheat
2014-2015	Paddy	Wheat
2015-2016	Paddy	Wheat

3.6 Experimental details-

A. Main treatment : 4

P₀ : 0% pruning of total tree height

P₂₅ : 25% pruning of total tree height

P₅₀ : 50% pruning of total tree height

P₇₅ : 75% pruning of total tree height

B. Sub Treatment : 3

F₁ : 100% of recommended dose of NPK (100:60:40:: N:P:K kg ha⁻¹) + normal seed rate (100 kg ha⁻¹).

F₂ : F₁+ 25% more N dose than normal (125:60:40:: N:P:K kg ha⁻¹)

F ₃	: F ₁ + 25% more seed rate than normal (125 kg ha ⁻¹).
Design	: Strip plot
Number of replications:	5
Gross plot size	: 5 m x 5 m
Net plot size	: 4.2 m x 4.2 m
Tree spacing	: 5 m x 5 m
Year of plantation	: 1998
Total number of plots	: 95
Variety of paddy	: IR-64
Variety of wheat	: GW-273
Row to row spacing of paddy	: 20 cm
Row to row spacing of wheat	: 20 cm

3.7 Characteristics of species

3.7.1 *Dalbergia sissoo*

Description of the tree species

Common name	: Shisham and Indian rosewood
Family	: Fabaceae
Scientific name	: <i>Dalbergia sissoo</i> Roxb.

Dalbergia sissoo known as shisham is an erect, medium to large-sized deciduous tree, native to the Indian subcontinent, growing up to 25 m in height and 80 cm dbh with a light crown which reproduces by seeds and suckers under favorable conditions. It is primarily found growing along river banks below 900 m elevation, but can range naturally up to 1300 m. It can withstand average annual rainfall up to 2000 mm and droughts of 3-4 months. *D. sissoo* grows well in a wide range of soil types, from pure sand and gravel to rich alluvial soil of riverbanks.

In its native countries of India and Pakistan, *D. sissoo* has been widely planted outside its natural range. It has been established in irrigated plantations, along roadsides and canals and around farms and orchards as windbreaks. Shisham is best known internationally as a premier timber species of the rosewood genus. However, shisham is also used as a fuel

wood, shade, and shelter purpose. With its multiple products, tolerance of light, frosts and long dry seasons, this species deserves greater consideration for tree farming, reforestation and agroforestry applications.

Uses

Young branches and foliage form an excellent fodder with a dry-matter content of 32.46%, crude protein 2.7-24.1%. The foliage has normally been used as emergency feed when other fodder sources fail. The species is fast growing, hence suitable for firewood. The calorific value of the sapwood and heartwood of excellent fuel wood is reported to be 4,908 kcal kg⁻¹ and 5,181 kcal kg⁻¹ respectively. As a fuel wood it is grown on a 10 to 15-year rotation. Shisham wood makes excellent charcoal for heating and cooking.

D. sissoo is one of the most useful timber species of India. The heartwood is very hard and close grained with a specific gravity of 0.62-0.82. It is used for high-quality furniture, cabinets, decorative veneer, marine and aircraft grade plywood, ornamental turnery, carving, engraving, tool handles and sporting goods. Sulphate pulp from wood is used in producing writing and printing paper. Oil obtained from the seeds is used to cure skin diseases. The powdered wood, applied externally as a paste, is reportedly used to treat leprosy and skin diseases.

Due to its vigorous reproduction through suckers, it is useful for stabilizing eroding sites. It is therefore found in a variety of wastelands, like in south Asia, where it is known as a colonizing species. As shisham tree fix atmospheric N₂ therefore it improves soil fertility. Heavy litter fall decomposes to enrich the soil with nitrogen, phosphorus and organic carbon. It may be planted as one component of a multitier home garden system, where it contributes several products.

3.7.2 IR-64 (Paddy variety)

IR-64 is one of the high yielding variety which is used by Indian farmers. It requires irrigated conditions with short periods of time and generally it attains a height of about 100 cm like semi dwarf and its morphological characters belonging as erect with dark green leaves ,profuse and compact tillering, long slender grain colour husk. It requires about 90-95

days to 50% flowering, 120-125 days for seed maturity. It is a disease resistant plant to major blast (durable type) and also tolerant to bacterial leaf blight, brown spot and sheath blight. It is tolerant to stem borer and susceptible to gall midge. It is having high yielding variety and average yield about 4-4.5 ton ha⁻¹ in normal condition.

3.7.3 GW-273 (wheat variety)

GW-273 (*Triticum aestivum*) was released in 1998 from GAU Vijaypur. It has potential to grow best under irrigated condition. Plant attains a height of 90-100 cm, spike length is more than 12cm, number of spikelet's/ ear 22-24 and number of seeds/spike is 68-70. Crop will take 91-100 days to heading and length of peduncle is 31-50 cm. Plant takes 126-134 days to maturity and provides yield about 41-45 qtls ha⁻¹. It is resistant to stem rust (Black rust), leaf rust (brown rust). It contains 11-12% of protein.

3.8 Cultural practices

3.8.1 Field preparation

The experimental field was thoroughly prepared by using cultivator followed by rotavator to obtain a well pulverized seed bed. The field was then leveled by using a planker.

3.8.2 Fertilizer application

The recommended dose of nitrogen, phosphorous and potash were given through Urea, SSP and MOP, respectively. The half of the nitrogen (100 kg ha⁻¹) and full quantity of phosphorous (60 kg P₂O₅ ha⁻¹) and potash (40 kg K₂O ha⁻¹) were applied at the time of sowing as basal dose.

3.8.3 Sowing

Sowing of paddy and wheat were done in all the plots of experiment on 25th June 2015 and 28th November 2015. Required quantity of seed was first treated with Dithane M-45 @ 2-3 gm per kg of seed against seed borne diseases prior to sowing. Sowing was done in lines 20 cm row to row and furrows of 5 cm depth were opened with the help of pickaxe. These furrows were dressed first with fertilizer (i.e. NPK as per treatment) mixed with soil and then with seeds, covered the open furrow properly with the help of manual labor to prevent damage from bird and for proper germination.

3.8.4 Gap filling

A week after the completion of germination the gap areas were again reseeded manually to obtain uniform plant population in all the plots.

3.8.5 Weeding

For both paddy and wheat weeds were removed from all plots at 25-30 days after sowing by manually.

3.8.6 Plant protection measures

There was little incidence of insect, pest and diseases during the crop season. Therefore, chlorpyrifos, 20% EC was applied as plant protection measures.

3.8.7 Water management

Due to less of rainfall at the end of monsoon season, one irrigation was given to paddy as lifesaving irrigation on 2nd October 2015 and four irrigation was given to wheat as lifesaving irrigation on 5th December 2015, 29th December 2015, 27th January and 21st February 2016.

3.8.8 Harvesting

Harvesting of paddy (IR-64) and wheat (GW-273) was done manually with the help of sickle on 18th November 2015 and 14th April 2016 respectively, when they attained maturity. One row (20 cm) from either side of each plots and at same distance from both the ends (N-S, E-W directions) were harvested separately to remove the border effect. The net plots were harvested separately and produce was left in the field for sun drying. After 2-3 days of drying, the bundles were made out of the harvested produce, and tagged.

3.8.9 Threshing and winnowing

After sun drying the produce was tied and weighed plot wise. Threshing was done on the threshing floor by manual labor with the help of wooden sticks and thresher. The material threshed from each plot was kept separately. Grains were separated from the straw by winnowing with the help of hand pan (Supa). After this clean grains were weighed plot wise. The straw yield was worked out by deduct grain yield from bundle weight (plot wise) per plot.

3.9 Observations recorded

3.9.1 Daily rainfall data

The daily rainfall data during the course of investigation recorded during crop season at Meteorological observatory, College of Agricultural Engineering, JNKVV, Jabalpur.

3.9.2 Daily pan-evaporation data

Daily pan-evaporation data was recorded at Meteorological observatory, College of Agricultural Engineering, JNKVV, Jabalpur.

3.9.3 Diameter measurement of *Dalbergia sissoo*

Diameter of trees was measured with the help of Tree calliper. Two diameters for each tree were taken perpendicularly and average was taken out as mean diameter.

3.9.4 Paddy and wheat grain yield (kg ha⁻¹)

After winnowing and cleaning the grains from each net plot, it was weighed on a double pan balance. The grain yield per hectare was obtained by multiplying the net plot yield by the converting factor {10,000 dividing by net area (m²) of plot}. The yield was expressed in kilograms per hectare.

3.9.5 Paddy and wheat straw yield (kg ha⁻¹)

The straw yield of each plot was determined by subtracting the grain yield from the biological yield of the respective plot. The values so obtained were converted into straw yield per ha by multiplying with net plot yield by the converting factor {10,000 dividing by net area (m²) of plot}. The yield was expressed in kilograms per hectare.

3.9.6 Volume of large-sized (diameter above 10 cm), small-sized timber (diameter 10 cm to 7 cm) and weight of fuel wood (diameter 7 cm to 4 cm)

The volume of timber and weight of fuel wood under different pruning intensities were calculated using the derived local volume table of Jabalpur region. The different regression models used were as follow;

A) For large-sized timber estimation	Pruning intensities
i) $\sqrt{v} = 0.0517 + 0.0159D$	P ₀
ii) $\sqrt{v} = -0.2817 + 0.0317D$	P ₂₅
iii) $\sqrt{v} = -0.1547 + 0.0275D$	P ₅₀
iv) $\sqrt{v} = -0.1312 + 0.0276D$	P ₇₅

B) For small-timber estimation

- | | | |
|------|---------------------------------|----------|
| i) | $\sqrt{v} = 0.0393 + 0.0054D$ | P_0 |
| ii) | $\sqrt{v} = - 0.0661 + 0.0092D$ | P_{25} |
| iii) | $\sqrt{v} = - 0.0105 + 0.0069D$ | P_{50} |
| iv) | $\sqrt{v} = - 0.1987 + 0.0165D$ | P_{75} |

C) For fuel wood estimation

- | | | |
|------|---------------------------------|----------|
| i) | $\sqrt{w} = 1.6664 + 0.1680D$ | P_0 |
| ii) | $\sqrt{w} = - 0.5306 + 0.2184D$ | P_{25} |
| iii) | $\sqrt{w} = - 0.5306 + 0.2184D$ | P_{50} |
| iv) | $\sqrt{w} = - 2.2383 + 0.2999D$ | P_{75} |

Where,

v = Volume (m^3)

w = Weight (kg)

D = diameter at breast height (cm)

3.10 Water used

It includes the effective rainfall, irrigation and Percolation (in case of agroforestry and agriculture only)

3.10.1 Effective rainfall

By considering daily rainfall data, mean monthly pan-evaporation and soil properties the effective rainfall have been derived from Potential Evapotranspiration/Precipitation Ratio Method (India) (Dastane 1978).

3.10.2 Irrigation

Water is supplied to all portions of field by pipe irrigation method. Irrigation water was calculated using pump discharge rate, time of irrigation and number of irrigation to a particular crop. The discharge rate was measured with a 40 liter drum and stop watch. This measurement was taken 3 times in a field and its means was considered for the calculation purpose.

$$IR (\text{Irrigation water}) = \text{Pump discharge rate} \times \text{time of irrigation} \times \text{No. of Irrigation}$$

The depth of irrigation was calculated by dividing the amount of irrigation with plot area.

3.10.3 Percolation

The depth of percolation was calculated on the basis of actual period of ponding rainfall water in the experiment field.

Outputs

Output of different practices were grain and straw in case of agriculture, wood in case of silviculture and grain, straw and wood in case of agroforestry. Wood was further classified as large-sized timber (diameter ≥ 10 cm), small-sized timber (diameter < 10 cm and ≥ 7 cm) and fuel wood (diameter < 7 cm). All outputs were converted into wheat equivalent yield considering the current market prices of the produces. The market prices were Rs 18 kg⁻¹, Rs 5 kg⁻¹, Rs 16 kg⁻¹, Rs 5 kg⁻¹, Rs 17200 m⁻³ (Rs 500 ft⁻³), Rs 10300 m⁻³ (Rs 300 ft⁻³) and Rs 5 kg⁻¹ respectively for paddy grain, paddy straw wheat grain, wheat straw, large-sized timber, small-sized timber and fuel wood.

3.11.1 Determination of Kharif water productivity under different pruning intensity

In Kharif season all crop components (Paddy grain and straw), large and small size timber and fuel wood were converted into paddy equivalent yield by considering market prices. This will become the paddy equivalent yield of agroforestry. Effective rainfall i.e. green water used in kharif season was 37.2 cm. Lifesaving irrigation i.e. blue water was applied to paddy crop and it is varies within different pruning intensity.

3.11.2 Determination of Rabi water productivity under different pruning intensity

In Rabi season all crop components (wheat grain and straw), large and small size timber and fuel wood were converted into wheat equivalent yield by considering market prices. This will become the wheat equivalent yield of agroforestry. Effective rainfall i.e. green water used in Rabi season was 4.5 cm .Lifesaving irrigation i.e. blue water was applied to wheat crop and it is varies within different pruning intensity.

3.11.3 Determination of water productivity in different farming practice during Kharif

In Kharif season all crop components (Paddy grain and straw), large and small size timber and fuel wood were converted into paddy equivalent yield by considering market prices. This will become the paddy equivalent yield of agroforestry. All the paddy equivalent yield of Kharif components were set in respective different farming practice viz. agriculture only, silviculture only, managed agroforestry and unmanaged agroforestry.

3.11.4 Determination of water productivity in different farming practice during Rabi

In Rabi season all crop components (wheat grain and straw), large and small size timber and fuel wood were converted into wheat equivalent yield by considering market prices. This will become the wheat equivalent yield of agroforestry.

All the WEY of Rabi components were set in respective different farming practice viz. agriculture only, silviculture only, managed agroforestry and unmanaged agroforestry.

3.11.5 Water productivity

The crop water productivity was worked out by dividing the paddy or Wheat equivalent yield by total water used.

Physical water Productivity =	Total yield(kg ha ⁻¹)
	Total water used (cm)

3.11.6 Total yield

- i) In case of agriculture, the total output will be grain and straw
- ii) In case of agroforestry, the total output will be grain, straw, large-sized timber, small-sized timber and fuel wood.
- iii) In case of silviculture, the total output will be large-sized timber, small-sized timber and fuel wood.

3.11.7 Statistical analysis

The data calculated from the experiment were tabulated and analyzed statistically by method of analysis of variance as suggested by Cochran and Cox (1950).

The significance of the treatment mean square at 5 percent level was tested with 'F' test. When 'F' test showed the significance of treatment using the significance of critical differences at 5 per cent level further tested the differences between the treatment means.

Skeleton for analysis of variance (ANOVA)

Table 3.5: To determine the water productivity of Agroforestry in different pruning intensity

Source of variation	d.f	S.S	M.S.S	F cal	F tab	
					at 5%	at 1%
Replication	4					
Main treatment (Pruning)	3				3.49	5.9
Error A	12					
Sub-treatment (fertilizer dose & seed rate)	2				4.46	8.6
Error B	8					
Interaction	6				2.51	3.7
Error C	24					
Total	59					

Mean sum of square (MSS) =	Sum of squares	=	SS
	Degree of freedom		df

'F' value =	Treatment mean sum of squares (TMSS)
	Error mean sum of squares (EMSS)

$$SE_{m\pm} \text{ for main treatment} = \sqrt{\frac{E(a)}{rXv}}$$

$$CD = SEm_{\pm} \times \sqrt{2} \times t_{5\%} \text{ for error (a) d.f}$$

$$SEm_{\pm} \text{ for sub-treatment} = \sqrt{\frac{E(b)}{rXv}}$$

$$CD = SEm_{\pm} \times \sqrt{2} \times t_{5\%} \text{ for error (b) d.f}$$

Interaction:

SEm_± for comparison of two main treatments means at same level of sub treatment means

$$SEm_{\pm} = \sqrt{\frac{[E(a) + (b-1)E(c)]}{rXb}}$$

$$CD = SEm_{\pm} \times \sqrt{2} \times t_{5\%} \text{ for Error(c) d.f}$$

SEm_± for comparison of two sum treatment means at same level of main treatment means

$$SEm_{\pm} = \sqrt{\frac{[E(a) + (a-1)E(c)]}{rXa}}$$

$$CD = SEm_{\pm} \times \sqrt{2} \times t_{5\%} \text{ for Error(c) d.f}$$

Where,

- r = Number of replication
- t = Number of main treatments
- v = Number of sub treatment
- E (a) = Error variance for main plot
- E (b) = Error variance for subplot
- E (c) = Error variance for interaction

DISCUSSION

The results obtained have been discussed critically in the light of research findings of other researchers. Relevant explanations have also been given to understand the cause-effect relationship. The findings of the present investigation have focused some interesting facts, which are critically discussed here in this chapter with the support data, established scientific facts and reporting of the other research workers. Besides the effects of weather condition, management factors like pruning, intensity of *Dalbergia sissoo* tree, fertilizer dose and seed rate also influenced the growth and yield of crops during Kharif and Rabi seasons. Hence, these are also briefly discussed here.

5.1 Effect of pruning intensities on timber and fuel wood

Volume of standing trees was significantly influenced by different pruning treatments in *Dalbergia sissoo*. 25% pruning recorded significantly higher timber and it was significantly superior to 0% pruning in both seasons (table 4.2 and 4.10 respectively). This was due to the fact that trees are commonly pruned by removing leaves and branches from lower part of the trunk which changes the stem shape to a more cylindrical form and resulting in trunk volume than other components allocation in bole than other components. Muhairwe (1994) also reported pruning changed stem shape to a more cylindrical form. Pinkard et al. (2004) reported that stem volume significantly reduced 70% pruning. This trend was also been confirmed with result of Ranjan and Sahu (2016), where they reported that highest volume of large size timber was obtained in P₂₅.

Different pruning intensity has no significant effect on fuel wood production. It was at par in all four pruning treatment.

5.2 Effect of pruning intensities on grain and straw yield (paddy and wheat)

The yield of paddy and wheat were highest in highest under the 75% pruning intensity (table 4.3 and 4.10), it gave 18% higher grain and straw yields (1875 and 3374 kg ha⁻¹ respectively) as compared to 50% pruning intensity (1584 and 2850 kg ha⁻¹ respectively) in paddy. Similarly in case of wheat the 75% pruning intensity increased 16 and 15% grain and straw yields as compare to 50% pruning intensity (2654 and 1202 kg ha⁻¹ respectively).

It makes the conclusion that the different pruning intensity affects the yield of grain due to the less penetration of sunlight on understory crop. The yield under 0% pruning intensity affected more than other pruning intensities. These results were conformity with the findings of (Islam et al., 2006) in *Dalbergia sissoo*- rice agroforestry system. Handa et al. (2007) Black gram under *Hardwickia binata*, *Anogeissus pendula* and *A latifolia* where they reported that under 75% pruning intensity the yield of understory crop is higher in compare to yield of crop under 0% pruning intensity. Similar result were also reported by Okun et.al. (2001) for the combination of Maize under *Albizia procera*.

5.3 Influence of different pruning intensity on total water by agroforestry

The total water used during Kharif was at par in all four pruning intensitis with numeric value as 41.5 cm (P₀), 42.0 cm (P₂₅), 42.4 cm (P₅₀) and 44.7 cm (P₇₅). (Table 4.7).

The total water used during Rabi was at par in all four pruning intensitis with numeric value as 22.5 cm (P₀), 24.5 cm (P₂₅), 27.7 cm (P₅₀) and 36.5 cm (P₇₅). (Table 4.15).

The present finding were little vary with finding of Wei et al. (2009), where they reported the less moisture content in heavy pruning intensity whereas more moisture content in less pruned trees.

5.4 Effect of different pruning intensity on water productivity of agroforestry

Kharif water productivity of P₇₅ (131 kg ha⁻¹ cm⁻¹), P₂₅ (142 kg ha⁻¹ cm⁻¹) and P₅₀ (147 kg ha⁻¹ cm⁻¹) were at par but significantly superior to P₀ (95 kg ha⁻¹ cm⁻¹) (Table 4.8). Rabi water productivity of P₂₅ (255 kg ha⁻¹ cm⁻¹) and P₅₀ (249 kg ha⁻¹ cm⁻¹) were at par but significantly superior to P₇₅ (189 kg ha⁻¹ cm⁻¹). P₂₅ was significantly superior P₀ (196 kg ha⁻¹ cm⁻¹). Both P₇₅ and P₀ were at par. (Table 4.16).

The 50% pruning intensity yielded the highest water productivity among all the selected pruning intensity which was followed by 25% pruning intensity. It leads to conclusion that light pruning is beneficial for efficient use of water and also higher water productivity as compare to no pruning and heavy pruning of trees.

These results were in agreement of minutely with the findings of Rajan and Sahu (2016). They also reported the highest productivity under 25% pruning intensity in *Dalbergia sissoo*- paddy agroforestry system.

5.5 Production trend under different farming practice

The paddy equivalent yield of agroforestry system was highest in managed agroforestry (6028 and kg ha⁻¹) during Kharif season. The PEY of silviculture (4221 kg ha⁻¹) was superior to agriculture (3924 kg ha⁻¹). (Table 4.17)

Among the different farming practice the highest WEY in Rabi season was found by managed agroforestry (6680 kg ha⁻¹). Next best practice was agriculture (5070 kg ha⁻¹) followed by unmanaged agroforestry (4414 kg ha⁻¹) and lowest was found in silviculture (3344 kg ha⁻¹). (Table 4.20).

It may due to that proper management of trees by pruning operation increase their clear bole length, timber quality and higher crop yield.

5.6 Quantity of total water used in different farming practice

In Kharif season quantity of total water used in different farming practices were at par to each other numeric value as silviculture (37.2 cm), unmanaged AF (41.5 cm), managed AF (43.0 cm) and agriculture (45 cm). (Table 4.18).

In Rabi season quantity of total water used in different farming practices were at par to each other numeric value as silviculture (4.5 cm), unmanaged AF (22.5 cm), managed AF (29.6 cm) and agriculture (45 cm). (Table 4.21).

5.7 Water productivity in different farming practice in Kharif

The highest water productivity (WP) was found in managed AF (140 kg ha⁻¹ cm⁻¹) followed by silviculture (113kg ha⁻¹ cm⁻¹). It was found managed agroforestry have 4 % more water productivity as compared to silviculture. Lowest WP was observed in agriculture (72 kg ha⁻¹ cm⁻¹) and unmanaged AF (95 kg ha⁻¹ cm⁻¹) farming practices.(Table 4.19).

This finding was compared with the finding of other research Droppelmonn et al. (2000) recorded the higher water productivity (159 kg ha⁻¹ cm⁻¹) in *Acacia saligna* + sorghum agroforestry system. He also recorded the higher water productivity (121 kg ha⁻¹ cm⁻¹) for *Acacia saligna* + cowpea.

Ranjan and Sahu (2016) also reported the same trend water productivity of agroforestry (141.8 kg ha⁻¹ cm⁻¹) was much higher than the agricultural (37.3 kg ha⁻¹ cm⁻¹) practice.

The water productivity of agriculture (72 kg ha⁻¹ cm⁻¹) in current findings are slightly higher than the findings of other research worker.

Swarup et al. (2008) reported that the water productivity of rice in Orissa is 39 kg ha⁻¹ cm⁻¹. Alauddin and Sharma (2013) recorded the water productivity of rice in Bangladesh districts in the range of 36.6 to 45.9 kg ha⁻¹ cm⁻¹. Ganiyu et al. (2002) recorded 43 kg ha⁻¹ cm⁻¹ water productivity of rice in Ghana.

5.8 Water productivity in different farming practice in Rabi season

During Rabi season higher water productivity was recorded in silviculture ($743 \text{ kg ha}^{-1} \text{ cm}^{-1}$) followed by managed agroforestry ($226 \text{ kg ha}^{-1} \text{ cm}^{-1}$). Lowest water productivity was recorded in agriculture ($196 \text{ kg ha}^{-1} \text{ cm}^{-1}$). (Table 4.22).

The observed water productivity of agriculture ($136 \text{ kg ha}^{-1} \text{ cm}^{-1}$) has been confirmed with the results of Ahmad et al. (2004) where they reported that the water productivity of wheat ranges between 78 to $203 \text{ kg ha}^{-1} \text{ cm}^{-1}$ Ahmad et al. (2004).

The research work of Yan et al. (2014) analysed the crop water productivity (CWP) of winter wheat. The results showed that the average CWP of winter wheat (*Triticum aestivum* L.) in the basin for 2003-2009 was $104.9 \text{ kg ha}^{-1} \text{ cm}^{-1}$, with Crop water potential values across the basin ranging between 70 and $140 \text{ kg ha}^{-1} \text{ cm}^{-1}$.

Water productivity of silviculture was much higher than recorded by Droppelmann et al. (2000). This may be due to effective rainfall was during Rabi season was very less.

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

The present investigation entitled “**Evaluation of water productivity under different pruning intensity in *Dalbergia sissoo* - Paddy - Wheat based Agrisilviculture system**” was carried out during Kharif and Rabi season of 2015-16 at Dusty Acre Area, Department of Forestry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). The present investigation was aimed to find out the Kharif and Rabi seasons water productivity under different pruning intensity and also to find out the Kharif and Rabi water productivity under different farming practices viz. agriculture, silviculture and managed and unmanaged agroforestry system.

In the Kharif and Rabi season for paddy and wheat crop weather parameters viz., temperature (minimum and maximum), relative humidity (morning and evening), sunshine hours were favorable for proper growth and development of paddy crop. The soil of experimental field was clay sandy loam in texture. The distribution of rainfall was not even during Kharif season hence there was shortage of moisture in the growing season of crop, so lifesaving irrigation were given to crop for proper growth and development. During Kharif season the year total 1029.2 mm rainfall was recorded in 44 rainy days. The maximum temperature was recorded during growing season was 37.8⁰c in June and minimum temperature 12.7⁰ c in November. During Rabi season the year total 86.3 mm rainfall was recorded in 9 rainy days. The maximum temperature was recorded of in May and minimum temperature 5.4⁰c in December. To test the water productivity of different pruning intensity in Kharif and Rabi season, the total 4 treatments viz., 4 pruning intensity in main plot and 3 different levels of fertilizer doses and seed rate in subplot were considered in strip plot design with 5 replications. The Kharif and Rabi water productivity under different farming practices viz. agriculture, silviculture and managed and unmanaged agroforestry system were also calculated and tabulated. Various observations on meteorological parameters (daily rainfall and daily pan-evaporation data), soil physical

parameters (soil texture), tree growth parameters (diameter at breast height) and crop parameters (grain yield and straw yield) were recorded. Data related to various observations were tabulated and subjected to statistical analysis.

6.1 Summary

The significant findings of experiment has been summarized and presented below in point-wise.

Kharif season (paddy + *Dalbergia sissoo*)

Paddy grain and straw yield

It was observed that paddy grain and straw yield shows significant difference within pruning intensity. The highest paddy grain and straw yield was recorded under P₇₅ (1875 and 3374 kg ha⁻¹ respectively), while the lowest was under P₀ (1092 and 1966 kg ha⁻¹ respectively) pruning intensity. Yield of treatment was having significant difference with other yield was in ascending order of P₀ < P₂₅ < P₅₀ < P₇₅.

For different package of practices the highest grain and straw yield was recorded in F₂ (1576 and 2837 kg ha⁻¹) and lowest was recorded in F₁ (1355 and 2439 kg ha⁻¹).

Seasonal increment of tree diameter

It was observed that seasonal increment of tree diameter showed non-significant among different pruning intensity. Maximum seasonal dbh increment was found in P₅₀ (0.86 cm) and minimum was found in P₂₅ (0.66 cm) pruning intensity.

Effect of different pruning intensity on PEY of paddy

Similar to paddy yield, the PEY of paddy crop was recorded highest under P₇₅ (2812 kg ha⁻¹) pruning intensity while the lowest was by P₀ (1638 kg ha⁻¹) pruning intensity.

Effect of different pruning intensity on timber size and fuel wood

Quantity of finished large sized timber produced during Kharif season shows a significant difference among different pruning intensity and it was maximum volume was found by P₂₅ (3.84 m³ ha⁻¹) pruning intensity, while

minimum volume by P₀ (2.07 m³ ha⁻¹). But, in case of small sized timber the highest volume was found by P₇₅ (0.43 m³ ha⁻¹) pruning intensity and lowest volume by P₀ (0.27 m³ ha⁻¹). Quantity of fuel wood produced during Kharif season was recorded highest volume in P₅₀ (570 kg ha⁻¹) pruning intensity while lowest volume in P₇₅ (519 kg ha⁻¹).

Effect of pruning intensities on paddy equivalent yield (PEY) of timber size and fuel wood

Maximum value PEY of tree component was observed in P₂₅ (4023 kg ha⁻¹) pruning intensity and followed by P₅₀ (3860 kg ha⁻¹) pruning intensity and P₇₅ (3058 kg ha⁻¹) pruning intensity. Minimum PEY of tree component value was by P₀ (2296 kg ha⁻¹) pruning intensity.

Effect of pruning intensities on PEY of Agroforestry

Total component during Kharif season shows a significant difference among different pruning intensity. The highest PEY of agroforestry component was found in P₅₀ (6235 kg ha⁻¹) pruning intensity and lowest in P₀ (3934 kg ha⁻¹).

Effect of pruning intensities on water productivity of agroforestry

During our experimentation water productivity shows statistical difference among different pruning intensity. Maximum water productivity was found by 50 % (147 kg ha⁻¹ cm⁻¹) pruning intensity, while minimum by 0% (95 kg ha⁻¹ cm⁻¹). Next best result was found by 25% (142 kg ha⁻¹ cm⁻¹) and 75 % (131 kg ha⁻¹ cm⁻¹) pruning intensity.

Wheat yield (grain and straw)

It was observed that wheat grain and straw yield shows significant difference within pruning intensity. The maximum wheat grain and straw yields were recorded under P₇₅ (3066 and 4445 kg ha⁻¹ respectively) pruning intensity, while the minimum under P₀ (1826 and 2647 kg ha⁻¹ respectively). Yield of treatment was having significant difference with other yield was in ascending order of P₀ < P₂₅ < P₅₀ < P₇₅.

For different package of practices the highest grain and straw yield was recorded in F₂ (2605 and 3778 kg ha⁻¹ respectively) and lowest was recorded in F₁ (2251 and 3264 kg ha⁻¹).

Seasonal increment of tree diameter

It was observed that seasonal increment of tree diameter showed non-significant among different pruning intensity. Maximum seasonal dbh increment was found in P₅₀ (0.57 cm) pruning intensity and minimum was found by P₂₅ (0.44).

Effect of pruning intensities on WEY of wheat

Similar to paddy yield, the WEY of wheat crop was recorded highest under P₇₅ (4455 kg ha⁻¹) pruning intensity while the lowest was by P₀ (2653 kg ha⁻¹).

Effect of different pruning intensity on Timber Size and Fuel wood

Quantity of finished large sized timber produced during Rabi season shows a significant difference among different pruning intensity and it was maximum volume was found by P₂₅ (2.67 m³ ha⁻¹) pruning intensity, while minimum volume by P₀ (1.42 m³ ha⁻¹). But, in case of small sized timber the highest volume was found by P₇₅ (0.31 m³ ha⁻¹) pruning intensity and lowest volume by P₀ (0.18 m³ ha⁻¹). Quantity of fuel wood produced during Rabi season was recorded highest volume in P₅₀ (398 kg ha⁻¹) pruning intensity while lowest volume in P₂₅ (361 kg ha⁻¹).

Effect of different pruning intensity on Wheat equivalent yield (WEY) of timber size and fuel wood

Maximum value WEY of tree component was observed in P₂₅ (3147 kg ha⁻¹) pruning intensity and followed by P₅₀ (3054 kg ha⁻¹) pruning intensity and P₇₅ (2427 kg ha⁻¹) pruning intensity. Minimum PEY of tree component value was by P₀ (1761 kg ha⁻¹) pruning intensity.

Effect of different pruning intensity on WEY of Agroforestry

Total component during Rabi season shows a significant difference among different pruning intensity. The highest WEY of agroforestry component was found in P₅₀ (6910 kg ha⁻¹) pruning intensity and lowest in P₀

(4414 kg ha⁻¹). Next best was P₇₅ (6881 kg ha⁻¹) and P₂₅ (6251 kg ha⁻¹) pruning intensity.

Effect of different pruning intensity on water productivity of agroforestry

During our experimentation water productivity of agroforestry Rabi season shows significant difference among different pruning intensity. Maximum water productivity was found by 25 % (255 kg ha⁻¹ cm⁻¹) pruning intensity and minimum water productivity 75% (189 kg ha⁻¹ cm⁻¹). Next best result was found by 50% (249 kg ha⁻¹ cm⁻¹) and 0 % (196 kg ha⁻¹ cm⁻¹) pruning intensity.

PEY in different farming practice in Kharif season

Different farming practice shows a significant difference within treatments in Kharif season. The highest yield was recorded in managed AF (6028 kg ha⁻¹) practice and lowest in agriculture (3231 kg ha⁻¹) farming practice. Next best practice was noticed by silviculture (4221 kg ha⁻¹) and unmanaged AF (3924 kg ha⁻¹) farming practices.

During investigation it was found that the maximum water productivity (WP) was observed in managed agroforestry (140 kg ha⁻¹ cm⁻¹) farming practice while minimum in agriculture (72 kg ha⁻¹ cm⁻¹) farming practice. Next best result was found by silviculture AF (113 kg ha⁻¹ cm⁻¹) and unmanaged AF (95 kg ha⁻¹ cm⁻¹) farming practices.

WEY in different farming practice in Rabi season

Different farming practice shows a significant difference within treatments in Rabi season. The highest yield was recorded in managed AF (6680 kg ha⁻¹) practice and lowest in silviculture (3344 kg ha⁻¹) farming practice. Next best practice was noticed by agriculture (5070 kg ha⁻¹) and unmanaged AF (4414 kg ha⁻¹) farming practices.

During investigation it was found that the maximum water productivity (WP) was observed in silviculture (743 kg ha⁻¹ cm⁻¹) farming practice while minimum in agriculture (136 kg ha⁻¹ cm⁻¹) farming practice. Next best result was found by managed AF (226 kg ha⁻¹ cm⁻¹) and unmanaged AF (196 kg ha⁻¹ cm⁻¹) farming practices.

6.2 Conclusion

During experimentation it was concluded that practicing of heavy pruning allows the better light penetration to understory crops so it improves paddy and wheat yield but practicing of heavy pruning will decrease the tree volume production in greater extent. In this context low pruning is recommended for better production from agroforestry system which gives maximum yield. Water scarcity is global problem in present century, so for better and sustainable use water resources in the system Limited pruning intensity (25%) gave the higher water productivity.

Incorporation of trees along with agricultural crops will not provide better yield unless there is certain operations. Among the different farming practice managed agroforestry perform best yield compare to other farming practices. In both the season the yield from managed agroforestry is highest.

6.3 Suggestions for further work

During the course of investigation, few important questions occurred, which need further in-depth study. Some of the important suggestions are

1. Water productivity varies with species, time and space. Hence water productivity of different agroforestry systems under various Agroclimatic zones of the country is desirable.
2. The seasonal (Kharif, Rabi and summer) and annual (crop year) water productivity of different agroforestry systems may be determined.
3. Water productivity may be used as a tool to combat the problems of water scarcity.
4. The low water productivity systems of agroforestry and silviculture may be replaced with higher water productivity systems of silviculture and agroforestry.
5. Since water productivity of agroforestry system is in general more than agriculture, hence trees must be incorporated with crop to enhance water productivity.

BIBLIOGRAPHY

- Ahmad MD, Masih I and Turrall H. 2004. Diagnostic analysis of spatial & temporal variations in crop water productivity: A field scale analysis of the rice-wheat cropping system of Punjab, Pakistan. *Journal of Applied Irrigation Science* 39(1): 43-63.
- Alauddin M and Sharma BR. 2013. Inter-district rice water productivity differences in Bangladesh: an empirical exploration and implications. *Ecological Economics* 93:210-218.
- Ali MH, Hoque MR, Hassan AA and Khair A. 2007. Effects of deficit irrigation on yield, water productivity, and economic returns of wheat. *agri cultural water management* 92 : 151-161.
- Alvaraez JA, Villagra PE, Villalba R and Debandi Gillerma. 2013. Effects of pruning intensity and tree size on multi-stemmed *Prosopis flexuosa* tree in the Central Monte Argentina. *Forest Ecology and Management* 310: 857-864.
- Attalla AM, Abdel-Sattan M, Mahrous AE and Abdel-Azeez AA. 2011. Olive trees productivity in response to supplemental irrigation under north-western coastal conditions in Egypt. *American-Eurasian Journal of Agricultural and Environmental Sciences* 11(5): 609-615.
- Bandara GD, Whitehead D, Mead DJ and Moot DJ. 1999. Effects of pruning and understory vegetation on crown development, biomass increment and aboveground carbon partitioning in *Pinus radiata* D. Don trees growing at dry land agroforestry site. *Forest Ecology and Management* 124: 241-254.
- Black CA. 1965. Method of Plant and Soil Analysis part 11. Publishing American Society Agronomy, Madison wisconsin, USA, pp. 1367-1373.
- Bouman BAM, Peng S, Castaneda AR and Visperas RM. 2005. Yield and water use of irrigated tropical aerobic rice systems. *Agricultural Water Management* 74: 87–105.
- Broadhead JS, Ong CK and Black CR. 2003. Tree phenology and soil water in semi-arid agroforestry systems. *Forest Ecology and Management* 180: 61-73.
- Cai X, Sharma BR, Matin MA, Sharma D and Gunasinghe S. 2010. An assessment of crop water productivity in the Indus and Ganges river basins: Current status and scope for improvement. Colombo, Srilanka: International Water Management Institute, (IWMI Research Report 140). pp. 30
- Chahal GBS, Sood A, Jalota SK, Choudhury BU and Sharma PK. 2007. Yield, evapotranspiration and water productivity of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system in Punjab (India) as influenced by transplanting date of rice and weather parameters. *agricultural water management* 88: 14–22.
- Cui X, Peng S, Guanghai X and Wansheng G. 2006. Soil water effect and productivity in *Poplar* and wheat-corn agroforestry system. *Scientia Agricultura Sinica* 39(4): 758-763.
- Dastane NG. 1978. Effective rainfall in irrigated agriculture. Irrigation and Drainage paper. FAO, Rome Italy.

- Droppelmann KJ, Lehmann J, Ephrath JE and Berliner PR. 2000. Water use efficiency and uptake patterns in a runoff agroforestry system in an arid environment. *Agroforestry Systems* 49(3): 223-243.
- Droppelmann K and Berliner P. 2003. Runoff agroforestry—a technique to secure the livelihood of pastoralists in the Middle East. *Journal of Arid Environments* 54: 571-577.
- Duguma B Kang BT and Okali DUU. 1988. Effect of pruning intensity of three woody leguminous species grown in alley cropping with maize and cowpea on an alfisol Agroforestry system 6(1): 19-35.
- Egea G, Nortes PA, Gonzalez MM, Baille A and Domingo R. 2010. Agronomic response and water productivity of almond trees under contrasted deficit irrigation regimes. *Agricultural Water Management* 97(1): 171-181.
- Frank B and Eduardo S. 2003. Biomass dynamics of *Erythrina lanceolata* as influenced by shoot-pruning intensity in Costa Rica. *Agroforestry Systems* 57: 19-28.
- Ganiyu S, Amanatu MK and Korese JK. 2012 Water use efficiency and productivity for rice (*oryza sativa*) in the Bontanga irrigation scheme of northern region of Ghana. *Agricultural Science Research Journals* 2(7): 362-368.
- Ghrab M, Zitouna R, Mimoun M, Masmoudi MM and Mechlia N. 2013. Yield and water productivity of peach trees under continuous deficit irrigation and high evaporative demand. *Biological Agriculture and Horticulture* 29(1): 29-37.
- Gowing JW, Rose DA and Ghamarnia H. 2009. The effect of salinity on water productivity of wheat under deficit irrigation above shallow groundwater. *Agricultural water management* 96: 517–524.
- Handa AK, Rai P, Ram P, Ajit Kumar M, Chauhan, RV and Ram Bahadur SPS. 2007. Effect of pruning intensity on growth and productivity of MPTs and crop under rainfed conditions. *Rainfed Management and Agroforestry* 28(2A): 85-86.
- Iskandar A and Molden D. 2004. Spatial and temporal variability of water productivity in the Syr Darya Basin, central Asia. *Water Resources Research* 40(8): 6.
- Islam KK, Hoque ATMR and Mamun MF. 2006. Effect of level of pruning on the performance of rice-sissoo based agroforestry system. *American Journal of Plant Physiology* 1(1): 13-20.
- Jackson NA, Wallace JS and Ong CK. 2000. Tree pruning as a means of controlling water use in an agroforestry system in Kenya. *Forest Ecology and Management* 126(2):133-148.
- Jackson ML. 1966. In *Encyclopedia of chemistry*, 2nd edition. Reinhold Publ. Corp, New York, NY. Soil chemistry, pp.979-980.
- Kaur B, Singh S, Garg BR, Singh JM and Singh J. 2012. Enhancing water productivity through on-farm resource conservation technology in Punjab agriculture. *Agricultural Economics Research Review* 25(1): 79.
- Kequin W and Binrui W. 2000. Study on the water productivity of stands afforested using water-harvesting. *Scientia Silvae Sinicae* 36(1): 1-9.
- Kijne JW, Barker R and Molden DJ. 2003. *Water productivity in agriculture: Limits and opportunities for improvement*. CAB International, UK. 332p.

- Kumar V 2016. Multifunctional agroforestry systems in tropics region. *Nature Environment and Pollution Technology* 15(2): 365-376.
- Li H, Zheng L , Lei Y , Li C , Liu Z and Zhang S. 2008. Estimation of water consumption and crop water productivity of winter wheat in North China Plain using remote sensing technology. *Agricultural water management* 95: 1271-1278.
- Liu J, Wiberg D, Zehnder AJB and Yang H. 2007. Modeling the role of irrigation in winter wheat yield, crop water productivity, and production in China. *Irrigation Science* 26:21-33.
- Libeyi A, Ustun H, Oweis T, Pala M and Benli B. 2006. Wheat water productivity and yield in a cool highland environment: Effect of early sowing with supplemental irrigation. *Agricultural Water Management* 82:399–410.
- Lott JE, Khan AAH, Black CR and Ong CK. 2003. Water use in a *Grevillea robusta*-maize overstorey agroforestry system in semi-arid Kenya. *Forest Ecology and Management* 180(1): 45-59.
- Miah MG ,Aragon ML and Garrity DP. 1997. Growth, biomass production and distribution of three multipurpose tree species in an agroforestry system as affected by pruning. *Journal of Tropical Forest Science* 10(1):35-49.
- Mojid MA, Wyseure GCL and Mustafa SMT. 2012. Water use efficiency and productivity of wheat as a function of clay amendment. *Environment Control in Biology* 50(4): 347-362.
- Molden D, Sakthivadivel R and Habib Z. 2001. Basin-level use and productivity of water: Examples from South Asia. IWMI Research Report 49, Colombo: International Water Management Institute.
- Montazar A and Azadegan B. 2012. Effects of seasonal water use and applied N fertilizer on wheat water productivity indices. *Irrigation and Drainage* 61(1): 52-59.
- Muhairwe CK. 1994. Tree form and taper variation over time for interior lodgepole pine. *Canadian Journal of Forest Research* 24: 1904-1913.
- Newaj R and Dar. 2007. Tree growth and biomass productivity of herbaceous layer under different pruning regimes in *Albizia procera* based agri-silviculture system. *Range Management and agroforestry* 28 (2A): 108-110.
- Newaj R, Dar SA, Bhargava MK, Yadav, RS and Ajit. 2007. Effect of management practices on growth of white siris (*Albizia procera*), grain yield of intercrops, weed population and soil fertility changes in agrisilviculture system in semi-arid India. *Indian Journal of Agricultural Sciences*, 77 (7): 403-407.
- Noda Y, Martin G, Machado R, Garcia DE and Medina MG. 2007. Effect of two pruning frequencies and heights on biomass of mulberry. *Zootenia Tropical* 25(4): 261-268.
- Okun OK, Bada SO and Ladipo DO. 2001. Effects of inter-hedge row spacing of *Albizia procera* Burkat on maize performance. *Journal of Sustainable Agriculture and the Environment* 3: 70-75.
- Ong CK, and Swallow BM. 2003. Water productivity in forestry and agroforestry. In: Kijne, JW, Barker R and Molden D. (Eds.). *Water Productivity in Agriculture: Limits and Opportunities for Improvement* 1: 217-228.

- Ong CK, Anyango S, Muthuri CW and Black CR. 2007. Water use and water productivity of agroforestry systems in the semi-arid tropics. *Annals of Arid Zone* 46:255-284.
- Ong CK, Black CR and Muthuri CW. 2006. Modifying forestry and agroforestry to increase water productivity in the semi-arid tropics. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 65:1-19.
- Ong CK, Odongo JCW, Marshall FM and Black CR. 1992. Water use of agroforestry systems in semi-arid India. In: Calder, IR, Hall RL, Adlard, PG. (Eds.), *Growth and Water Use of Forest Plantations*. Wiley, Chichester, US, pp. 347–358.
- Ong CK, Wilson J, Deans JD, Mulayta J, Raussen T and Wajjamosukwe N. 2002. Tree-crop interactions: Manipulation of water use and root function. *Agricultural Water Management* 53(1-3): 171-186.
- Peter I and Lehmann J. 2000. Pruning effects on root distribution and nutrient dynamics in an acacia hedgerow planting in northern Kenya. *Agroforestry Systems* 50: 59–75.
- Pinkard EA, Battaglia M, Beadle CL and Sands PJ. 1999. Modeling the effect of physiological responses to green pruning on net biomass production of *Eucalyptus nitens*. *Tree Physiology* 19: 1-12.
- Pinkard EA, Mohammed CL, Hall MF, Worledge D and Nollon A. 2004. Growth responses, physiology and decay associated with pruning plantation-grown *Eucalyptus globulus* Labill and *E. nitens* (Deane and Maiden) Maiden. *Forest Ecology and Management* 200: 263-270.
- Piper CS. 1967. *Soil and Plant Analysis*. Asia publishing House. Bombay. pp 157-176.
- Ranjan A and Sahu ML. 2016. Water productivity of *Dalbergia sissoo* L.- Paddy based agroforestry system in response to pruning, nitrogen application and varied seed rate. *Indian Journal of Agroforestry* 18(1):29-33.
- Rijsberman FR. 2006. Water scarcity: fact or fiction? *Agricu. Water Manage.* 80:5–22.
- Sahu ML, Ranjan A, Kushwaha KS. and Koshta LD. 2015. Allometric models to estimate timber and fuel wood of *Dalbergia sissoo* Roxb. by pruning classes under agroforestry system. *Indian Journal of Agroforestry* 17(1):52-56.
- Sahu ML. 2006. Evaluation of differential responses of selected farm forestry trees in relation to stem flow, through fall and interception losses. Ph.D. Thesis, JNKVV, Jabalpur. 2p
- Samsuzzaman S, Alim A, Momin MA, Karim MR and Uddin MM. 2002. Tree-crop interaction as affected by tree spacing and pruning management in Bangladesh. *Indian Forester.* 128: 1231-1244.
- Seeta A, Sistla, Adam B, Roddy, Nicholas E, Williams, Daniel B. Kramer, Stevens K and Steven DA. 2016. Agroforestry practices promote biodiversity and natural resource diversity in Atlantic Nicaragua. *PLoS One* 11(9): 1-20.
- SEI. 2005. Sustainable pathways to attain the Millenium Development Goals: Assessing the key role of water, energy and sanitation. 104pp.

- Singh G and Singh Bilas. 2009. Effect of varying soil water stress regimes on nutrient uptake and biomass production in *Dalbergia sissoo* seedling in Indian desert. *Journal of Forestry Research* 20(4): 307-313.
- Swarup A, Panda D, Mishra B and Kundu DK. 2008. Water and nutrient management for sustainable rice production. In *Rice Research Priorities and Strategies for Second Green Revolution* (Singh et al., Eds.). Central Rice Research Institute, Cuttack, India. pp. 79-101.
- Tadayon MR, Ebrahimi R and Tadayyon A. 2012. Increased Water Productivity of Wheat under Supplemental Irrigation and Nitrogen Application in a Semi-arid Region. *Journal of Agricultural Science and Technology* 14: 995-1003.
- Thakur PS and Singh S. 2000. Impact of tree management on growth and production behavior of intercrops under rain fed agroforestry. *Indian Journal Forestry* 31(1): 37-46.
- Upadhyaya SD and Nema S. 2003. Tree-crop interaction studies in Acacia based agrisilviculture system at farmer's field. *JNKVV Research Journal* 37(2): 20-24.
- Wei SS, Lin YW, XinLi X , Dong LX and Kun CS. 2009. Effects of different pruning intensity on microclimate growth and yield of crops in agroforestry systems. *Journal of Beijing Forestry University* 31(1):25-30.
- Wongprom J, Wachrinrat C, Srigongpan R, Jumwong N and Klangsap N. 2010. Water use and water use efficiency of different spacing eucalypt planted on paddy bund at Phanom Sarakham district, Chachoengsao province. In *Proceedings of the 48th Kasetsart University Annual Conference, Kasetsart, 3-5 March, Subject: Natural Resources and Environment*. Kasetsart University.
- Yan N and Wu B. 2014. Integrated spatial-temporal analysis of crop water productivity of winter wheat in Hai Basin. *Agricultural Water Management* 133:24-33.
- Zeng B. 2003. Aboveground biomass partitioning and leaf development of Chinese sub-tropical trees following pruning. *Forest Ecology Management* 173:135-144.
- Zwart SJ, Bastiaanssen WGM, Fraiture CD and Molden DJ. 2010. A global benchmark map of water productivity for rainfed and irrigated wheat. *Agricultural Water Management* 97: 1617-1627.
- Zwart SJ and Bastiaanssen WGM. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural Water Management* 69:115-133.

APPENDIX

ANOVA for Paddy grain yield (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	190361	47590	0.86	3.26
MT	3	5200447	1733482	31.49	3.49
Error A.	12	660641	55053		
ST	2	489241	244620	3.48	4.46
Error B.	8	561657	70207		
Interaction	6	163794	27299	0.48	2.51
Error C	24	1369167	57049		
Total	59	8635309			

ANOVA for PEY of Paddy straw (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	47590	11898	0.86	3.26
MT	3	1300112	433371	31.49	3.49
Error A.	12	165160	13763		
ST	2	122310	61155	3.48	4.46
Error B.	8	140414	17552		
Interaction	6	40949	6825	0.48	2.51
Error C	24	342292	14262		3.26
Total	59	2158827			

ANOVA for PEY of paddy grain and paddy straw (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	428313	107078	0.86	3.26
MT	3	11701005	3900335	31.49	3.49
Error A.	12	1486443	123870		
ST	2	1100792	550396	3.48	4.46
Error B.	8	1263729	157966		
Interaction	6	368537	61423	0.48	2.51
Error C	24	3080626	128359		
Total	59	19429445			

ANOVA for PEY of LST (Kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	9481713	2370428	0.89	3.26
MT	3	28039718	9346573	3.51	3.49
Error A.	12	31976081	2664673		
ST	2	2580379	1290190	0.55	4.46
Error B.	8	18817530	2352191		
Interaction	6	10689176	1781529	0.99	2.51
Error C	24	43120841	1796702		
Total	59	144705438			

ANOVA for PEY of SST (Kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	113882	28471	1.38	3.26
MT	3	69814	23271	1.13	3.49
Error A.	12	246845	20570		
ST	2	27026	13513	0.87	4.46
Error B.	8	124715	15589		
Interaction	6	124304	20717	1.06	2.51
Error C	24	467937	19497		
Total	59	1174524			

ANOVA for PEY of Fuel Wood (Kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	29663	7416	1.20	3.26
MT	3	2589	863	0.14	3.49
Error A.	12	74017	6168		
ST	2	4881	2441	0.42	4.46
Error B.	8	46899	5862		
Interaction	6	34719	5786	1.09	2.51
Error C	24	127263	5303		
Total	59	320031			

ANOVA for PEY from trees (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	12683859	3170965	0.96	3.26
MT	3	28527275	9509092	2.87	3.49
Error A.	12	39736696	3311391		
ST	2	3312840	1656420	0.57	4.46
Error B.	8	23274043	2909255		
Interaction	6	14308648	2384775	1.01	2.51
Error C	24	56779597	2365817		
Total	59	178622956			

ANOVA for PEY from agroforestry (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	13496430	3374108	0.98	3.26
MT	3	50349148	16783049	4.86	3.49
Error A.	12	41430114	3452509		
ST	2	885106	442553	0.17	4.46
Error B.	8	20990108	2623763		
Interaction	6	12488195	2081366	1.06	2.51
Error C	24	47054777	1960616		
Total	59	186693878			

ANOVA for Water productivity of PEY from total Kharif component (kg ha⁻¹ cm⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	7281.1	1820.3	0.95	3.26
MT	3	25177.3	8392.4	4.38	3.49
Error A.	12	23019.0	1918.3		
ST	2	444.4	222.2	0.15	4.46
Error B.	8	11658.9	1457.4		
Interaction	6	6665.4	1110.9	1.04	2.51
Error C	24	25587.9	1066.2		
Total	59	99833.9			

ANOVA for Wheat grain yield (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	4793615	1198404	3.73	3.26
MT	3	13579427	4526476	14.09	3.49
Error A.	12	3855725	321310		
ST	2	1263559	631779	2.40	4.46
Error B.	8	2106182	263273		
Interaction	6	182713	30452	0.16	2.51
Error C	24	4486915	186955		
Total	59	30268136			

Wheat equivalent weight of Wheat straw (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	984236	246059	3.73	3.26
MT	3	2788159	929386	14.09	3.49
Error A.	12	791666	65972		
ST	2	259437	129718	2.40	4.46
Error B.	8	432446	54056		
Interaction	6	37515	6253	0.16	2.51
Error C	24	921264	38386		
Total	59	6214722			

ANOVA WEY of Wheat grain and wheat straw (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	10122065	2530516	3.73	3.26
MT	3	28673942	9557981	14.09	3.49
Error A.	12	8141641	678470		
ST	2	2668096	1334048	2.40	4.46
Error B.	8	4447355	555919		
Interaction	6	385812	64302	0.16	2.51
Error C	24	9474445	394769		
Total	59	63913356			

ANOVA for WEY from LST (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	6124116	1531029	0.92	3.26
MT	3	18229294	6076431	3.65	3.49
Error A.	12	19997025	1666419		
ST	2	1601983	800991	0.53	4.46
Error B.	8	12004343	1500543		
Interaction	6	6968897	1161483	1.04	2.51
Error C	24	26811155	1117131		
Total	59	91736813			
CD =	1380				

ANOVA for WEY from SST (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	66223	16556	1.38	3.26
MT	3	64430	21477	1.78	3.49
Error A.	12	144474	12040		
ST	2	18497	9249	0.91	4.46
Error B.	8	81617	10202		
Interaction	6	85721	14287	1.18	2.51
Error C	24	291155	12131		
Total	59	752117			

WEY from Fuel wood (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	17909	4477	1.18	3.26
MT	3	1189	396	0.10	3.49
Error A.	12	45406	3784		
ST	2	3136	1568	0.43	4.46
Error B.	8	29416	3677		
Interaction	6	22624	3771	1.16	2.51
Error C	24	77719	3238		
Total	59	197400			

ANOVA for WEY from trees (Kg ha⁻¹)

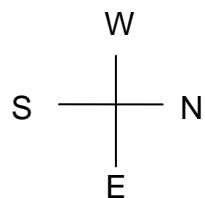
Source	DF	SS	MS	F Cal	at 5%
Replication	4	8086917	2021729	0.98	3.26
MT	3	18573463	6191154	3.00	3.49
Error A.	12	24752699	2062725		
ST	2	2068367	1034184	0.56	4.46
Error B.	8	14890942	1861368		
Interaction	6	9377677	1562946	1.06	2.51
Error C	24	35252202	1468842		
Total	59	113002266			

ANOVA for WEY from agroforestry (kg ha⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	15773058	3943265	1.18	3.26
MT	3	61929385	20643128	6.17	3.49
Error A.	12	40150605	3345884		
ST	2	435316	217658	0.11	4.46
Error B.	8	15486545	1935818		
Interaction	6	12613263	2102210	1.07	2.51
Error C	24	46963494	1956812		
Total	59	193351666			

ANOVA for Water productivity of WEY from total rabi component (kg ha⁻¹ cm⁻¹)

Source	DF	SS	MS	F Cal	at 5%
Replication	4	15576	3894	0.87	3.26
MT	3	54537	18179	4.07	3.49
Error A.	12	53598	4467		
ST	2	1267	634	0.23	4.46
Error B.	8	22412	2801		
Interaction	6	14993	2499	0.98	2.51
Error C	24	60965	2540		
Total	59	223348			



Agrisilviculture System (*D. sissoo* + Paddy) and (*D. sissoo* + Wheat) 2015-16

F1 open	F3 open	F2 open
------------	------------	------------

P75 F1	P50 F1	P0 F1	P25 F1	F3	F1	F2	P25 F1	P50 F1	P75 F1	P0 F1	F3	F2	F1	P75 F3	P50 F3	P25 F3	P0 F3	F1	F2	F3	P75 F1	P50 F1	P25 F1	P0 F1	F3	F2	F1	P75	P0	P25	P50
P75 F2	P50 F2	P0 F2	P25 F2				P25 F3	P50 F3	P75 F3	P0 F3				P75 F2	P50 F2	P25 F2	P0 F2				P75	P50	P25	P0				P75 F3	P0 F3	P25 F3	P50 F3
P75	P50	P0	P25				P25 F2	P50 F2	P75 F2	P0 F2				P75 F1	P50 F1	P25 F1	P0 F1				P75 F3	P50 F3	P25 F3	P0 F3				P75 F2	P0 F2	P25 F2	P50 F2
P75 F3	P50 F3	P0 F3	P25 F3				P25	P50	P75	P0				P75	P50	P25	P0				P75 F2	P50 F2	P25 F2	P0 F2				P75 F1	P0 F1	P25 F1	P50 F1

R5
Main treatment-4

P₀ – No pruning

P₁ – 25% pruning

P₂ – 50% pruning

P₃ – 75% pruning

Open - Crop only

R4

R3
Sub treatment - 3

F₁ - Recommended dose of fertilizer and seed rate

F₂ - F₁+25 % more nitrogen than recommended dose of fertilizer

F₃ – F₁+25% more seed rate than recommended dose of seed rate
(Recommended dose of fertilizer = 120:60:40 kg/ha⁻¹)
(Recommended dose of seed rate = 100 kg/ha⁻¹)

R2

Gross Plot Size = 5m x 5m

Net Plot Size = 4.2 x 4.2 m

R1

Figure 3 - Layout Plan of experimental field.



Plate 1: dbh measurement using tree calliper



Plate 2: Lifesaving irrigation in Wheat experimental plots



Plate 3: View of wheat experimental plot

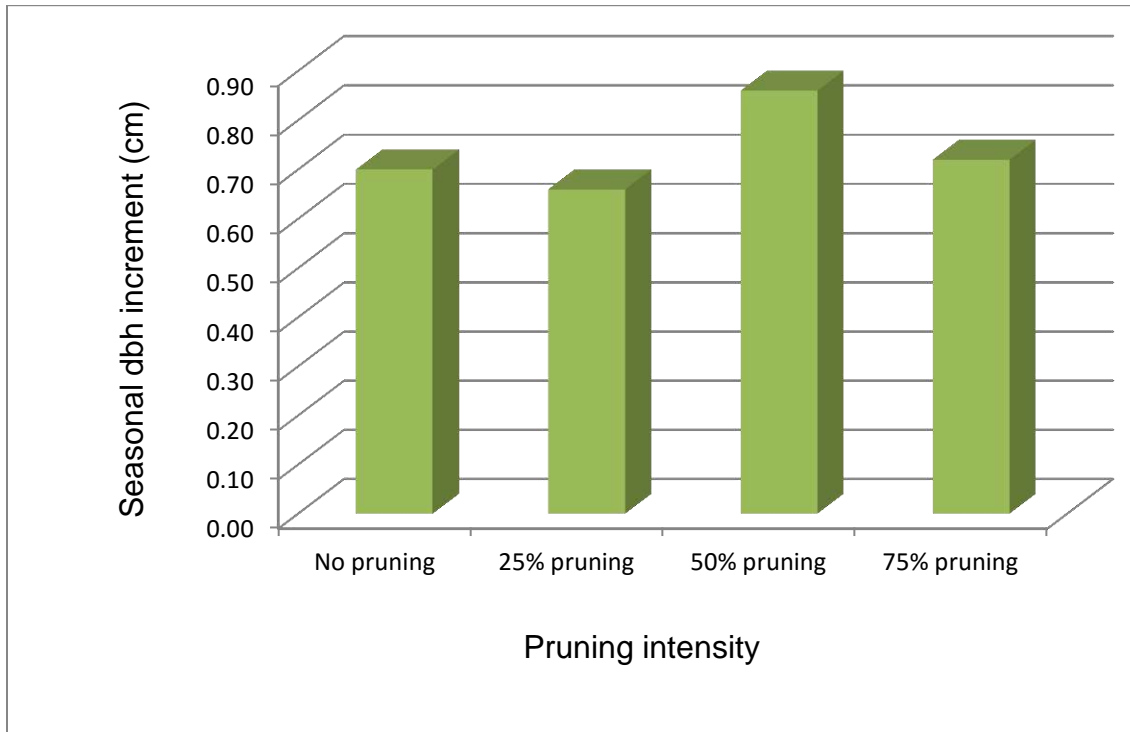


Fig. 4 : Seasonal increment of dbh under different pruning intensity

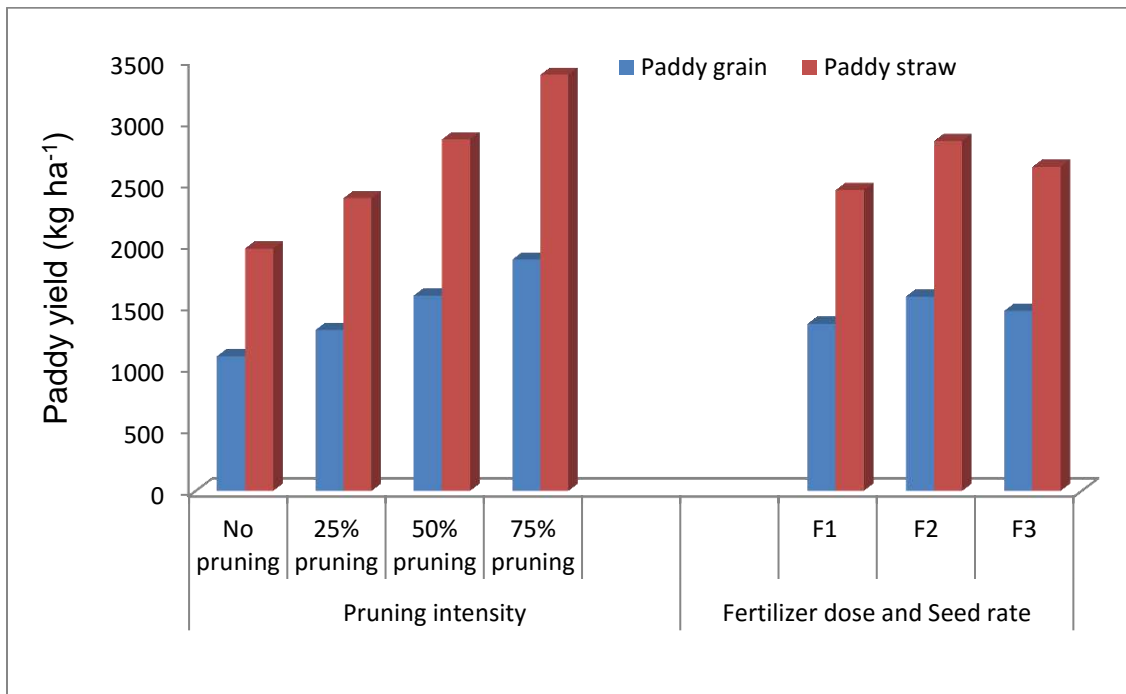


Fig. 5 : Effect of different pruning and package of practice on paddy grain and straw yield

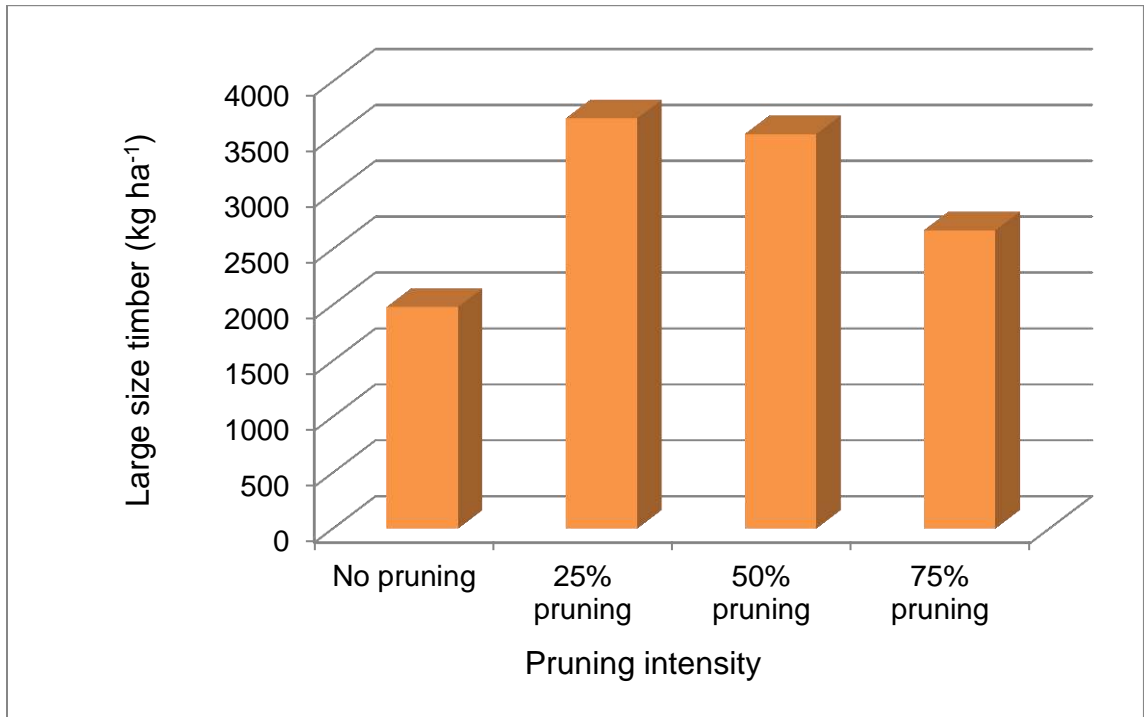


Fig. 6 : Effect of different pruning intensity on paddy equivalent yield of large size timber of tree component

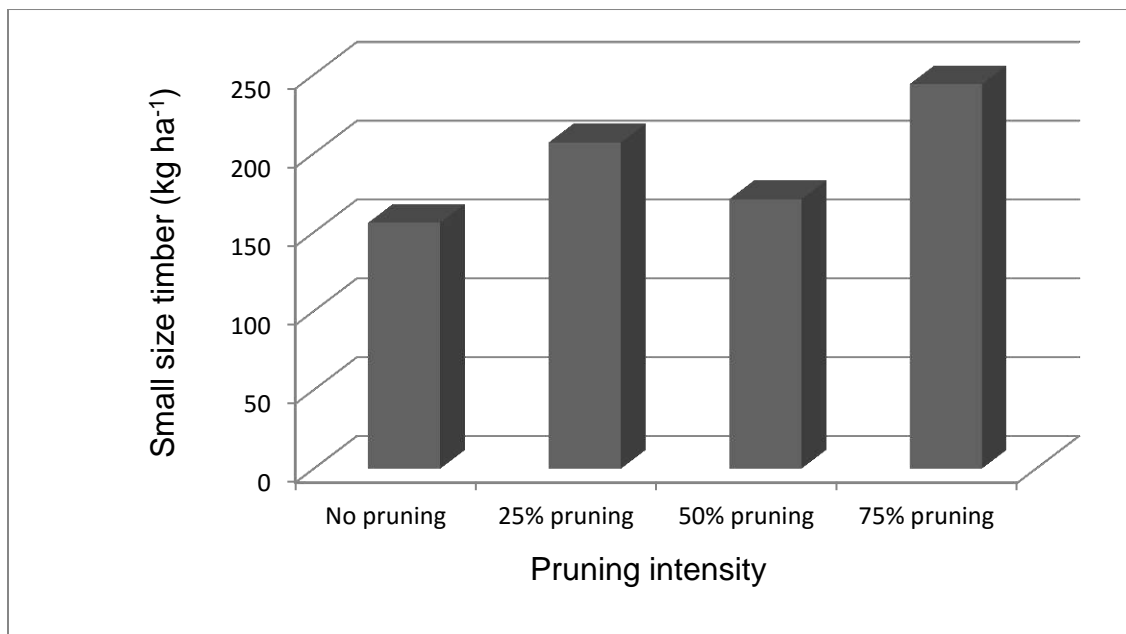


Fig. 7: Effect of different pruning intensity on paddy equivalent yield of SST of tree component

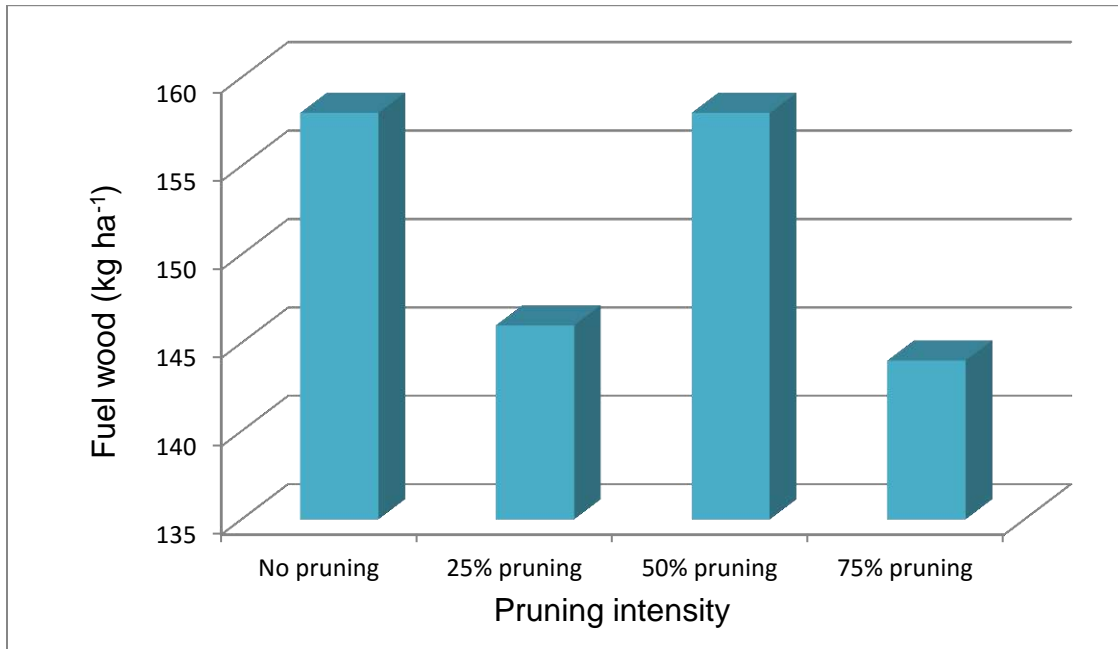


Fig. 8: Effect of different pruning intensity on paddy equivalent yield of fuel wood component

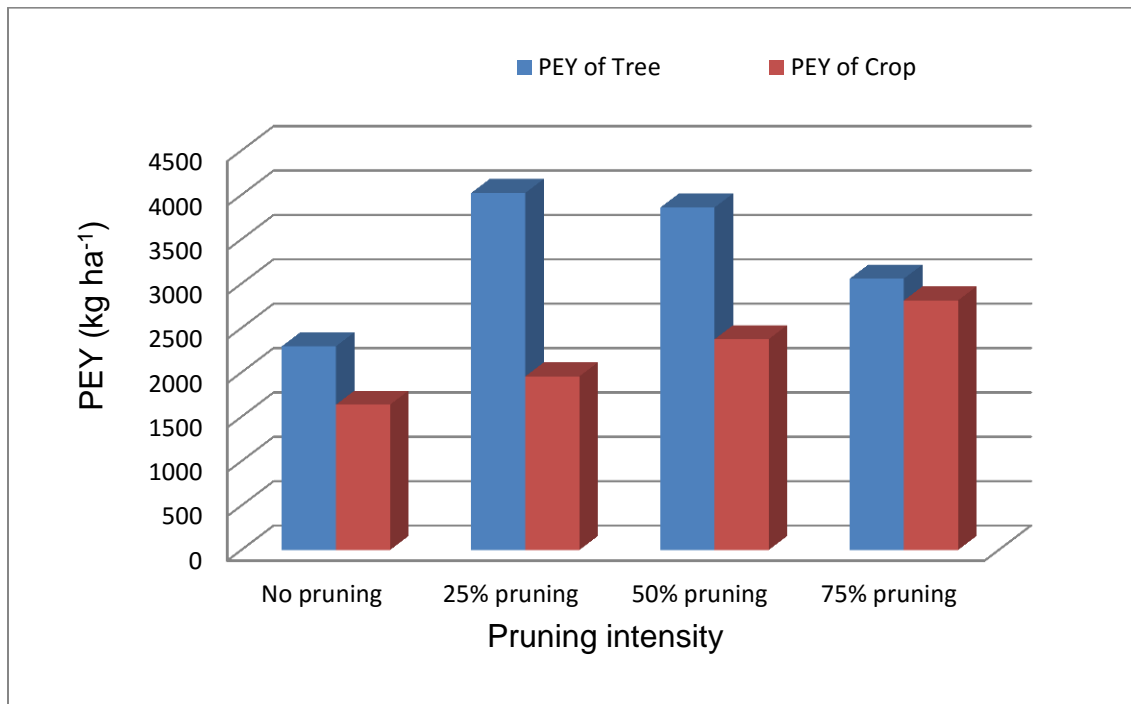


Fig. 9: Effect of different pruning intensity on paddy equivalent yield of agroforestry (crop + tree)

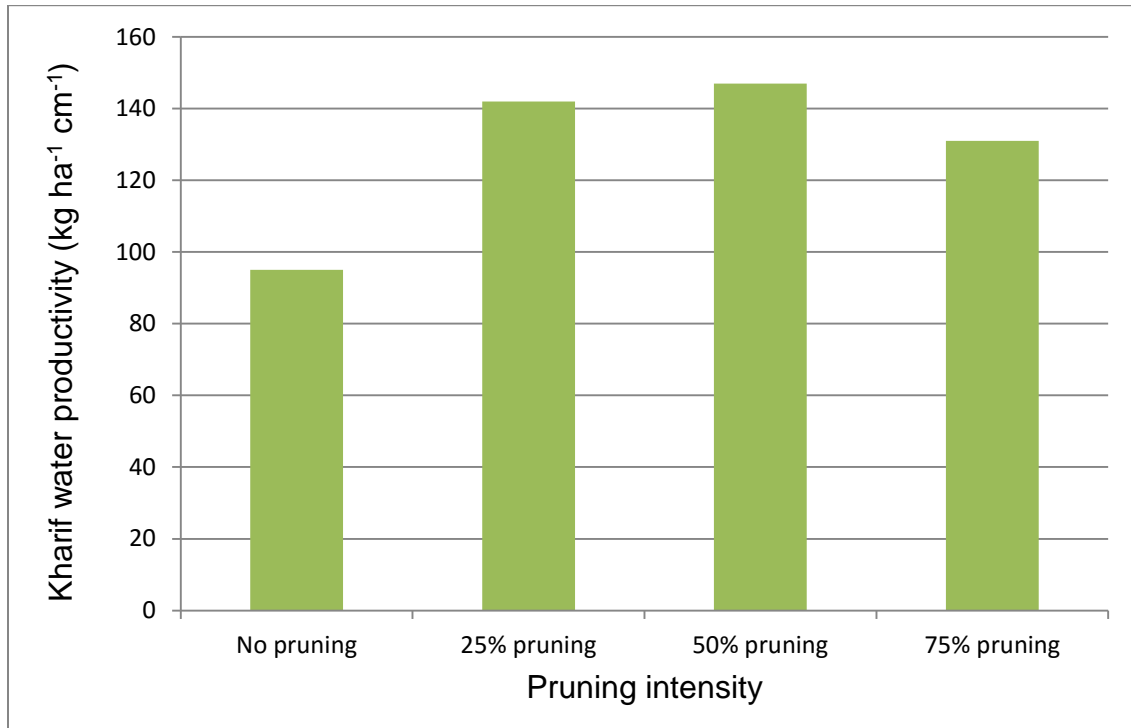


Fig. 10: Effect of different pruning intensity on Kharif water productivity of agroforestry

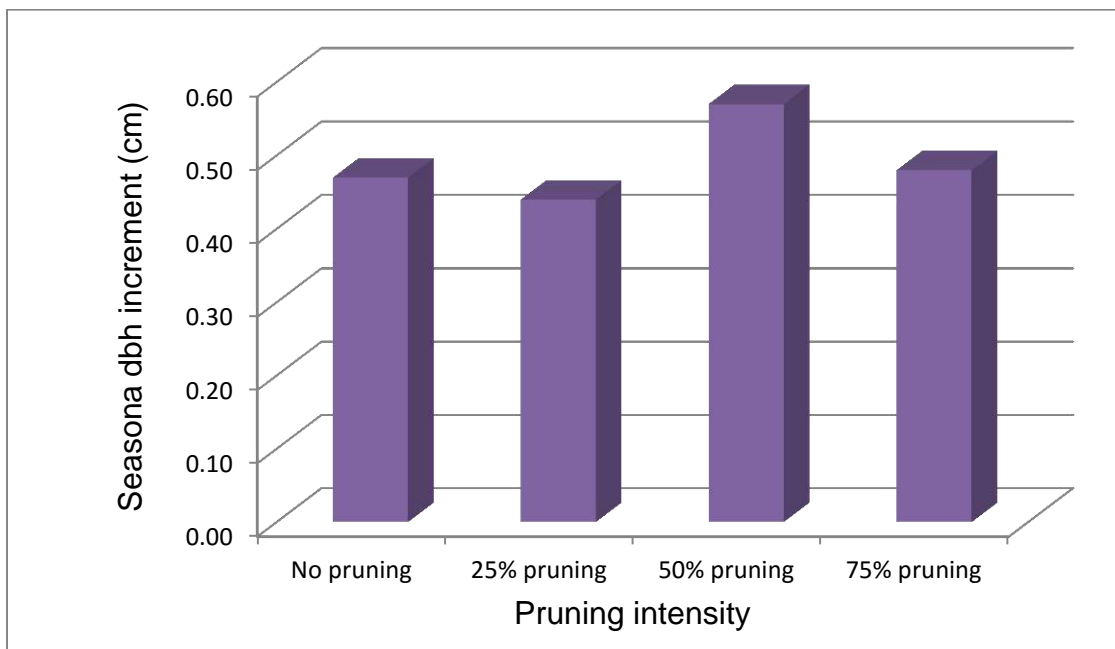


Fig. 11: Seasonal increment of dbh on effect of different pruning intensity

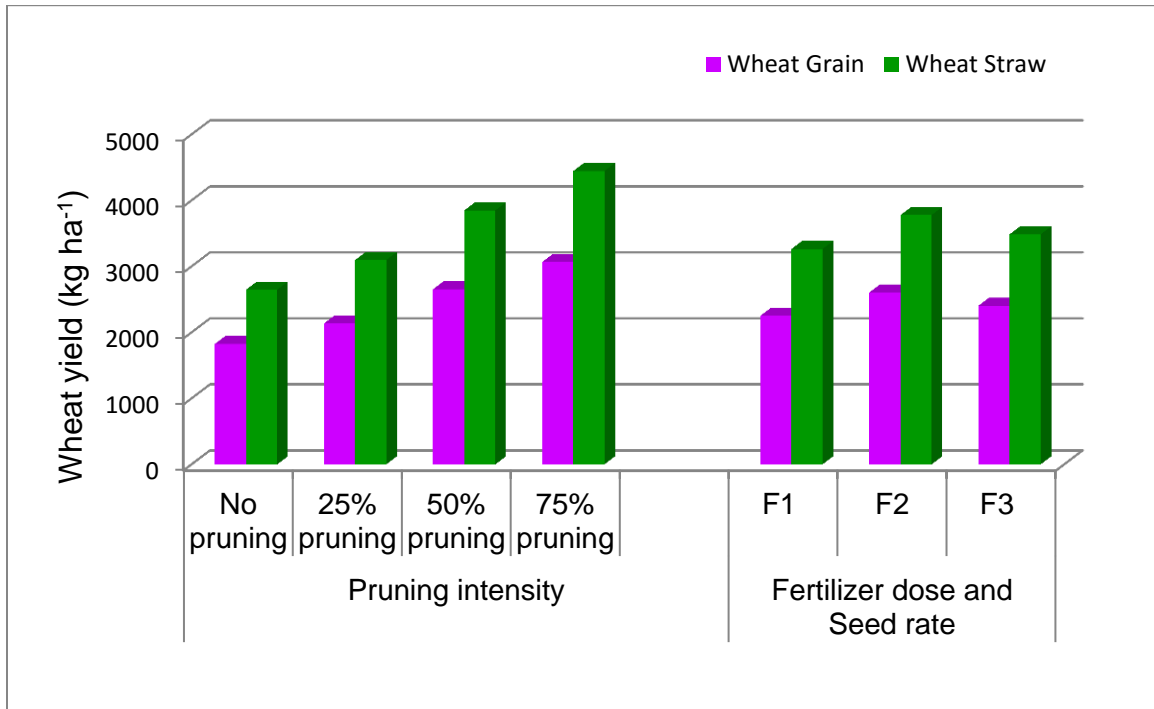


Fig. 12: Effect of different pruning and package of practices on wheat grain and straw yield

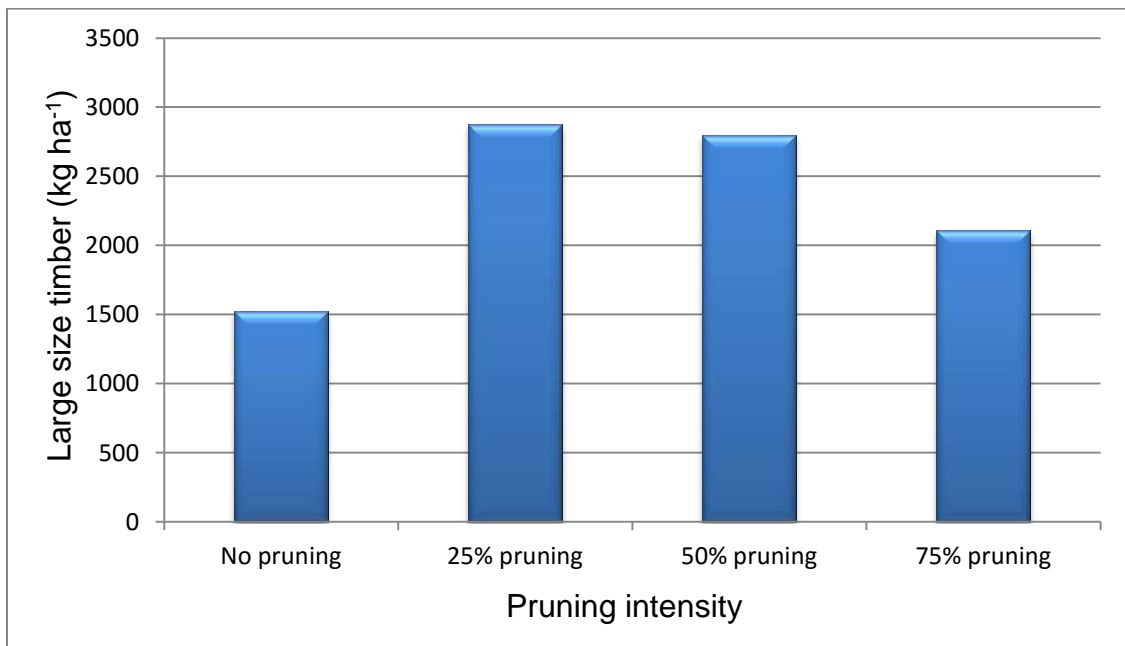


Fig. 13: Effect of different pruning intensity on wheat equivalent yield of large size timber component

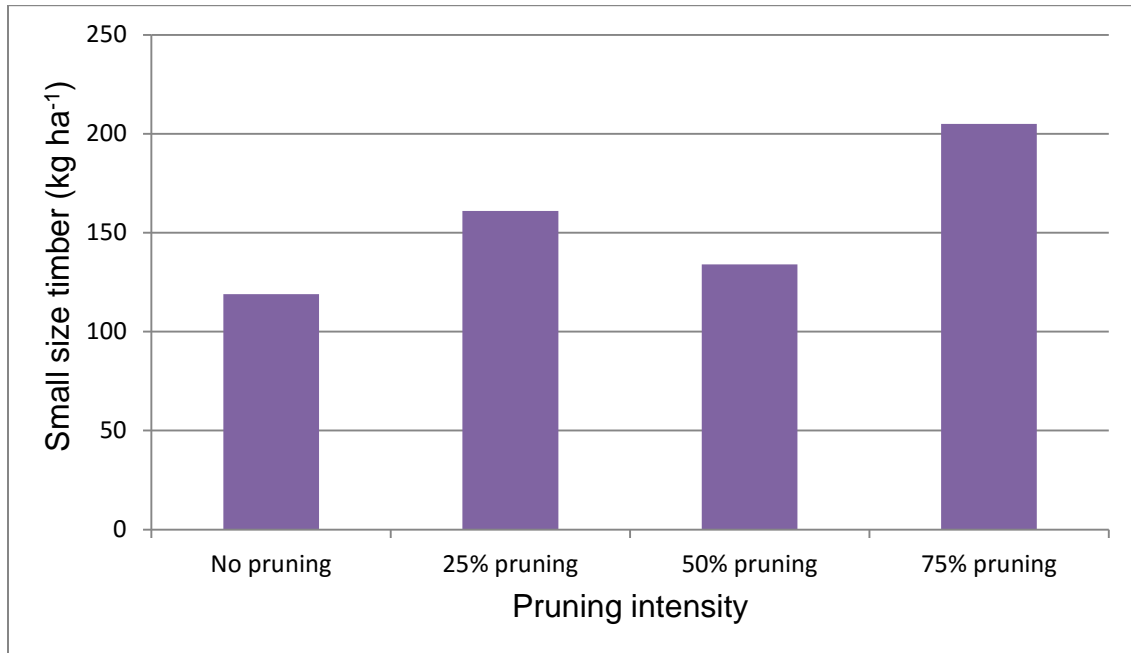


Fig. 14: Effect of different pruning intensity on wheat equivalent yield on Small size timber component

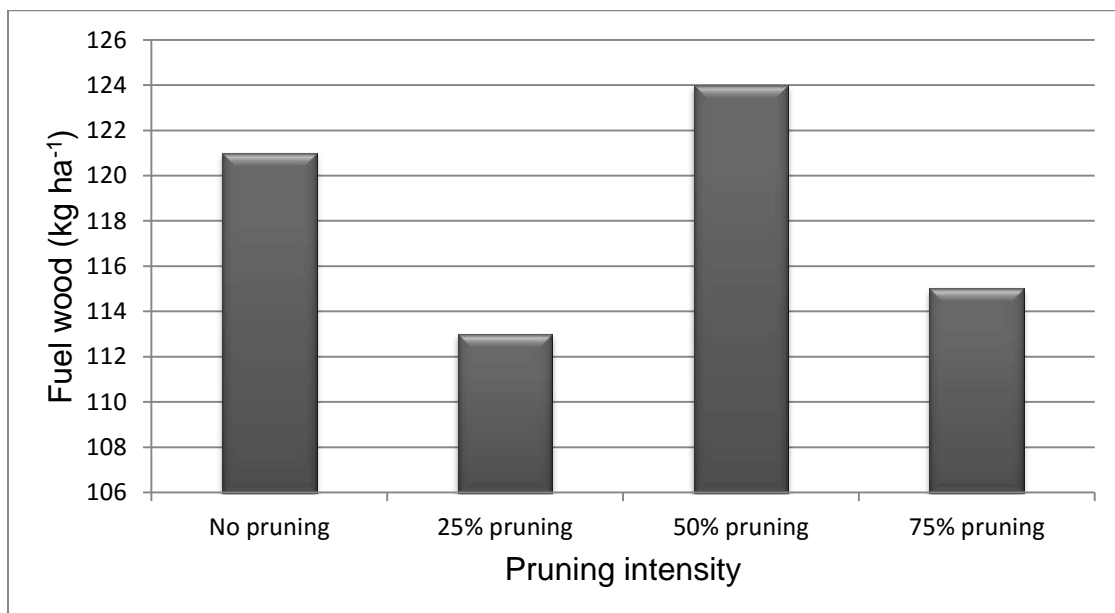


Fig. 15: Effect of different pruning intensity on wheat equivalent yield on Fuel wood component

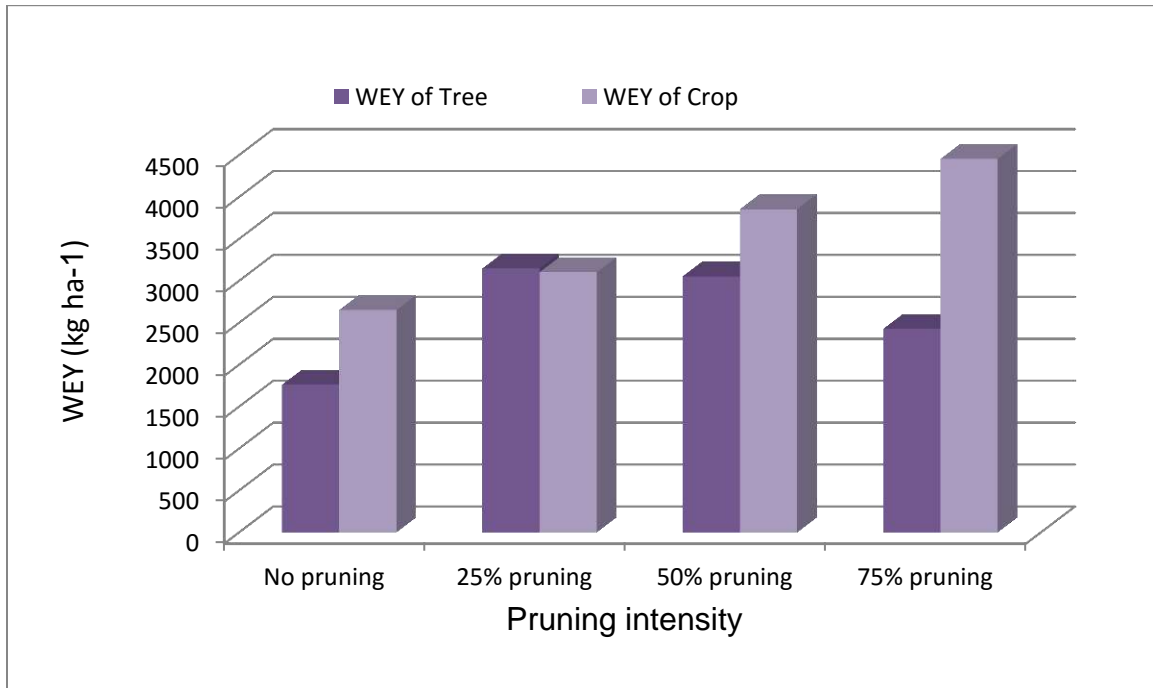


Fig. 16: Effect of different pruning intensity on wheat equivalent yield of agroforestry (crop + tree)

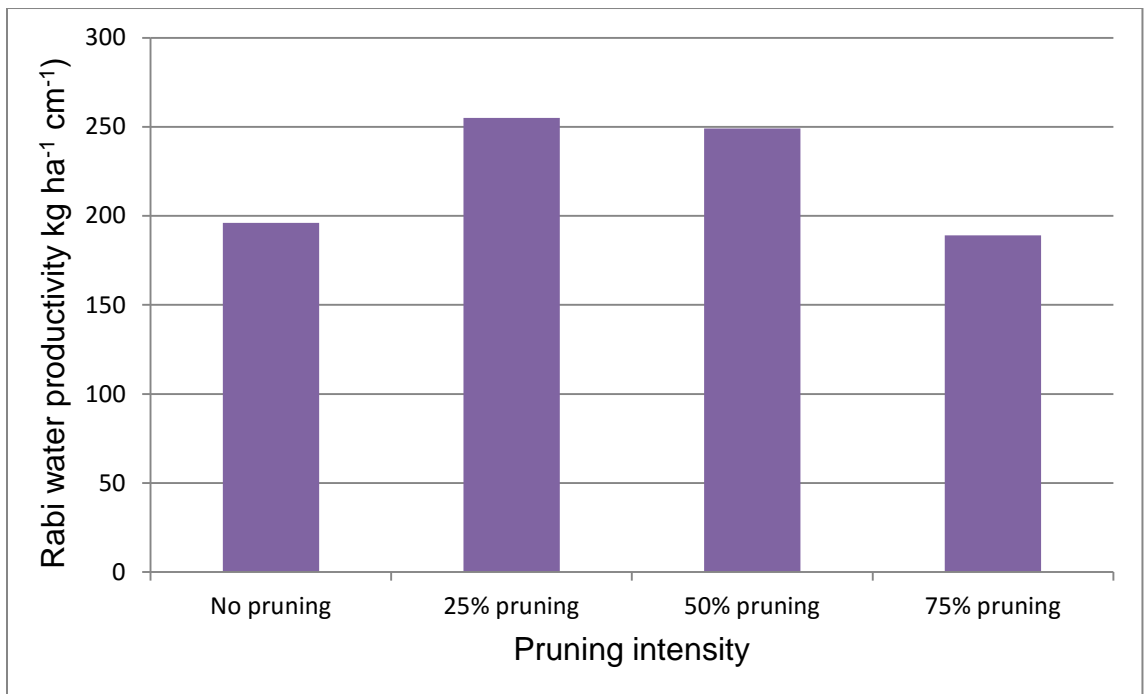


Fig. 17: Effect of different pruning intensity on Rabi water productivity of agroforestry

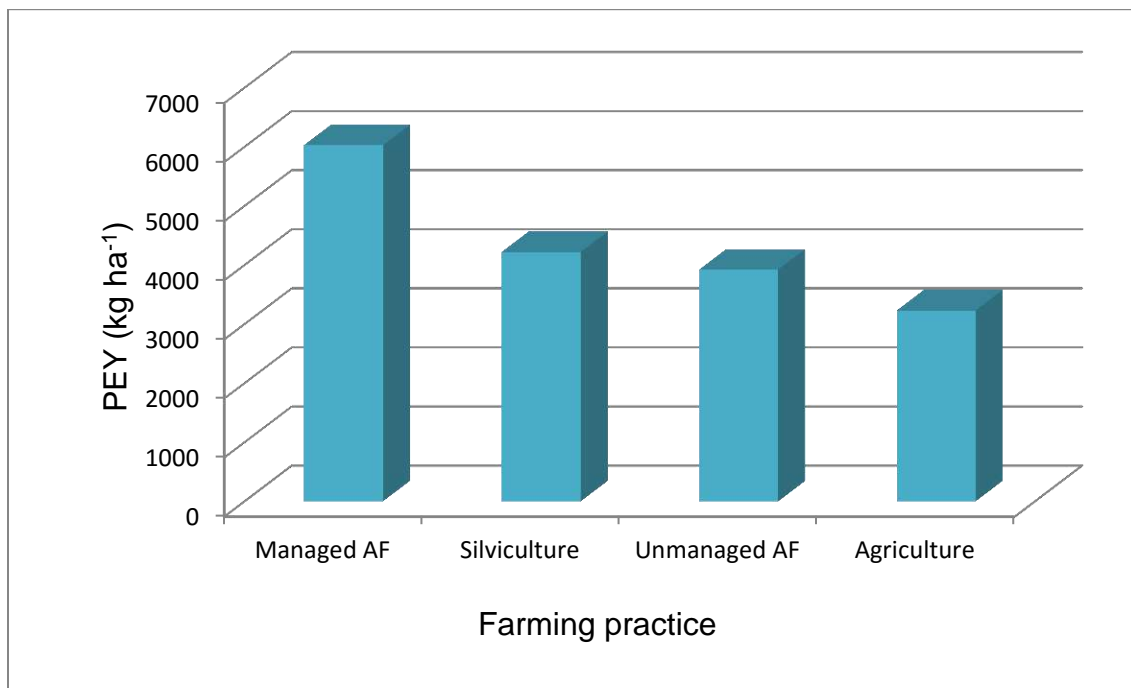


Fig. 18: Paddy equivalent yield in different farming practice

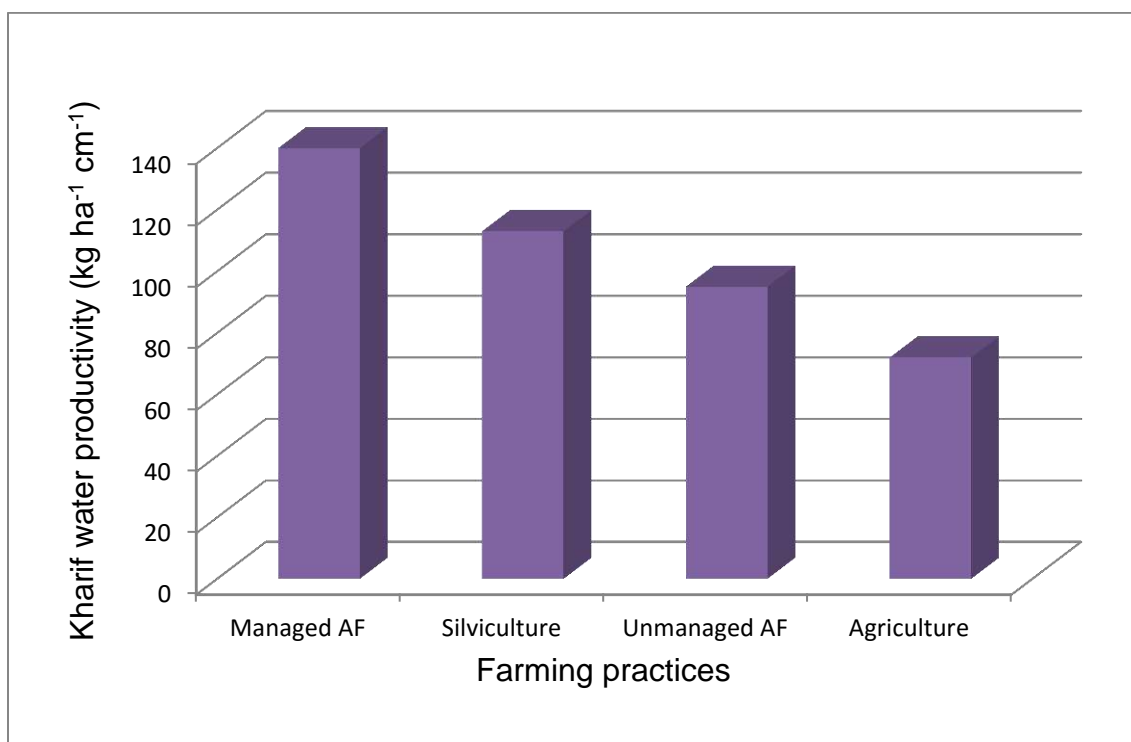


Fig. 19: Paddy equivalent water productivity in different farming practice during Kharif season

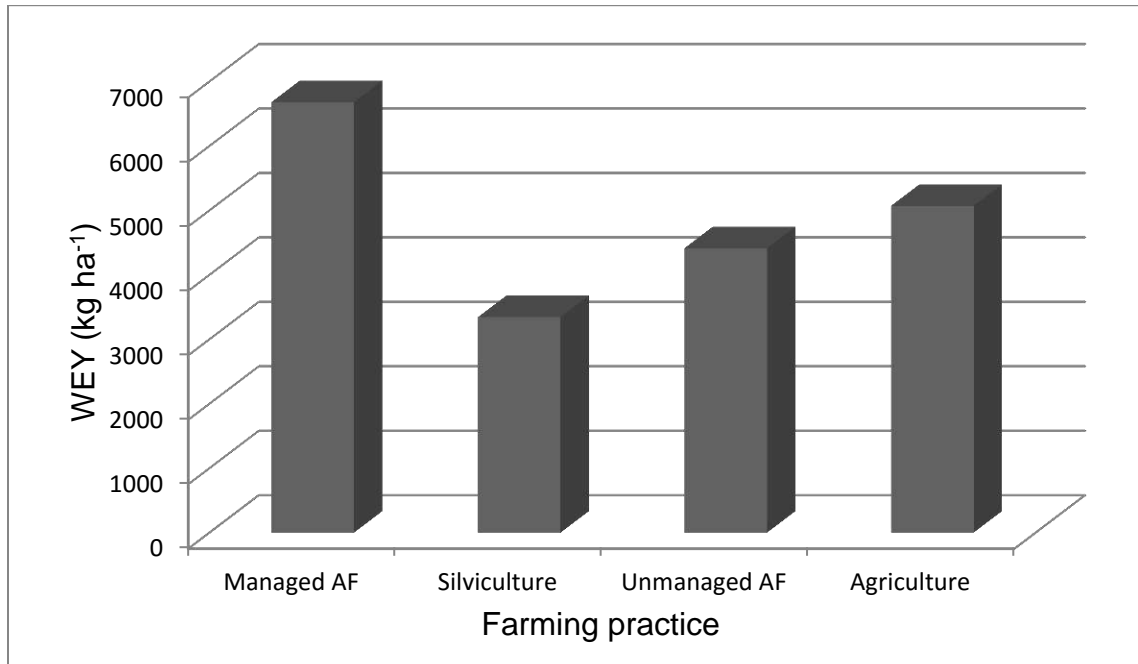


Fig. 20: Wheat equivalent yield in different farming practice

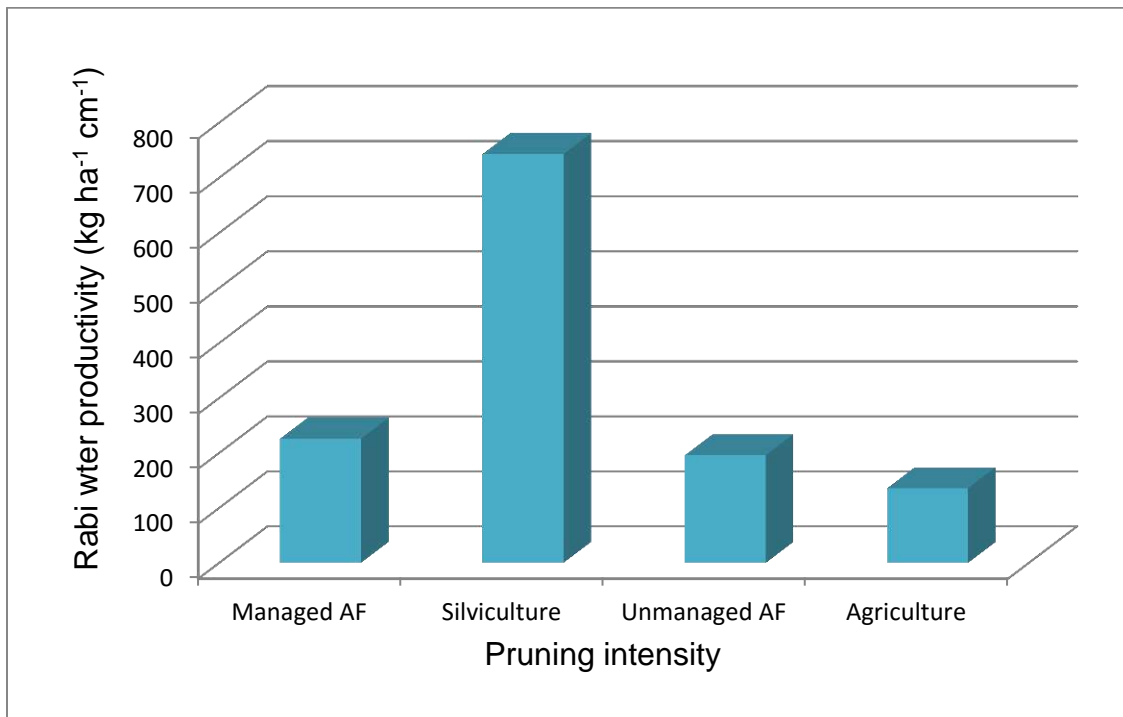


Fig. 21: Wheat equivalent water productivity in different farming practice during Rabi season

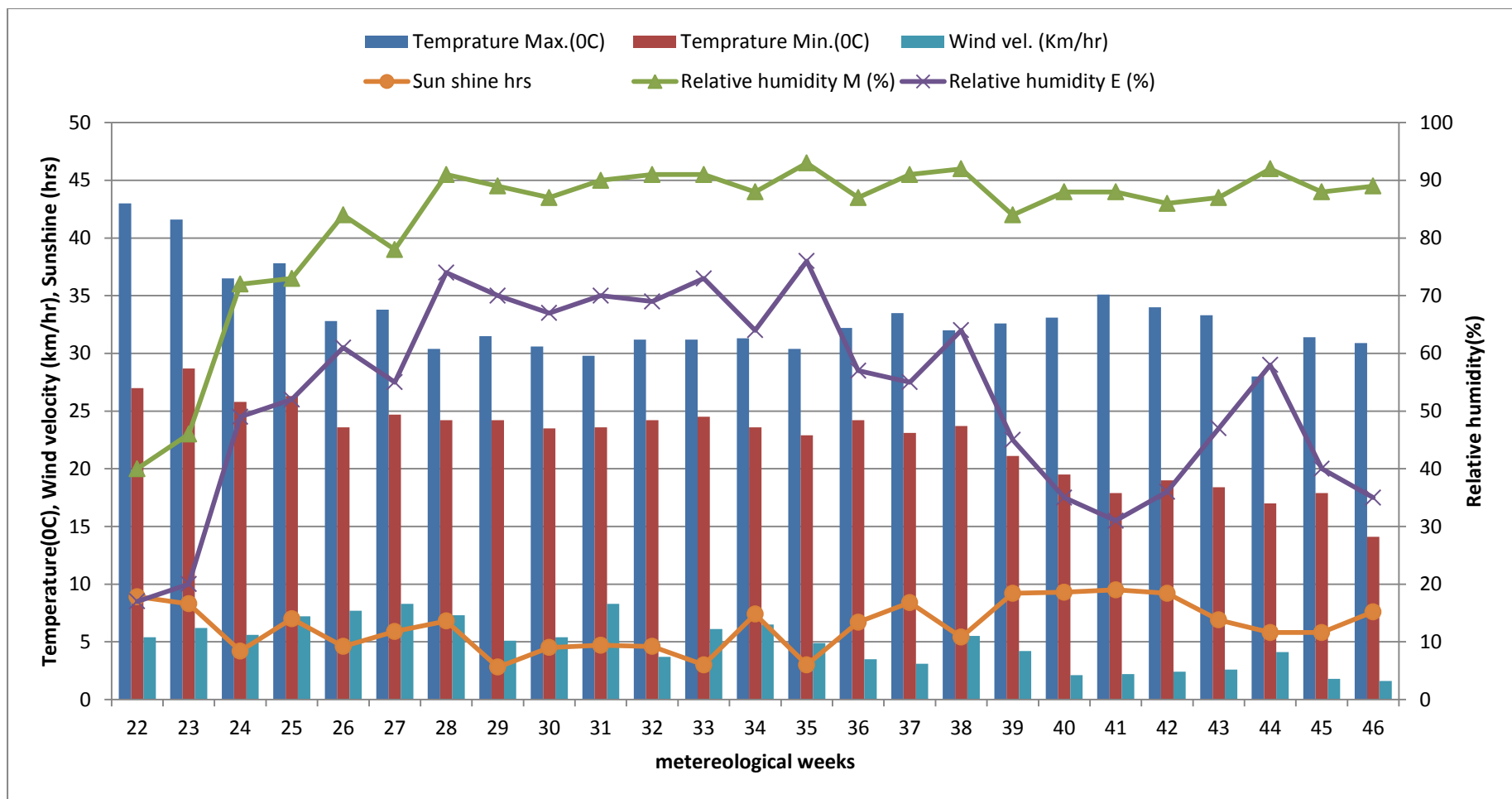


Fig. 1: Weekly meteorological parameters during the Kharif crop season (June 2015 to November 2015)

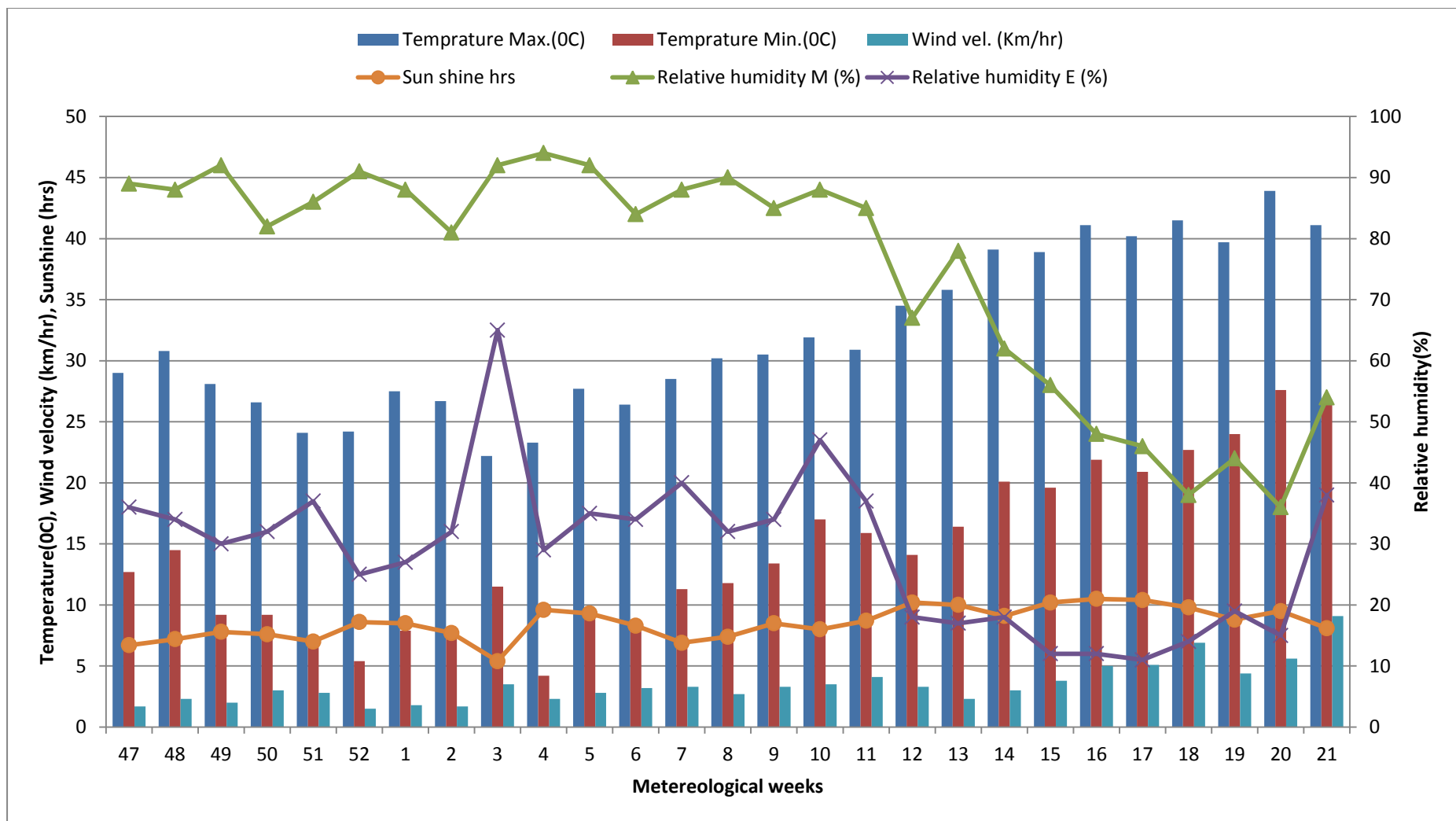


Fig. 2 : Weekly meteorological parameters during the Rabi crop season (November 2015 to May 2016)

CURRICULUM VITAE

The author of this thesis **Ganesh B.H.** was born on 31st October 1991 at Davanagere district Karnataka. Author has passed 10th class with 74 percentage in 2007 and 12th class with 61 percentage. Then author joined B.Sc. Forestry programme in 2010 at College of Forestry under UAHS Shimoga, Karnataka. He successfully completed and graduated with an OGPA of 8.02 (for 10 scales). He got awarded for the best outgoing student, 2014 during B.Sc. (Forestry).



Later author joined M.Sc. Forestry specialization in Agroforestry programme in 2014 at Department of Forestry, College of Agriculture, JNKVV, Jabalpur. Author completed his entire course successfully with an OGPA of 7.5 (approximately) on 10-point scale in the year 2017. Now he submitting this thesis in partial fulfilment of the requirement of M.Sc. (Forestry) degree.