RHIZOSPHERE MANAGEMENT FOR HIGHER ROOT PRODUCTION IN ASHWAGANDHA (*Withania somnifera* L. Dunal)

by

ASHIBA A

(2015-11-115)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY

COLLEGE OF AGRICULTURE

PADANNAKKAD, KASARGOD- 671 314

KERALA, INDIA

2017

DECLARATION

I, hereby declare that this thesis entitled **"Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Padannakkad
Date : 26.09.2017

Ashiba A
(2015-11-115)

CERTIFICATE

Certified that this thesis entitled **"Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)"** is a record of research work done independently by Ms. Ashiba A under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

26/9/17

Place: Padannakkad

Date: 26.09.2017

Dr. A.S. Anilkumar
(Major Advisor, Advisory Committee)
Professor
Department of Agronomy
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Ashiba A, a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled **"Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)"** may be submitted by Ms. Ashiba A in partial fulfillment of the requirement for the degree.

Dr. A.S. Anilkumar
(Chairman, Advisory Committee)
Professor
Department of Agronomy
College of Agriculture, Vellayani

Dr. T. K. Bridgit
(Member, Advisory committee)
Professor and Head
Department of Agronomy
College of Agriculture, Padannakkad

Dr. G.V. Sudarsana Rao
(Member, Advisory committee)
Professor
(Plant Physiology)
College of Agriculture, Padannakkad

Dr. M. Govindan
(Member, Advisory committee)
Associate Dean
College of Agriculture, Padannakkad

External Examiner
P. SUBRAMANIAN

Acknowledgement

First and foremost, praises and thanks to the Almighty, for everything that happens to me...

With immense pleasure, I would like to express my sincere gratitude to **Dr. A.S. Anilkumar**, *Professor, Department of Agronomy, College of Agriculture, Vellayani and Chairman of Advisory Committee for his constructive guidance, wholehearted dedication, advice, constant inspiration and valuable suggestions which render me to accomplish the research work successfully. I extend my sincere gratitude for providing a stress free situation by the open minded approach and for the care and affection bestowed on me throughout the study period.*

I wish to express my sincere gratitude to **Dr. T. K. Bridgit**, *Head and Professor and member of Advisory Committee, for her meticulous personal care and timely help for research work and course study.*

I am grateful to **Dr. M. Govindan**, *Associate Dean, College of Agriculture, Padannakkad, for his critical suggestions and instructions throughout the post graduate programme.*

I express my heartfelt gratitude to **Dr. G. V. Sudarshana Rao,** *Professor, Department of Plant Physiology and Member of Advisory Committee, for his constant encouragement, support, critical suggestions and timely help throughout the research work and course of study.*

I express my heartfelt gratitude to **Dr. R. Ilangovan,** *Associate Professor for his valuable and positive advices and instructions which were always informative and helpful to me throughout the course of investigation.*

I take this opportunity to express sincere thanks to teachers **Dr. Bineetha N. K., Dr. Yamini, Dr. P. R. Suresh, Dr. Namboodiri Raji Vasudevan, Dr. K. M. Sreekumar, Dr. Reshmi, Dr. Belliraj, Mr. Ashique, Dr. Shimi G. J., Dr. Nishan**

M. A. *and* ***Mr. Anees*** *who have always given encouragement and support. Their personal involvement at times of need was highly valuable.*

Above all, my success would have remained an illusion without the ambitious encouragement, unquantifiable love, continued calm endurance, constant support and affection showered on me throughout the educational endeavour from my beloved parents ***Sri. Mohammed*** *and* ***Smt. Kadeeja.*** *I have been highly fortunate and lucky to express my heartfelt respect to my loving sisters* ***Rashila*** *and* ***Habeeba*** *who have always been so proud of me and my relatives for their kind blessings and well wishes showed on me.*

Selfless love is the dearest commodity on this planet and only a few in this world are kind enough to extend their helping hands, just for love and affection shown to me by my blossom friends, ***Sherin, Ashwathi, Sunayana, Santhi, Ebi, Vishnupriya, Vineetha, Swaroop, Neethu, Ashok, Nusrath, Giridhari, Afna*** *and* ***Chinnu****, my seniors* ***Abhimanue, Saravankumar, Ishrath*** *and* ***Kokila****, my juniors* ***Chanchala, Shiva, Shaana*** *and all* ***2015 batch UG students*** *and all my friends for their everlasting source of inspiration and love.*

I sincerely acknowledge the Kerala Agricultural University for financial support in the form of KAU Junior Research Fellowship during my studies.

Ashiba A

TABLE OF CONTENTS

Sl. No.	Content	Page No.
1	INTRODUCTION	1
2	REVIEW OF LITERATURE	3
3	MATERIALS AND METHODS	19
4	RESULTS	36
5	DISCUSSION	71
6	SUMMARY	85
7	REFERENCES	91
	ABSTRACT	
	APPENDICES	

LIST OF TABLES

Table No.	Title	Page No.
1	Mechanical composition and moisture characteristics of soil	20
2	Chemical properties of soil	21
3	Abstract of weather data during December 2015 to April 2016	21
4	Treatment details	22
5	Details of irrigation given during experimental period	26
6	Plant height (cm) of ashwagandha as influenced by INM practices and summer irrigation	37
7	Number of functional leaves per plant of ashwagandha as influenced by INM practices and summer irrigation	37
8	Leaf area (cm^2) of ashwagandha as influenced by INM practices and summer irrigation	39
9	Number of primary branches per plant of ashwagandha as influenced by INM practices and summer irrigation	39
10	Number of secondary branches per plant of ashwagandha as influenced by INM practices and summer irrigation	40
11	Number of tertiary branches per plant of ashwagandha as influenced by INM practices and summer irrigation	40
12	Primary root number per plant of ashwagandha as influenced by INM practices and summer irrigation	42
13	Root length (cm) as influenced by INM practices and summer irrigation	42
14	Root spread (cm) as influenced by INM practices and summer irrigation	44
15	Root volume (cm^3) of ashwagandha as influenced by INM practices and summer irrigation	44
16	Fresh root weight (g $plant^{-1}$) of ashwagandha as influenced by INM practices and summer irrigation	46

LIST OF TABLES CONTINUED

17	Dry root weight (g $plant^{-1}$) of ashwagandha as influenced by INM practices and summer irrigation	46
18	Fresh and dry root yield (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	48
19	Seed production of ashwagandha as influenced by INM practices and summer irrigation	48
20	Relative leaf water content (%) of ashwagandha as influenced by INM practices and summer irrigation	50
21	Leaf temperature (^0C) of ashwagandha as influenced by INM practices and summer irrigation	50
22	Stomatal conductance (mmol m^{-2} s^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	52
23	Spad chlorophyll meter reading of ashwagandha as influenced by INM practices and summer irrigation	52
24	Dry matter production (t ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	54
25	Dry matter partitioning of ashwagandha into leaf, stem, root and berry and total dry matter production (g $plant^{-1}$) as influenced by INM practices and summer irrigation	54
26	Per cent distribution of dry matter production of ashwagandha as influenced by INM practices and summer irrigation	56
27	Root shoot ratio of ashwagandha as influenced by INM practices and summer irrigation	56
28	Leaf Area Index of ashwagandha as influenced by INM and summer irrigation	58
29	Leaf area ratio (cm^2 g^{-1}) of ashwagandha as influenced by INM and summer irrigation	58
30	Absolute growth rate for height (cm day^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	60

LIST OF TABLES CONTINUED

31	Crop growth rate (g m^{-2} day^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	60
32	Biochemical parameters of ashwagandha as influenced by INM practices and summer irrigation	62
33	Azospirillum population per gram dry soil of ashwagandha as influenced by INM practices and summer irrigation	62
34	Soil moisture before irrigation (Mbi) and after irrigation (Mai), seasonal consumptive use and mean daily consumptive use of ashwagandha as influenced by INM practices and summer irrigation	64
35	Crop water use efficiency (CWUE), field water use efficiency (FWUE) and water productivity (WP) of ashwagandha as influenced by INM practices and summer irrigation	64
36	Plant nutrient status of ashwagandha as influenced by INM practices and summer irrigation	67
37	Plant nutrient uptake of ashwagandha as influenced by INM practices and summer irrigation	67
38	Soil nutrient status (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	70
39	Economic analysis of ashwagandha as influenced by INM practices and summer irrigation	70

LIST OF FIGURES

Fig. No.	Title	Page No./ Pages Between
1	Layout of experimental plot	23
2	Plant height (cm) of ashwagandha as influenced by INM practices and summer irrigation	71 & 72
3	Number of functional leaves of ashwagandha as influenced by INM practices and summer irrigation	71 & 72
4	Root number of ashwagandha as influenced by INM practices and summer irrigation	73 & 74
5	Root length (cm) of ashwagandha as influenced by INM practices and summer irrigation	73 & 74
6	Root spread (cm) of ashwagandha as influenced by INM practices and summer irrigation	73 & 74
7	Root volume (cm^3) of ashwagandha as influenced by INM practices and summer irrigation	77 & 78
8	Root shoot ratio of ashwagandha as influenced by INM practices and summer irrigation	77 & 78
9	Total dry matter production (t ha^{-1}) as influenced by INM practices and summer irrigation	77 & 78
10	Fresh root weight (g $plant^{-1}$) of ashwagandha as influenced by INM practices and summer irrigation	81 & 82
11	Dry root weight (g) of ashwagandha as influenced by INM practices and summer irrigation	81 & 82
12	Total dry matter (g $plant^{-1}$) of ashwagandha as influenced by INM practices and summer irrigation	81 & 82
13	Crude alkaloid content (%) of ashwagandhaas influenced by INM practices and summer irrigation	82 & 83
14	Seasonal consumptive use (mm) of ashwagandha as influenced by INM practices and summer irrigation	82 & 83
15	Mean daily consumptive use (mm) of ashwagandha as influenced by INM practices and summer irrigation	82 & 83

LIST OF FIGURES CONTINUED

16	Crop water use efficiency (g m^{-3})of ashwagandha as influenced by INM practices and summer irrigation	83 &84
17	Total nitrogen uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	83 &84
18	Total phosphorus uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	83 &84
19	Total potassium uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	83 &84
20	Total magnesium uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	83 &84
21	Total boron uptake (g ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation	83 &84

LIST OF PLATES

Plate No.	Title	Page No.
1	General view of experimental field	23 & 24
2	Different stages of crop growth	72 & 73
3	Effect of treatments on root growth	73 & 74

LIST OF APPENDIX

Sl. No.	Title	Appendix No.
1	Monthly weather data during the crop period	I

LIST OF ABBREVIATIONS

%	-	Per cent
@	-	At the rate of
^0C	-	Degree Celsius
₹	-	Rupees
BCR	-	Benefit: cost ratio
CD	-	Critical difference
Cfu	-	Colony forming unit
cm	-	Centimeter
CO_2	-	Carbon dioxide
Cu	-	Consumptive use
CWUE	-	Crop water use Efficiency
DAT	-	Days after transplanting
et al	-	And others
Fig.	-	Figure
FWUE	-	Field water use efficiency
FYM	-	Farmyard manure
g	-	Gram
gm^{-3}	-	Gram per cubic meter
ha^{-1}	-	Per hectare
K	-	Potassium
K_2O	-	Potash
kg ha^{-1}	-	Kilogram per hectare
kg	-	Kilogram
LAI	-	Leaf Area Index
L ha^{-1}	-	Litre per hectare

mmol m^{-2} s^{-1}	-	milli mole per metre square per second
m^2	-	Square metre
m^3	-	Cubic metre
Mai	-	Moisture after irrigation
Mbi	-	Moisture before irrigation
mg	-	milligram
ml	-	Millilitre
mm	-	Milli meter
MSL	-	Mean sea level
N	-	Nitrogen
NS	-	Not significant
P	-	Phosphorus
P_2O_5	-	Phosphate
ppm	-	parts per million
RLWC	-	Relative Leaf Water Content
SEm	-	Standard error of mean
t ha^{-1}	-	Tonnes per hectare
v/v	-	Volume / volume
viz	-	Namely
w/w	-	Weight / weight
yr^{-1}	-	Per year
RDF	-	Recommended dose of fertilizer

Introduction

1. INTRODUCTION

Ashwagandha (*Withania somnifera* L. Dunal) also known as Indian ginseng, is a wonder herb with multiple medicinal properties. It is widely grown in dry parts of subtropical regions of India. All plant parts of ashwagandha have medicinal properties and are used in the preparation of various drugs, however, roots are mainly used for preparation of vital tonics. It is aphrodisiac, tonic, rasayan drug, general tonic in arthritis and debility from old age. It is used in anxiety, depression, phobias, alcoholic paranoia, schizophrenia *etc*.

The root of *W. somnifera* is a constituent of over 200 formulations in Ayruveda, Siddha and Unani medicines for the treatment of various physiological disorders. Among them, only two species: *W. somnifera* and *W. coagulans* are of economic and medicinal importance as they are widely used and extensively cultivated (Panwar and Tarafdar, 2006). The medicinal properties of the plant are due to the presence of steroidal alkaloids and lactones commonly known as withanoloids. They have anticancer, antiinflamatory and hepatoprotective properties. Ashwagandha is a hardy and drought tolerant plant. The estimated production of its roots in India is more than 1500 tonnes, while the annual requirement is about 7000 tonnes, necessitating increase in its cultivation and higher production (Thakur *et al.*, 2014).

Ashwagandha grows well in sandy loam and light red soil having pH 7.5 to 8.0 with good drainage. It is grown as late rainy season rainfed crop. The crop requires relatively dry season during its growing period. It can tolerate a temperature range of 20°C to 38°C. The plant grows up to an altitude of 1500 m above sea level.

The global interest in ashwagandha and the high demand for its roots provide ample scope for its cultivation on a commercial scale (Kattimani *et al.*, 1999). Present price for roots is attractive and the crop gives economic and remunerative returns in comparison to traditional crops. The crop can be integrated with traditional crops through crop sequencing. Opportunities for marketing of leaf and seed also exist and byproducts can be profitably utilized. However, current exports are limited and large scale exports of roots and value added products need to be explored.

Even though the crop ashwagandha is one of the oldest known medicinal crops, limited success has been achieved so far in increasing root yield and alkaloid content, mainly because of inadequate information on nutrient requirement and source of nutrients to be used for improving the growth, yield and quality. As the root is an economic part, the factors affecting root yield are to be studied and optimized for making ashwagandha cultivation the most remunerative. Ashwagandha responds very well to management practices. Root development in ashwagandha is very slow compared to shoot growth. Providing appropriate rooting medium consisting of a combination of various inorganic or organic sources of nutrients and bioinoculants can result in proliferation of roots.

Investigations on soil based plant nutrient management plan for agroecosystems of Kerala conducted by the Kerala State Planning Board revealed the deficiency of Magnesium, an essential secondary nutrient, in three fourth of the composite soil samples drawn from the state and tested. Among the investigated micronutrients, the deficiency of boron only is significant and extensive, requiring immediate intervention. Possibilities of application of these nutrients as part of INM strategy are to be explored for achieving higher use efficiency without soil contamination.

There is lack of information on integrated nutrient management practices and summer irrigation in ashwagandha, especially in Kerala. In this context, the present experiment was undertaken to study the effect of integrated nutrient management practices and summer irrigation on growth promotion and root production in ashwagandha.

Review of Literature

2. REVIEW OF LITERATURE

The investigation titled "Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)" was undertaken to study the effect of integrated nutrient management practices and summer irrigation on growth promotion and root production in ashwagandha. The literature pertaining to the subject with special emphasis on ashwagandha are reviewed hereunder. Wherever sufficient literature on ashwagandha are not available, studies on other medicinal plants and horticultural crops are also reviewed.

2.1 THE CROP ASHWAGANDHA

Ashwagandha (*Withania somnifera* L. Dunal.) commonly known as winter cherry belonging to the family Solanaceae is a medicinally important and commercially valuable crop. Ashwagandha is hardy and drought tolerant and can be cultivated both as a rainfed and irrigated crop. It is widely grown in dry parts of subtropical regions of India. The major ashwagandha growing states are Rajasthan, Punjab, Haryana, Uttar Pradesh, Gujarat, Maharashtra and Madhya Pradesh (Jat *et al.*, 2015).

The medicinal property of ashwagandha is due to the presence of steroidal alkaloids and lactones commonly known as withanoloids. They possess anticancer, antiinflamatory and hepatoprotective properties. All plant parts are credited with medicinal properties. The dried roots are a rich source of 'withanine' and 'somniferine', which are mainly used in Ayurvedic, Siddha and Unani preparations for the treatment of various physiological disorders. Chemical constituents of ashwagandha and their derivatives act as neuroprotective agents by enhancing the expression of low density lipoprotein receptor in brain which results in degradation of amyloid β peptide. Leaves are used for curing fever, lesions, swelling, sore eyes and syphilitic sores. Green berries are used for treating ringworm infection, animal sores and horse's girth galls. Extracts of *W. somnifera* are effective and can be used to manage stored pests as part of integrated pest management programme (Suvanthini, 2012).

Botanically ashwagandha is an annual to perennial, branched, small woody shrub of about 30 to 120 cm height with minutely stellate and tomentose branches, ovate leaves. Mature fruits are orange red berries. Roots are fleshy, tapering, whitish brown (Jat *et al.*, 2015).

2.2 SOIL AND CLIMATIC REQUIREMENT OF ASHWAGANDHA

Ashwagandha prefers areas with dry climate. The crop require dry season during its growing period. Semi tropical areas receiving 500-750 mm rainfall are highly suitable for its cultivation. Later winter rains are conducive for root development. Its cultivation in rainy season causes severe crop loss. This loss could be reduced either by choosing low rainfall areas or by raising it as a post rainy season crop. Growing ashwagandha during rabi season is more suitable as well as more economical (Shrivastava and Srivastava, 2015).

Withania somnifera comes up well in well drained sandy loam and light red soils with a pH of 7.5 - 8.0 (Jat *et al.*, 2015).

2.3 INFLUENCE OF SEED TREATMENT ON GERMINATION

Among the stages of plant life cycle, seed germination is one of the important stages in plant survival and growth. Traditionally, ashwagandha is propagated from seeds but germination is very low. There may be a possibility of dormancy in the seeds that prevent germination immediately. According to Kambizi *et al.* (2006), the seeds of ashwagandha is light-dependent for germination but exposure to regimes of alternating temperatures may probably suppress the effect of the photoperiod and the seeds did not germinate when exposed to constant temperatures in continuous darkness. Seed rate and sowing time are also influencing the yield and quality of ashwagandha (Chaudhari *et al.*, 2013). Different reports on this species suggest that germination percentage can be improved by presowing seed treatments (Shravankumar and Datta, 2014).

Seed treatment with GA3 500 μg L^{-1} for 24 hours before sowing can be adopted to overcome dormancy of ashwagandha seeds with good germination percentage and the mechanical scarification of seeds can also be carried out as an alternative, cost-effective and eco-friendly way to break seed dormancy (Niyaz and Siddiqui, 2014).

2.4 INFLUENCE OF TILLAGE, SOWING TIME, SEED RATE AND SPACING ON YIELD AND QUALITY

Preparatory tillage to a depth of 30 cm in combination with a density of 60 plants m^{-2} produced the highest root yield of 1.2 t ha^{-1}. Highest plant height, number of branches per plant and shoot biomass yield were also recorded with a tillage depth of 30 cm (Kothari *et al.*, 2003).

Variation in population was found to affect growth and dry matter accumulation due to variability in the availability of above and underground resources such as light, CO_2, O_2, moisture and nutrients (Singh *et al.*, 2014). Farooqui and Sreenivas (2001) reported a higher root yield in ashwagandha when the plant population was 20,000 to 25,000 ha^{-1}. Pakkiyanthan *et al.* (2004) observed maximum plant height, root length, number of roots and fresh shoot weight at 30 cm x 30 cm spacing in ashwagandha. Agarwal *et al.* (2004) reported the longest roots at closer spacing (20 cm x 5 cm) compared to wider spacing (25 cm x 7.5 cm).

A spacing of 15 cm × 10 cm along with fertilizer application of 24:21.2 kg N and P ha^{-1} was found optimum for ashwagandha in vertisols of Northern dry zone of Karnataka (Kubsad *et al.*, 2009). Though dry matter production per plant in roots was significantly lower in ashwagandha at closer spacing of 15 cm x 10 cm, the dry root yield was significantly higher due to higher plant population (Kubsad *et al.*, 2010).

According to Reddy *et al.* (2011), broadcasting of ashwagandha seeds @17.5 kg ha^{-1} produced higher dry root yield (4.51 q ha^{-1}). Root length (17.39 cm) was significantly higher in broadcasting of seed @ 17.5 kg ha^{-1}. According to Kumari and Upadhyay (2012), ashwagandha showed best growth and yield when transplanted at a wider spacing of 60 cm × 60 cm with the application of vermicompost @ 10 t ha^{-1} as organic manure.

Chaudhari *et al.* (2013) observed maximum alkaloid content in treatment combination of 1^{st} August sowing with a seed rate of 5 kg ha^{-1} followed by 1^{st} August sowing with 7.5 kg ha^{-1} seed rate and 15^{th} July sowing with 7.5 kg ha^{-1} seed rate and minimum in the treatment 15^{th} September sowing with a combination of 7.5 kg ha^{-1} seed rate.

2.5 INFLUENCE OF MULCHING ON GROWTH AND YIELD

Mulching is one of the important practices which are used to conserve soil moisture and it is beneficial in weed suppression, improvement of soil fertility and modification of the soil physical environment (Yoo-Jeong *et al.*, 2003). Use of different types of mulches is the cheap and simple option for *in situ* soil moisture conservation and enhancing water use efficiency. Different moisture conservation practices such as ridges and furrows along with mulch, enhanced the vigour and also helped to promote the productivity of cluster bean and chillies (Allolli *et al.*, 2008). Mulching significantly increased available N, P and K, bacterial and fungal population compared to unmulched plots (Kumar *et al.*, 2014).

2.6 INFLUENCE OF SOIL MOISTURE ON GROWTH AND YIELD

According to Kirnak *et al.* (2001) high water stress situation inhibited the uptake of nitrogen, phosphorus and potassium by egg plants. Behera, *et al.* (2012) recorded the highest root and seed yield in ashwagandha at 80 per cent pan evaporation followed by 100 and 60 per cent pan evaporation.

In ashwagandha, drip irrigation at 80 per cent pan evaporation combined with application of 100 per cent of the recommended dose of nutrients through fertigation resulted in significant improvement in growth, physiological parameters such as crop growth rate, relative growth rate, net assimilation rate, leaf area index, chlorophyll content and root and seed yields (Behera *et al.*, 2014).

2.7 INFLUENCE OF DIFFERENT INORGANIC NUTRIENTS ON GROWTH, YIELD AND QUALITY

2.7.1 Effect of nitrogen, phosphorus and potassium on growth and yield

Nigam *et al.* (1984) reported that the application of a fertilizer dose of 30: 30 kg N: P_2O_5 ha^{-1} recorded significantly higher root yield of ashwagandha (632 kg ha^{-1}). Fertilizing ashwagandha with 40:60:20 N: P_2O_5: K_2O kg ha^{-1} (entire dose of P_2O_5, K_2O and 50 % N as basal + 50% N as top dressing) resulted in highest dry root yield of 770.37 kg ha^{1} (Muthumanickam and Balakrishnamurthy, 1999). Maryada *et al.* (2001) reported the effect of N nutrition in ashwagandha and found that N at 60 kg ha^{-1} produced highest number of leaves and branches per plant. Kaushal *et al.* (2002) found tallest plants, highest number of fruits and increased root and seed yield in ashwagandha with application of 15 kg N and 60 kg P_2O_5 ha^{-1}. Application of NPK (80:40:20 kg ha^{-1}) significantly increased the plant height, number of branches, number of berries, 1000 seed weight, germination percentage, root and seed yield per hectare in ashwagandha (Karad *et al.,* 2009). Soil application of 45 kg N ha^{-1} and 26 kg P ha^{-1} proved to be the best dose for increasing shoot and root length, leaf area, fresh and dry weight of shoot and root, total chlorophyll, seed yield per plant, root yield per plant and berries per plant in ashwagandha (Nasir and Khan, 2012). Goel and Duhan (2014) observed significant increase in plant height, number of primary branches, plant spread and dry weight of shoot with the application of 12.5 mg P_2O_5 kg^{-1} soil.

2.7.2 Effect of magnesium on growth, yield and quality parameters

Foliar spay of secondary nutrient magnesium has increased the pseudostem length in banana compared to others which are not receiving any foliar sprays and higher number of fingers per bunch was found in banana when it was supplied with magnesium in chelated form (Mostafa *et al.,* 2007). Thankamani *et al.* (2011) observed maximum number of spikes and yield in black pepper plants supplied with 50 per cent recommended dose of nitrogen along with magnesium.

Rao and Rajput (2011) reported that application of magnesium and micronutrients had increased the plant height in palmarosa. According to Cakmak (2013), magnesium plays an important role in transport of photoassimilates in to roots, shoot tips and seeds and proper magnesium nutrition is essential for obtaining better nitrogen use efficiency and accumulation of nitrogen in grain. In crops, heat and radiation related losses can be reduced by proper magnesium fertilization.

2.7.3 Effect of boron on growth, yield and quality parameters

According Mallick and Sawhney (1998), boron is an important element which is involved in the flowering, fertilization, hormonal metabolism and translocation of sugars. Babu (2002) reported that foliar application of boron at 50, 100, 150, 200, 250 and 300 ppm improved the plant height, number of branches, number of fruits per plant and total tomato yield. Boron deficiency is high in light textured acid soils receiving high precipitation and the crop use efficiency of fertilizer boron is also low under such boron leaching environments. Under the acidic environment, soil solution B remains as non-ionized H_3BO_3. With high precipitation, B leaches out of light textured soil surface layer resulting in its deficiency. Usually boron is applied in the form of borax to soil or as foliar sprays. In the case of root crops where translocation of photosynthates from source to sink is needed for a longer period, a steady and prolonged supply of boron throughout their growth period is needed (Sarkar and Mandal, 2007).

Borax is associated with the development of cell wall, cell differentiation, root elongation and shoot growth. It has important role in carbohydrate synthesis, uptake of Ca^{2+} and absorption of NO_3^-. Boron is essential for the formation of the pollen and ovary and also for the subsequent development of the seed. The maturation of seeds is weakened in the absence of boron (Kumar, 2015). Singh *et al.*(1990) observed higher leaf number (43.3 plant^{-1}), leaf area (1493 cm^2 plant^{-1}) and dry matter content in potato with the foliar spray of 0.3 per cent boric acid along with 2 per cent urea in conjunction with top dressing of 30 kg N ha^{-1}.

Sharma (1995) found significant increase in growth parameters like plant height (189.2 cm) and number of branches per plant (9.2) with the application of 20 kg boron ha^{-1}compared to 10 kg borax ha^{-1} in tomato and concluded that boron exhibited pronounced beneficial effect on number of fruits plant^{-1} (23.1), fruit yield (762.7 q ha^{-1}) and seed yield (246.2 kg ha^{-1}) with the soil application of 20 kg borax ha^{-1}. Sharma *et al.* (1999) stated that application of 20 kg borax ha^{-1} gave the highest plant height (70.6 cm) and number of branches (6.9 plant^{-1}), while the least (59.0 cm and 5.8 branches plant^{-1}) was recorded in the control of radish plants.

Investigations on soil based plant nutrient management plan for agro ecosystems of Kerala conducted by the Kerala State Planning Board revealed the deficiency of Magnesium, an essential secondary nutrient, in three fourth of the composite soil samples drawn from the state and tested. Regular application of magnesium sulphate @ 80 kg ha^{-1} is essential to ensure adequate levels of Mg in the soils. Among the investigated micronutrients, the deficiency of boron only is significant and extensive, requiring immediate intervention. Boron deficiency can be alleviated by application of borax @ 10 kg ha^{-1} (KSPB, 2013).

2.8 INFLUENCE OF ORGANIC NUTRIENT SOURCES ON GROWTH, YIELD AND QUALITY

Application of organic manures to the soil decreases both bulk density and particle density and increases the percent pore space and water holding capacity. Organic manures facilitate easy supply and availability of nutrients whereas nutrient available through fertilizer are not fully utilized by the crop. The enhanced microbial activities cause the transportation of soluble nitrogen into microbial protein, thereby preventing nitrogen loss (Tiwari *et al.*, 1989).

The yield contributing characters of ashwagandha differed with different manuring practices which were reflected in the root yield. Increased yield under organic treatments is due to higher magnitude of yield attributes effected by increased pore space in the soil which helped in better aeration, infiltration and more macro pores thus more conservation of soil moisture and activity of microorganisms in soil resulting in more availability of nutrients and ultimately more photosynthates (Ghosh *et al.*, 2009).

According to Gupta and Banoo (2012), acid phosphomonoesterase and alkaline phosphomonoesterase activity increased significantly with the application of FYM and vermicompost. FYM and vermicompost contributed to increased microbial population and activities which are key factors in soil nutrient cycling and production of plant growth influencing materials and influenced the soil dehydrogenase and phosphatase enzyme activities.

Studies on the impact of vermicomposts *viz.,* cowdung vermicompost, leaf ash vermicompost and poultry feather vermicompost with and without chemical fertilizer on ashwagandha revealed that the plant growth parameters such as shoot length, root length, shoot dry weight, root dry weight, shoot wet weight, root wet weight, shoot: root ratio and the alkaloid withaferin A and withanolide D were significantly increased in plants cultivated in the soil amended with poultry feather vermicompost (Raja and Veerakumari, 2013).

Maheshwari *et al.* (2000) reported on the basis of two year field trial conducted on ashwagandha cultivars "JA 20" and "JA 134" that application of 5 t ha^{-1} FYM produced a higher root yield of 862 and 425 kg ha^{-1} respectively with a total alkaloid content of 0.139 and 0.174 % respectively compared to application of inorganics (25 kg N + 50 kg P_2O_5) which produced 809 and 431 kg ha^{-1} of roots and 0.147 and 0.168 % of alkaloid respectively. Chauhan *et al.* (2005) also observed a significant increase in number of roots per plant, fresh root and dry root yield per hectare with application of FYM @ 15 t ha^{-1} compared to NPK (50:50:50 kg ha^{-1}) and control in safed musli.

According to Joy *et al.* (2005), application of FYM @ 30 t ha^{-1} resulted in higher plant height, canopy spread, number of suckers per plant and number of leaves per sucker in black musli. Ganorkar *et al.* (2006) observed the highest tuber yield in safed musli with the application of FYM @ 20 t ha^{-1} and nitrogen @ 75 kg ha^{-1} alone or in combination.

2.10 EFFECT OF LIQUID ORGANIC MANURES ON GROWTH, YIELD AND QUALITY

2.10.1 Effect of panchagavya on growth, yield and quality

Natarajan (2003) reported that spraying of panchagavya @ 3% on plants improve the growth, yield and quality of different crops considerably. Gopal and Natarajan (2009) observed synergistic activity of panchagavya that will trigger the activity of rhizobacteria, which in turn enhanced the biochemical constituent of ashwagandha.

According to Vajantha *et al.* (2014), application of four sprays of 5 % panchagavya produced from cow resulted in the highest dry matter production (2322 and 2238 kg ha^{-1} during *Rabi* and *Kharif* respectively), root yield (290 and 280 kg ha^{-1} during *Rabi* and *Kharif* respectively) in ashwagandha. There was no significant effect on root length, girth, alkaloid content with different concentration and sources of panchagavya.

2.10.2 Effect of vermiwash on growth, yield and quality

Shivsubramanian and Ganeshkumar (2004) noticed higher number of flowers in marigold treated with vermiwash. According to Zaller (2006), quality improvement in tomato was possible by the foliar application of vermicompost leachate. According to Ansari (2008), slow nutrient release along with plant hormones like gibberellin, cytokinin and auxin present in vermiwash resulted in improved yield in crops. Gopal *et al.* (2010) observed that foliar application of coconut leaf vermiwash at 1:20 dilution on cowpea resulted in the highest per cent increase in biomass production, higher nodule number and higher nodule weight. However, highest cob weight and fresh biomass yield in maize were observed with1:5 dilution of vermiwash. A increase in yield of 33 per cent was reported in bhindi with the application of coconut leaf vermiwash in 1:5 dilution.

Protein and fat content were higher in okra treated with vermiwash and vermicompost (Ansari and Kumar., 2010). Application of vermiwash at 20 per cent concentration improved vegetative and yield attributes in chilli and okra in acid soils (Meghvansi *et al.*, 2012). More *et al.* (2013) reported that application of vermiwash in three sprays in maize produced higher plant height, dry matter production and LAI and reduced the period for 50 per cent tasseling and silking compared to no vermiwash spray. According to Rekha *et al.* (2013), vermiwash is rich in nutrients and plant hormones which enhances the growth of plants.

Ayyobi *et al.* (2014) noticed more number of leaves, number of pods per plants and lateral branches in dwarf French bean with the application of vermiwash compared to vermicompost leachate. Jadhav *et al.* (2015) recorded maximum root diameter, length and weight in radish plants receiving vermiwash spray (1:4) compared to control and higher yield components, yield per hectare and marketable yield.

2.10.3 Effect of fermented plant juice on growth, yield and quality

A study by Gore and Sreenivasa (2010) in tomato revealed significant improvement in growth and yield consequent to combined application of liquid organic manure compared to recommended dose of fertilizers alone. Patil *et al.* (2012) reported that foliar spray of liquid organic manures at flowering and 15 days after flowering positively influenced growth in chick pea. Foliar spray with liquid organic manures supplied major and micro nutrients, stimulated growth promoting hormones and enhanced the growth and yield potential of crops (Kirankumar, 2013). Udabal *et al.* (2014) reported maximum capitulum diameter, seed filling percentage and seed yield in sunflower plants treated with liquid organic manures. Waghmode *et al.* (2015) recorded higher cob length, cob girth and cob yield in corn plants receiving bio digester liquid spray @ 10 per cent.

2.10.4 Effect of sequential application of nutrients on growth and yield

Growth and yield of plants can be regulated by sufficient supply of nutrients. Need based application of nutrients is the best approach for obtaining appreciable growth and yield in crops. So split and sequential application of nutrients can be adopted for improving the growth and yield of crops. Feleafel and Mirdad (2013) observed an increase in plant height, number of branches and leaves, leaf area and dry weight per plant in brinjal with the increasing the number of doses of fertilizers and weekly fertigation. According to Tumbare and Nikam (2004), fertigating chilli plants at two days interval with recommended dose of fertilizers increased number of fruits per plant, weight of fruit per plant and green chilli yield. Buckerfield *et al.* (1999) observed 7.3 per cent increase in radish yield by the weekly application of vermiwash.

2.11 BIOFERTILIZERS

Biofrtilizers play an important role in sustainable agriculture. They are eco-friendly, provide better crop yield and plant nutrient uptake and improve productivity of the soil and provide good soil health by reducing the consumption of chemical fertilizers. Biofertilizers accelerate the mineralization of plant nutrients. According to Srinivasappa *et al.* (2007), biofertilizers contain living cells of different types of microorganisms which have an ability to make the soil live and dynamic.

2.11.1 Azospirillum

Azospirillum is an associative symbiotic nitrogen fixing bacteria. According to Tien *et al.* (1979), Azospirillum is known to produce growth promoting hormones such as gibberellins, cytokoinin, and auxin like IAA from tryptophan. This will simply result in improved absorption of water and nutrients from soils. Okon *et al.* (1983) suggested that the presence of Azospirillum in the rhizosphere affects the metabolism of endogenous phytohormones in the plant. Govindan and Chandy (1985) found that Azospirillum inoculation improved rooting on pepper cuttings.

Conty *et al.* (1994) observed an increased yield of crops by 5 to 20 per cent with saving of nitrogen up to 40 per cent of recommended dose. Azospirillum helps not only in nitrogen fixation but also in the release of various growth promoting agents which lead to better root growth, better translocation of water, and uptake of nutrients (Raj *et al.*, 2001). Subbaiah (1991) observed significant increase in total dry matter yield of bhindi by Azospirillum treatment. According to Arumugan *et al.* (2001), in senna, dry leaf, pod yield and over all dry matter production enhanced due to Azospirillum treatment. Application of Azospirillum through soil and seedling dipping along with 100 per cent recommended dose of fertilizers recorded 31.75 per cent higher yield in cabbage over the recommended dose of fertilizers only (Bhagavantagoudra and Rokhada, 2002). Baby *et al.* (2002) reported higher plant growth response, increase in soil and plant total nitrogen and leaf nitrate reductase activity in tea plants with the Azospirillum application. Yadav *et al.* (2005) recorded higher bulb yield in onion (323.7 q ha^{-1}) with the Azospirillum inoculation. Inoculation of Azospirillum along with 93.75 kg N and P_2O_5 each per hectare recorded highest value for plant growth, number of laterals, fresh and dry shoot weight in davana over 125 kg N and P_2O_5 each per hectare only (Sentilkumar *et al.*, 2006). Khanna *et al.* (2006) revealed that seed treatment with *Azospirillum brasilense* at the rate of 0.5 kg ha^{-1} in ashwagandha resulted in beneficial effects on root and shoot biomass production.

According to Gopal and Natarajan (2009), the natural resources like microbial inoculants (*Azosprillum, Azotobacter, Phosphobacteria, and Pseudomonas fluorescens*) could be considered as potential sources of nutrients and the rhizosphere effect of bacterial inoculants would satisfy the nutrient requirement of ashwagandha crop. According to Kalyanasundaran *et al.* (2008), Azospirillum inoculation @ 2 kg ha^{-1} along with 75 kg N + 50 kg P per hectare in *Acorus calamus* improved the plant height, number of leaves, number of clumps, fresh and dry weight of cabbage and dry weight of roots.

Dual inoculation with Azospirillum and *Pseudomonas fluorescens* in vetiver remarkably influenced the root length (Anusha, 2013). Shimi and Anilkumar (2014) reported positive effect on growth characters and root yield in vetiver with the combined application of Azospirillum, *Pseudomonas fluorescens* and AM fungi.

2.12 INTEGRATION OF DIFFERENT SOURCE OF NUTRIENTS

Integrated nutrient management aims at the maintenance of soil fertility and plant nutrient supply to an optimum level for sustaining desirable crop productivity by maximizing the benefit of all possible sources of plant nutrients in an integrated manner.

2.12.1 Effect of integration of different source of nutrients on growth and yield

According to Ghosh *et al.* (2009), inorganic fertilizer can be integrated with 50 per cent substitution of urea by organic manure like vermicompost (8.5 t ha^{-1}) or neem cake (2.5 t ha^{-1}) for good growth and better yield of ashwagandha.

Kumar *et al.* (2009) observed highest plant height, number of laterals, fresh and dry weight of shoot and dry matter production in davana with the application of nitrogen 93.75 kg ha^{-1} along with Azospirillum. According to Manohar *et al.* (2012) application of organic manure in combination with urea and single super phosphate enhanced growth, yield and quality attributes in ashwagandha over control. According to Vajantha *et a*l. (2011), conjuctive application of 150% NPK along with castor cake @ 2.5 t ha^{-1} and biofetilizers (Azospirillum + PSB) in ashwagandha improved the fertility status of soil. Ravikumar (2012) recorded significantly higher tuber yield in coleus treated with recommended dose of FYM @ 5t ha^{-1} and NPK @ 40:60:50 kg ha^{-1} along with 10 kg ha^{-1} each of *Azotobacter crucocum*, *Bacillus megaterium* (PSB) and *Glomus fasciculatum*.

According to Priyadarshani (2013), in vetiver, compost and inorganic fertilizers in the proportion of 3:1 could be used as optimal fertilizer mixture for higher biomass production. Application of recommended dose of NPK (40:60:50 kg ha^{-1}) + recommended dose of FYM (15 t ha^{-1}) + Azotobacter + Azospirillum recorded the highest fresh and dry tuber yield (Ravikumar, 2013). According to Shinde *et al.* (2013), application of inorganic and organic manures significantly influenced all growth, quality and yield attributing characters in ashwagandha. Application of FYM @ 12.5 t ha^{-1} in combination with 12.5 mg P_2O_5 kg^{-1} soil improved all the vegetative parameters whereas FYM @ 12.5 t ha^{-1} in combination with 25 mg P_2O_5 kg^{-1} soil showed significantly higher dry root yield (Goel and Duhan, 2014).

Patil *et al.* (2014) recorded maximum growth and root yield in ashwagandha treated with 2 tons of FYM + 0.5 tonnes of vermicompost + 20:30:20 kg NPK ha^{-1} under rainfed condition. According to Vajantha *et al.* (2014), application of inorganic fertilizers, organic manure, panchagavya and biofertilizers in ashwagandha significantly increased the root yield.

2.12.2 Effect of integration of different source of nutrients on quality

Alkaloids are nitrogen containing compounds. The availability of nitrogen is expected to play an important role in the biosynthesis and accumulation of alkaloids in plants (Waller and Nowacki, 1978). They have also stated 2 to 10 fold increase in alkaloid content (in *Nicotiana* spp., *Lupinus* spp., *Hordeum* spp.) by treating the plant with high levels of nitrogen and the exception to this behavior are plants producing indole alkaloids and the solanum glycol alkaloids.

Application of nitrogen has been reported to have significant effect in increasing the glycoside, solasodine, morphine and alkaloid contents in Digitalis, *Solanum khasianum*, Opium, Dioscorea and *Catharanthus roseus* respectively (Mishra, 1992). On the contrary, Rameshbabu (1996) reported that the total alkaloid content was not influenced due to application of nitrogen. However, Maitra *et al.* (1998) observed an increase in alkaloid content of ashwagandha roots with NPK treatments of 28:28:28 and 42:42:42 g per 1.3 m^2.

Application of 40:60:20 kg N: P_2O_5: K_2O ha^{-1} produced roots with higher withanolide content of 0.49 per cent in ashwagandha (Muthumanickam and Balakrishnamurthy, 1999). Maheshwari *et al.* (2000) observed that the total alkaloids present in dry root of ashwagandha were not affected by different treatments of manures and fertilizers. Patel (2001) also observed that N levels and stage of harvesting had no influence on total withanoloides and starch content in the roots of ashwagandha.

Nasir and Khan (2012) observed that soil application of 45 kg N ha^{-1} and 26 kg P $ha^{-1}$was proved to be the best dose for enhancing total alkaloid content. The alkaloid yield in ashwagandha roots was increased significantly with the application of 25 mg P_2O_5 kg^{-1} soil (Goel and Duhan, 2014).

2.12.3 Effect of integration of different source of nutrients on nutrient uptake

Ramesh Babu (1996) reported that the application of nitrogen (90 kg ha^{-1}) had significantly increased NPK uptake to the tune of 187.46, 14.28 and 187.09 kg ha^{-1}respectively compared to control in ashwagandha. Patel (2001) reported an increased NPK uptake (80.5, 47.6 and 123.0 kg ha^{-1} respectively) with application of N at 75 kg ha^{-1} compared to control. NPK uptake by ashwagandha shoot increased significantly with the application level of 12.5 mg P_2O_5 kg^{-1} soil over control whereas in case of ashwagandha roots, the increase in nutrients uptake at the level of 25 mg P_2O_5 kg^{-1}soil over control (Goel and Duhan, 2014).

Kumar *et al.* (2009) noticed higher fresh herbage and essential oil yield in davana treated with nitrogen @ 93.75 kg ha^{-1} and phosphorus 93.75 kg ha^{-1} along with Azospirillum. Application of vermicompost @ 2.5 t ha^{-1} + Azospirillum 2 kg ha^{-1} + PSB 2 kg ha^{-1} significantly increased root quality in ashwagandha (Barche *et al.*, 2010). Kumar *et al.* (2012) found maximum withanoloid content in ashwagandha treated with vermicompost @ of 3 kg per plot, FYM @ of 2 kg per plot and an inoculation of plant roots with Azospirillum @ 10^6 CFU. Ravikumar (2012) reported application of FYM @ 5t ha^{-1} and NPK @ 40:60:50 kg ha^{-1} along with 10 kg ha^{-1} each of *Azotobacter crococcum, Bacillus megaterium* (PSB) and *Glomus fasciculatum* resulted higher forskolin content in coleus tubers.

Vajanta *et al.* (2014) recorded highest nutrient uptake in ashwagndaha with the conjuctive application of 150 per cent recommended dose of fertilizers + castor cake @ 2.5 t ha^{-1} + biofertilizers. Application of compost and inorganic fertilizer (3:1) mixture in vetiver showed significantly higher amount of β-vetivenene, khusimol and iso-valencinol content (Priyadarshani, 2013). Goel (2014) noticed significant increase in total alkaloid yield of ashwagandha roots with the application of FYM @ 12.5 t ha^{-1} and highest amount of total alkaloid was found in the treatment combination of 12.5 t FYM ha^{-1} + inorganic P @ 25 mg P_2O_5 kg^{-1} soil.

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)" was carried out at the Instructional farm attached to the College of Agriculture, Padannakkad, Kasargod to study the effect of integrated nutrient management practices and summer irrigation on growth promotion and root production in ashwagandha during the period from 2015-2017.

3.1 MATERIALS

3.1.1 Site

The experiment was conducted at the Instructional farm attached to the College of Agriculture, Padannakkad. The site is located at 12^0 20' 30" N latitude and 75^0 04' 15" E longitude at an altitude less than 20 m above MSL.

3.1.2 Soil and climatic condition

Soil of experimental site is sandy. Mechanical composition, soil moisture characteristics and chemical composition of soil are presented in Tables 1 and 2.

Weather parameters observed during December 2015 to April 2016 are given in Appendix 1. Abstract of these data are given in Table 3.

3.1.3 Crop

Ashwagandha is an annual to perennial, branched, small woody shrub of about 30 to 120 cm height. Roots are fleshy, tapering and whitish brown. 'Jawahar ashwagandha-134' bought from Anand Agricultural University was used for the experiment.

3.1.3.1 Jawahar ashwagandha-134

Jawahar Ashwagandha-134 (JA-134), was released from the College of Horticulture, Mandsaur, JNKVV, Jabalpur, Madhya Pradesh, during the year 1998 by pedigree selection method. It is a selection from JA-20 and wild types of ashwagandha. JA-134 is erect, tall and leaf is chordates, dark green colour, surface is hairy, berries are yellow or yellowish brown. It takes about 150 - 175 days for maturity and average dry root yield is about 4 to 6 q ha^{-1} (Shrivastava and Sahu, 2013).

Table 1. Mechanical composition and moisture characteristics of soil

Particulars	Content	Method used
1. Mechanical composition (%)		Bouyoucos hydrometer (Bouyoucos, 1962)
Coarse sand	30.28	
Fine sand	57.65	
Silt	07.50	
Clay	4.57	
2. Soil moisture characteristics		
Particle density, (g cc^{-1})	2.16	Pycnometer method (Black,1965)
Bulk density, (g cc^{-1})	1.34	
Maximum water holding capacity, % (w/w)	18.2	Core method (Gupta and Dakshinamoorthi, 1980)
Porosity, % (v/v)	47	
Field capacity, % (w/w)	11.74	
Permanent wilting point, % (w/w)	4.98	

Table 2. Chemical properties of soil

Particulars	Content	Method
Organic carbon, %	0.30	Walkley and Black titration method (Jackson, 1973)
Organic matter, %	0.51	
Available nitrogen, kg ha^{-1}	239.39	Alkaline $KMnO_4$ method (Subbiah and Asija, 1956)
Available phosphorus, kg ha^{-1}	25.15	Bray's colorimetric method (Jackson, 1973)
Available potassium, kg ha^{-1}	65.26	Ammonium acetate method (Jackson, 1973)
Available magnesium, kg ha^{-1}	31.66	Atomic absorption spectroscopy (Jackson, 1958)
Available boron, kg ha^{-1}	2.47	Photoelectric colorimetry (Bingham, 1982)
Soil reaction	5.6	pH meter with glass electrode (Jackson, 1973)

Table 3. Abstract of weather data during December 2015 to April 2016.

Weather parameters	Range	Mean
Maximum temperature (^{0}C)	32.00 to 35.50	33.05
Minimum temperature (^{0}C)	14.50 to 27.80	23.09
Relative humidity (%)	25.00 to 85.00	62.38
Mean daily evaporation (mm)	2.10 to 4.83	3.40
Total rainfall (mm)	0.00 to 2.10	0.02

3.2. METHODS

3.2.1 Design and layout of experiment

Design: RBD Treatments: 14 Replication: 2 Plot size: 2.5 m x 2 m

3.2.2 Treatments

Table 4. Treatment details

No.	Representation of treatment	Treatment details
1	T_1	High density planting (HDP) in trenches mulched with polythene and filled with enriched growing medium
2	T_2	T_1 + Recommended dose of NPK
3	T_3	T_1 + Liquid organic manures
4	T_4	T_2 + azospirillum
5	T_5	T_3 + azospirillum
6	T_6	T_4 + B and Mg
7	T_7	T_5 + B and Mg
8	T_8	T_6 + Summer irrigation at 15 mm CPE
9	T_9	T_7 + Summer irrigation at 15 mm CPE
10	T_{10}	T_6 + Summer irrigation at 30 mm CPE
11	T_{11}	T_7 + Summer irrigation at 30 mm CPE
12	T_{12}	HDP in trenches filled with enriched growing medium.
13	T_{13}	NRP in trenches filled with enriched growing medium.
14	T_{14}	Broadcasting in trenches filled with enriched growing medium.

3.2.3 Cultivation

3.2.3.1 Nursery

Seeds of Jawahar ashwagandha-134 were soaked in water for 24 hours. Seeds were sown in the nursery on 1st December 2015 (post monsoon). Seeds germinated in 6-7 days. The germination percentage was 84.

N

Fig.1. Layout of experimental plot

T_8R_1	T_9R_1	$T_{10}R_1$	$T_{11}R_1$
T_6R_1	T_4R_1	T_2R_1	T_1R_1
$T_{12}R_1$	T_7R_1	T_5R_1	T_3R_1
$T_{13}R_1$	$T_{14}R_1$	$T_{14}R_2$	$T_{13}R_2$
T_3R_2	T_5R_2	T_7R_2	$T_{12}R_2$
T_6R_2	T_4R_2	T_2R_2	T_1R_2
T_8R_2	T_9R_2	$T_{10}R_2$	$T_{11}R_2$

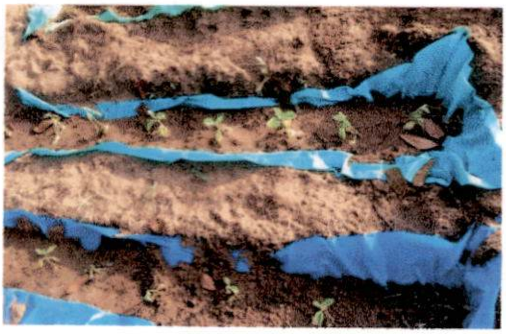
3.2.3.2 Land preparation

The land was ploughed thoroughly and dug trenches of 30 cm depth. Low density polyethylene sheets were spread inside trenches as per the technical programme. A mixture of FYM (20 t ha^{-1}), coir pith compost and dried plant leaves were applied to each trench and filled with top soil.

Plate 1. General view of experimental field

a. Nursery

b. Taking trenches in main field



c. Trenches mulched with polythene and filled with growing medium

d. Uniform crop stand in main field

e. Seed collection

3.2.3.3 Transplanting

One month old seedlings of ashwagandha were transplanted at a spacing of 50 cm × 25 cm in HDP and at 50 cm × 50 cm spacing in NRP. Broadcasting was carried out in the control plot.

3.2.4 Treatment imposition

3.2.4.1 Irrigation

Irrigation was given based on soil moisture studies. Summer irrigation was imposed at 15 mm CPE and 30 mm CPE.

3.2.4.2 Fertilizers

NPK fertilizers were given as basal application @ 40:40:40 kg ha^{-1} $year^{-1}$. Magnesium and boron were also given as basal application in the form of magnesium sulphate and borax @ 40 kg ha^{-1} and 5 kg ha^{-1}respectively.

3.2.4.3 Liquid organic manures

Three liquid organic manures, *viz*., vermiwash, fermented plant juice and panchagavya were applied sequentially at monthly intervals starting from one month after transplanting. Vermiwash (10 %), fermented plant juice (5 %) and panchagavya (3 %) were given as foliar spray @ 500 L ha^{-1}.

3.2.4.3.1 Vermiwash

Vermiwash was prepared as per the protocol standardized by KAU (KAU, 2011).

3.2.4.3.2 Fermented plant juice

Fermented plant juice was prepared as follows. Tender parts of Singapore daisy (*Spagneticola trilobata*) was taken and chopped in to small pieces. Equal amount of powdered brown sugar (weight basis) was added to this. Mixture was transferred to a plastic vessel and completely filled with water. Mouth of the vessel was sealed using a towel and tied. The vessel was kept as such without any disturbance for one week and allowed for complete fermentation. After one week the mixture was strained using a cloth or sieved and applied in the field.

3.2.4.3.3 Panchagavya

Panchagavya was prepared as per the protocol standardized by KAU (KAU, 2009).

3.2.4.4 Azospirillum

Slurry of azospirillum culture was prepared by mixing 500 g culture with 50 ml water and the roots were dipped in the slurry for 15 – 20 minutes before transplanting.

3.2.5 Post planting care

3.2.5.1 Gap filling

Gap filling was done to maintain uniform population across the treatments.

3.2.5.2 Weeding

Plot area was predominated by the perennials like *Cyperus rotundus* and *Cynodon dactylon* and annual grasses like *Digitaria sanguinalis* and broad leaved weeds like *Croton sparsiflorus, Cleome viscosa* which were hand weeded at monthly intervals.

3.2.5.3 Plant protection

Epilachna beetle attack was found in nursery stage. Spraying of acephate was done for controlling the beetle attack.

3.2.5.4 Harvesting

Crop was harvested at 156 days after sowing, when the plants started drying and all the fruits matured. Field was irrigated one day before harvesting and crop was uprooted.

3.2.6 Irrigation scheduling

Table 5. Details of irrigation given during experimental period

Treatments	No. of irrigations	Irrigation requirement (L $plot^{-1}$)	Pretreatment irrigation (L $plot^{-1}$)	Effective rainfall (L $plot^{-1}$)	Total water requirement (L $plot^{-1}$)
T1	20	1680	84	0	1764
T2	20	1680	84	0	1764
T3	20	1680	84	0	1764
T4	20	1680	84	0	1764
T5	20	1680	84	0	1764
T6	20	1680	84	0	1764
T7	20	1680	84	0	1764
T8	40	3360	84	0	3444
T9	40	3360	84	0	3444
T10	24	2016	84	0	2100
T11	24	2016	84	0	2100
T12	20	1680	84	0	1764
T13	20	1680	84	0	1764
T14	20	1680	84	0	1764

3.2.7 Observations

3.2.7.1 Morphological observations

The observation on growth and yield parameters were recorded from four plants selected randomly.

3.2.7.1.1 Plant height

Plant height was measured from ground level to the growing tip and the average was worked out. It was expressed in centimeter.

3.2.7.1.2 Number of functional leaves

Total number of functional leaves per plant was counted and recorded.

3.2.7.1.3 Number of branches

Number of primary branches, secondary branches and tertiary branches per plant were counted and recorded.

3.2.7.1.4 Leaf area

Leaf area was determined by using a leaf area meter and expressed in cm^2.

3.2.7.2 Root parameters

3.2.7.2.1 Root number

Total number of primary roots per plant was counted and the mean value was worked out.

3.2.7.2.2 Root length

Length of the longest root was measured using a scale and expressed in cm.

3.2.7.2.3 Root spread

Root spread was measured by graph paper method and expressed in cm.

3.2.7.2.4 Root volume

Root volume was taken by water displacement method and expressed in cm^3.

3.2.7.2.5 Root weight

Fresh and dry weight of roots were recorded and expressed in grams.

3.2.7.2.6 Root and seed yield

The berries harvested were dried under sun and seeds were separated and the seed yield per plant was recorded. The seed yield per hectare was also estimated and expressed in kg ha^{-1}.

Fresh roots were harvested by uprooting the plants and yield was recorded in gram per plant. Dry root yield was recorded by drying of harvested fresh roots under sun. Fresh and dry root yields in kg per hectare were also estimated.

3.2.7.3 Physiological parameters

3.2.7.3.1 Relative leaf water content

Method proposed by Slatyer and Barrs (1965) was used to determine relative leaf water content of leaf and expressed in percentage.

$$\text{RLWC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.2.7.3.2 Leaf temperature

Leaf temperature was measured using a steady state porometer and expressed in ^0C.

3.2.7.3.3 Stomatal conductance

Stomatal conductance was measured using a steady state porometer and expressed in CO_2 mmol $m^{-2}s^{-1}$.

3.2.7.3.4 Chlorophyll content

Chlorophyll reading was taken using SPAD chlorophyll meter and expressed as SPAD chlorophyll meter reading (SCMR).

3.2.7.3.5 Total dry matter production

Plants were uprooted and oven dried. Weight was taken and expressed in grams per plant.

3.2.7.3.6 Dry matter partitioning

The dry weight of leaf, stem, root, berries and total dry matter per plant were recorded at harvest and expressed in g $plant^{-1}$.

3.2.7.3.7 Per cent distribution of dry matter

The dry weight of leaf, stem, root and berries were expressed as per cent of total dry matter production per plant.

3.2.7.3.8 Root shoot ratio

Root shoot ratio was estimated by dividing the dry weight of root and dry weight of shoot.

3.2.7.3.9 Leaf area index

The following formula was used for calculating leaf area index.

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Land area}}$$

3.2.7.3.10 Leaf area ratio

Leaf area ratio was calculated by the formula given by Radford (1967) and expressed in $cm^2\ g^{-1}$.

$$\text{Leaf area ratio} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

3.2.7.3.11 Absolute growth rate for plant height

The following formula was used for calculating absolute growth rate for plant height and expressed in cm day^{-1}.

$$\text{Absolute growth rate for plant height} = \frac{h_2 - h_1}{t_2 - t_1}$$

Where, h_1 and h_2 are plant heights at times t_1 and t_2 respectively.

3.2.7.3.12 Crop growth rate

Crop growth rate was estimated by using the formula suggested by Watson (1956) and expressed in g m^{-2} day^{-1}.

$$\text{Crop growth rate} = \frac{(W_2 - W_1)}{A\,(t_2 - t_1)}$$

Where, W1 and W2 are plant dry weight at time t1 and t2 respectively

A is the ground area on which W1 and W2 are recorded.

3.2.7.4 Biochemical parameters

3.2.7.4.1 Total alkaloid

Crude alkaloid extract from dried root was determined using the Soxhlet extraction method (Harbone, 1973).

Well dried roots were made in to fine powder and exactly five grams of sample weighed and transferred in to a filter paper to hold the sample. The sample packet was then dropped in to the extraction tube of soxhlet apparatus. A previously weighed soxhlet apparatus connected to the soxhlet flask and 100 ml of solvent was poured through extraction tube in to the flask. The top of flask was attached to a condenser. Extraction was carried out at 80^0C on a water bath. Solvent (methanol) got continuously vaporized and allowed to condense and collected inside the extraction tube. This cycling repeated up to which the solvent inside extraction tube turned colourless. The extraction tube was dismantled and sample removed from the extraction tube. The solvent in the soxhlet flask was evaporated on a water bath. After complete evaporation of solvent from the soxhlet flask, weight of the flask along with residue was recorded and alkaloid estimated using the following formula.

$$\text{Weight of residue (g)} = \text{Weight of soxhlet flask along with residue (g)} - \text{Weight of empty soxhlet flask (g)}$$

$$\text{Total alkaloid (\%)} = \frac{\text{Weight of residue (g)}}{\text{Weight of dried sample used for extraction}} \times 100$$

3.2.7.4.2 Total amino acid

Total amino acid was estimated by using colorimeter with ninhydrin extract of root (Sadasivan and Manickam, 1996).

3.2.7.4.3 Total sugar

Total sugar content was determined by titrating fresh root juice with Fehling solution A and B and the results are expressed in percentage.

3.2.7.5 Microbiological studies

3.2.7.5.1 Population of Azospirillum

Azospirillum population was enumerated using Most Probable Number (MPN) technique (Alexander, 1965).

3.2.7.6 Soil moisture studies

Soil moisture observations were taken 15 cm away from the base of the plant at a depth of 10 cm at repeated intervals by using soil moisture meter.

3.2.7.6.1 Consumptive use of water

Consumptive use of water was calculated using the formula described by Dasthane (1972).

$$Cu = \sum_{1}^{N} (Ep \times 0.6) + \sum_{1}^{N} (Mai - Mbi) \times Asi \times Di + ER$$

Where Cu = Consumptive use of water in mm

Ep = Pan evaporation from USWB class A open pan evaporimeter from the date of irrigation to date of soil sampling after irrigation

0.6 = A constant for obtaining ET value from pan evaporation value for the given period of time

Mai = Percentage of soil moisture (w/w) of the i^{th} layer of soil at the time of sampling after irrigation.

Mbi = Percentage of soil moisture (w/w) of the i^{th} layer of soil at the time of sampling before irrigation.

Asi = Apparent specific gravity of i^{th} layer of soil, g cc^{-1}

Di = Depth (mm) of the i^{th} layer of soil

ER = Effective rainfall if any within the season (mm)

N = Number of soil layers

n = Number of days between irrigation and post irrigation sampling

3.2.7.6.2 Irrigation requirement

Irrigation requirement was calculated by adding the quantity of water applied for irrigation in each treatment.

3.2.7.6.3 Water use efficiency

Crop water use efficiency (CWUE) and field water use efficiency (FWUE) were calculated using the formula and expressed in g m^{-3}

$$CWUE = \frac{\text{Yield}}{\text{Consumptive use}}$$

$$FWUE = \frac{\text{Yield}}{\text{Total water requirement}}$$

3.2.7.6.4 Water productivity (WP)

Water productivity was worked out using the formula suggested by Kinje *et al*. (2003) and expressed in g m^{-3}

$$WP = \frac{\text{Total biomass}}{\text{Total water depleted}}$$

3.2.7.7 Nutrient uptake studies

Plant nutrient uptake was assessed by multiplying per cent nutrient content with total dry matter production.

3.2.7.8 Economics

3.2.7.8.1 Cost of cultivation

Cost of each input in rupees at the time of experiment was considered for calculating cost of cultivation.

3.2.7.8.2 Gross return

Gross return per hectare was worked out using the price of market produce prevailing in market at the time of experiment.

3.2.7.8.3 Net return

The net return was worked out by subtracting cost of cultivation from gross return.

3.2.7.8.4 Benefit cost ratio

Benefit cost ratio was worked out using the following formula

$$BCR = \frac{\text{Gross income}}{\text{Total cost of cultivation}}$$

3.2.7.9 Statistical analysis.

Statistical analysis was done using WASP 2.0 software given by ICARGOA.

Results

4. RESULTS

An experiment entitled "Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)"was carried out in the Instructional farm attached to the College of Agriculture, Padannakkad during 2015 to 2017. The objective of the experiment was to study the effect of integrated nutrient management practices and summer irrigation on growth promotion and root production in ashwagandha. The trial was carried out in RBD with fourteen treatments and two replications. Planting methods, source efficacy of nutrients, bioinoculants, micronutrients and the irrigation intervals were studied. The results obtained are presented in the following pages.

4.1 MORPHOLOGICAL CHARACTERS

4.1.1 Plant height

Data recorded on the effect of treatments on mean plant height at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are presented in Table 6.

Treatments significantly influenced plant height at all stages of growth. The treatment T_4 (HDP + NPK + azospirillum) on par with T_9 and T_6 recorded significantly higher plant height at 45 DAT. The above treatment combined with boron and magnesium (T_6) registered higher plant height at all other stages of crop growth. T_6 (HDP + NPK + azospirillum +B + Mg) was on par with T_9, T_4 and T_7 at 60 DAT; T_7, T_9, T_{13}, T_4, T_8, T_{11}, T_{10} and T_5 at 75 DAT; T_4, T_7, T_{13}, T_{11}, T_9 and T_8 at 90 DAT; T_{13}, T_4, T_7, T_{10}, T_8, T_{11}, and T_9 at 105 DAT; and T_{13}, T_7, T_4, T_{10}, T_8, T_{11} and T_9 at 120 DAT respectively. Broadcasting (T_{14}) resulted in lesser plant height at all stages of crop growth.

4.1.2 Functional leaf number

Data on functional leaf number recorded at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are presented in Table 7.

Table 6. Plant height (cm) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	29.63	40.96	47.93	49.44	50.34	50.50
T_2	24.38	36.05	43.06	44.81	45.91	46.05
T_3	35.94	44.95	50.13	51.93	52.81	53.00
T_4	44.81	52.61	53.69	56.06	57.04	57.20
T_5	29.13	35.00	50.75	53.25	54.51	54.60
T_6	38.13	54.86	58.00	60.00	62.00	62.20
T_7	32.75	49.29	54.25	55.25	57.72	57.85
T_8	33.44	47.65	53.25	54.25	56.50	56.65
T_9	39.35	53.00	54.00	54.75	55.50	55.65
T_{10}	29.38	46.75	52.00	53.50	56.75	56.90
T_{11}	32.50	47.90	52.50	54.75	55.50	55.65
T_{12}	22.56	39.00	46.00	46.94	48.11	48.30
T_{13}	22.44	34.16	54.00	55.00	58.21	58.35
T_{14}	16.63	33.19	38.88	44.01	45.89	45.95
SEm (±)	2.42	2.14	2.95	2.02	2.25	2.22
CD (0.05)	7.413	6.529	7.278	6.152	6.870	6.787

Table 7. Number of functional leaves per plant of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	60.13	76.63	104.38	86.75	55.76	45.50
T_2	48.75	74.13	106.88	80.00	48.34	34.00
T_3	59.75	96.25	121.38	72.00	59.26	41.50
T_4	58.88	91.38	154.63	66.50	60.03	42.00
T_5	28.25	91.13	105.50	60.13	59.89	45.50
T_6	44.75	94.25	108.13	70.13	62.18	48.00
T_7	50.38	93.50	104.00	76.50	60.55	45.50
T_8	35.88	66.50	104.00	72.50	58.26	40.00
T_9	56.00	69.50	105.50	74.00	57.25	41.00
T_{10}	44.75	67.25	106.00	74.50	54.05	40.00
T_{11}	53.25	88.13	107.00	75.50	54.55	42.00
T_{12}	39.88	93.50	115.50	51.75	46.52	35.50
T_{13}	35.50	70.13	128.63	60.00	55.93	44.50
T_{14}	18.25	55.25	75.75	35.49	31.79	22.00
SEm (±)	4.46	4.05	9.02	5.54	3.68	2.15
CD (0.05)	13.603	12.369	27.558	16.936	11.249	6.559

DAT - Days After Transplanting

Significant effect of treatments on functional leaf number was observed throughout the period of crop growth. The treatment T_1 (HDP) on par with T_3, T_4, T_9, T_{11}, T_7, and T_2 registered the highest functional leaf number at 45 DAT. The treatments T_3 (HDP + LOM), T_4 (HDP + NPK + azospirillum), T_9 (HDP + LOM + azospirillum + B + Mg + summer irrigation at 15 mm CPE) and T_1 (HDP) showed higher values at 60, 75 and 90 DAT respectively. T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_1, T_5, T_7, T_{13}, T_4, T_{11} and T_3 at 105 DAT and 120 DAT recorded higher functional leaf number and were 5 and 6 per cent higher compared to T_{14} (Broadcasting) respectively.

4.1.3 Leaf area

Data on leaf area as influenced by INM practices and summer irrigation are summarized in Table 8.

INM practices and summer irrigation were found to significantly influence the leaf area throughout the period of crop growth. T_1 (HDP) on par with T_3, T_4, T_9, T_{11}, T_7, and T_2 at 45 DAT; T_3 (HDP + LOM) on par with T_6, T_{12}, T_7, T_4, T_5, and T_{11} at 60 DAT; T_4 (HDP + NPK + azospirillum) on par with T_{13} at 75 DAT; T_1 (HDP) on par with T_2, T_7, T_{11}, T_{10}, T_9, T_8, T_3 and T_6 at 90 DAT; T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_7, T_4, T_5, T_3, T_8, T_9, T_{13}, T_1 T_{11} and T_{10} at 105 DAT and T6 (HDP + NPK + azospirillum + B + Mg) on par with T_1, T_5, T_7, T_{13}, T_4, T_{11} and T_3 at 120 DAT recorded significantly higher values and were 69.51 per cent, 42.60 per cent, 51.01 per cent, 59.17 per cent, 48.88 per cent and 54.17 per cent high respectively compared to T_{14} (Broadcasting).

4.1.4 Primary, secondary and tertiary branches

Mean data on primary, secondary and tertiary branches as influenced by INM practices and summer irrigation at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are given in Table 9, 10 and 11.

Table 8. Leaf area (cm^2) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	721.50	919.50	1252.50	1041.00	669.08	546.00
T_2	585.00	889.50	1282.50	960.00	580.02	408.00
T_3	717.00	1155.00	1456.50	864.00	711.14	498.00
T_4	706.50	1096.50	1855.50	798.00	720.36	504.00
T_5	339.00	1093.50	1266.00	721.50	718.65	546.00
T_6	537.00	1131.00	1297.50	841.50	746.13	576.00
T_7	604.50	1122.00	1248.00	918.00	726.60	546.00
T_8	430.50	798.00	1248.00	870.00	699.11	480.00
T_9	672.00	834.00	1266.00	888.00	687.01	492.00
T_{10}	537.00	807.00	1272.00	894.00	648.60	480.00
T_{11}	639.00	1057.50	1284.00	906.00	654.60	504.00
T_{12}	478.50	1122.00	1386.00	621.00	558.21	426.00
T_{13}	426.00	841.50	1543.50	720.00	671.12	534.00
T_{14}	220.50	663.00	909.00	425.85	381.42	264.00
SEm (±)	53.55	48.60	108.27	66.54	44.19	22.77
CD (0.05)	163.552	148.426	330.669	203.234	134.986	78.704

Table 9. Number of primary branches per plant of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	1.63	3.38	4.75	6.25	6.25	6.25
T_2	1.63	3.38	4.00	4.50	4.50	4.50
T_3	2.13	3.75	5.00	5.50	5.50	5.50
T_4	1.88	4.00	5.13	5.25	5.25	5.25
T_5	2.00	3.38	5.38	5.13	5.13	5.13
T_6	2.00	3.13	4.13	4.25	4.25	4.25
T_7	2.25	4.25	6.13	6.88	6.88	6.88
T_8	1.38	3.00	3.88	3.88	3.88	3.88
T_9	1.88	3.63	4.63	5.13	5.13	5.13
T_{10}	1.75	3.75	4.50	4.63	4.63	4.63
T_{11}	1.75	4.75	5.25	6.00	6.00	6.00
T_{12}	1.63	2.88	3.63	3.63	3.63	3.63
T_{13}	1.38	3.00	5.88	5.50	5.50	5.50
T_{14}	1.00	2.88	3.50	4.00	4.00	4.00
SEm (±)	0.25	0.51	0.72	0.85	0.85	0.85
CD (0.05)	NS	NS	NS	NS	NS	NS

NS - Not significant, DAT - Days After Transplanting

Table 10. Number of secondary branches per plant of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	1.75	5.00	9.13	9.50	9.50	9.50
T_2	1.75	3.75	7.63	8.38	8.38	8.38
T_3	3.13	5.25	8.25	9.63	9.63	9.63
T_4	1.88	5.88	9.13	11.63	11.63	11.63
T_5	1.75	4.50	8.38	10.00	10.00	10.00
T_6	2.13	4.38	8.13	8.50	8.500	8.50
T_7	2.88	6.88	11.00	10.38	10.38	10.38
T_8	1.63	3.88	5.63	6.38	6.38	6.38
T_9	2.50	4.25	6.25	8.75	8.75	8.75
T_{10}	2.00	5.63	7.38	7.75	7.75	7.75
T_{11}	2.63	6.25	8.38	9.63	9.63	9.63
T_{12}	1.75	4.13	7.00	6.88	6.88	6.88
T_{13}	1.00	4.25	8.38	9.63	9.63	9.63
T_{14}	0.75	4.25	5.88	6.13	6.13	6.13
SEm (±)	0.45	0.72	1.07	1.58	1.58	1.58
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 11. Number of tertiary branches per plant of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	0.00	4.00	9.00	9.25	9.25	9.25
T_2	0.50	3.75	8.50	10.00	10.00	10.00
T_3	3.00	3.88	8.50	12.25	12.25	12.25
T_4	1.00	8.13	13.13	15.50	15.50	15.50
T_5	0.50	4.75	9.00	13.13	13.13	13.13
T_6	0.50	4.50	8.00	12.13	12.13	12.13
T_7	0.63	4.75	8.38	11.75	11.75	11.75
T_8	0.00	4.25	7.63	7.50	7.50	7.50
T_9	1.00	3.25	6.25	8.25	8.25	8.25
T_{10}	0.00	3.25	6.25	8.25	8.25	8.25
T_{11}	0.75	5.75	8.63	10.88	10.88	10.88
T_{12}	0.00	5.00	8.00	8.00	8.00	8.00
T_{13}	0.00	3.75	7.75	7.500	7.50	7.50
T_{14}	0.00	0.00	4.75	7.500	7.50	7.50
SEm (±)	0.76	1.08	1.73	1.56	1.56	1.56
CD (0.05)	NS	NS	NS	NS	NS	NS

NS - Not significant, DAT - Days After Transplanting

The treatment did not exert any significant effect on primary, secondary and tertiary branches at any of the growth stages. However higher number of primary branches were recorded by T_7 (HDP + LOM + azospirillum + B + Mg) at all crop growth stages except at 60 DAT and T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) recorded the higher number of primary branches at 60 DAT.

T_3, T_7 and T_{10} showed higher number of secondary branches at 45 DAT, 60 DAT and 75 DAT respectively and T_{11} at 3, 3.5 and 120 DAT.

Tertiary branches were found to be more in T_3 and T_{11} at 45 DAT and 60 DAT respectively and T_4 at 75 DAT, 9 DAT, 105 DAT and 120 DAT.

4.2 ROOT STUDIES

4.2.1 Primary root number

Mean data on primary root number as influenced by INM practices and summer irrigation at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are furnished in Table 12.

The treatments had no significant effect on primary root number during early stages of growth (45 DAT and 60 DAT). However, the treatments T_2, T_4 and T_6 and T_2 and T_6 recorded highest values of 2.75 and 3.75 at 45 DAT and 60 DAT respectively. The effect of treatments was evident from 75 DAT onwards. T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_9, T_{11}, T_8, T_6 and T_2 at 75 DAT; T_9 (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_8, T_{11} and T_{10} at 90 DAT; and T_8, T_{10}, T_{11}, T_6, T_4, T_7 and T_5 at 105 DAT and 120 DAT recorded the higher primary root number. However, T_{14} (Broadcasting) showed lowest value and found significantly different from the treatment which is registered highest root number at different stages of growth.

Table 12. Primary root number per plant of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	2.25	3.25	5.50	6.50	7.25	7.25
T_2	2.75	3.75	6.25	7.50	7.75	7.75
T_3	2.25	2.75	5.25	6.75	7.50	7.50
T_4	2.75	3.25	5.75	7.75	8.25	8.25
T_5	2.25	3.00	5.75	7.50	8.00	8.00
T_6	2.75	3.75	6.25	7.75	8.25	8.25
T_7	2.25	3.25	5.75	7.50	8.00	8.00
T_8	2.25	3.25	6.50	8.25	8.50	8.50
T_9	2.00	3.00	6.75	8.75	8.75	8.75
T_{10}	2.25	3.25	7.00	8.00	8.50	8.50
T_{11}	2.00	3.00	6.75	8.25	8.50	8.50
T_{12}	2.25	3.25	5.75	6.75	7.25	7.25
T_{13}	2.25	3.50	5.50	7.00	7.25	7.25
T_{14}	1.75	2.75	4.50	6.00	6.25	6.25
SEm (±)	0.23	0.23	0.32	0.29	0.33	0.33
CD (0.05)	NS	NS	0.969	0.879	0.987	0.987

Table 13. Root length (cm) as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	8.25	16.25	23.00	26.25	28.30	28.50
T_2	8.75	18.55	26.00	33.25	35.70	36.00
T_3	8.75	16.95	24.50	31.30	33.40	33.75
T_4	8.70	16.80	24.70	36.00	37.75	38.00
T_5	13.75	22.00	29.75	35.50	37.80	38.00
T_6	14.00	22.65	30.45	37.50	40.85	41.00
T_7	13.50	22.00	30.00	37.00	40.00	40.10
T_8	8.00	22.50	30.50	37.75	42.25	42.25
T_9	10.00	21.75	28.75	36.50	41.00	41.10
T_{10}	10.00	22.75	31.00	38.25	42.25	42.25
T_{11}	11.00	20.75	29.25	37.50	41.50	41.50
T_{12}	9.00	19.50	26.50	29.65	30.90	31.00
T_{13}	9.50	18.70	24.50	27.00	28.05	30.50
T_{14}	7.50	16.40	21.00	23.50	25.45	25.50
SEm (±)	0.66	0.32	0.51	0.54	0.74	0.81
CD (0.05)	2.002	0.969	1.544	1.637	2.261	2.472

NS - Not significant, DAT - Days After Transplanting

4.2.2 Root length

Effect of INM practices and summer irrigation on root length was recorded at fortnightly intervals are given in Table 13.

Root length was found to be significantly influenced by treatments at all growth stages of crop. T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_5 and T_7 recorded significantly higher value at 45 DAT which was 46.43 per cent high compared to T_{14} (Broadcasting). At 60, 75 and 90 DAT the longer root was showed by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE). It was found to be on par with T_6, T_8, T_5 and T_7 at 60 DAT; T_8, T_6, T_7 and T_5 at 75 DAT; and T_8, T_{11}, T_6 and T_7 at 90 DAT. At 105 and 120 DAT, the treatment T_8 and T_{10} registered the greatest length. It was on par with T_{11}, T_9, T_6 and T_7 at both the stages of growth. Except at 60 DAT, the treatment T_{14} registered the lowest value.

4.2.3 Root spread

Data on root spread as influenced by treatment effect are summarized in Table 14.

Significant influence of treatment on root spread was observed at all growth stages. The treatment T_6 (HDP + NPK + azospirillum + B +Mg) recorded higher values at 45 DAT and 60 DAT and it was on par with T_{10}, T_{11}, T_8, T_5, T_9, T_4 and T_7 at 45 DAT; T_{10} and T_8 at 60 DAT. The performance of the treatment T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) was found to be significantly superior at 75 DAT, 90 DAT and 120 DAT. T_{11} was found to be on par with T_{10}, T_9, T_6, T_8, T_7 and T_4 at 75 DAT; T_{10}, T_9, T_8, T_6 and T_7 at 90 DAT and T_{10}, T_9, T_8 and T_6 at 120 DAT respectively. At 105 DAT, T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) showed greater root spread and was found to be on par with T_{11}, T_8, T_6 and T_9.

Table 14. Root spread (cm) as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	6.20	9.50	16.25	24.75	27.75	29.65
T_2	6.50	19.75	21.95	35.45	37.60	40.15
T_3	5.75	19.50	25.00	33.50	36.50	37.90
T_4	10.00	27.00	36.20	44.45	47.95	49.80
T_5	10.38	23.25	31.65	40.15	44.15	45.50
T_6	11.63	31.50	38.75	47.25	50.25	52.25
T_7	9.13	24.50	37.70	46.20	48.10	50.75
T_8	10.50	30.50	38.50	47.50	50.50	52.50
T_9	10.25	26.25	39.25	48.25	50.25	53.25
T_{10}	11.50	31.50	39.50	48.50	51.50	53.50
T_{11}	11.00	27.00	40.00	49.00	51.00	54.00
T_{12}	8.63	15.25	23.25	31.75	35.33	38.00
T_{13}	8.88	11.88	23.50	32.00	36.50	40.00
T_{14}	7.83	15.53	19.75	28.25	30.38	33.50
SEm (±)	0.83	1.30	1.63	1.04	0.97	1.05
CD (0.05)	2.555	3.978	4.984	3.172	2.959	3.186

Table 15. Root volume (cm^3) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	1.15	2.95	3.90	4.50	5.00	6.65
T_2	1.30	4.95	5.25	5.55	6.30	6.45
T_3	3.30	4.50	4.85	5.40	5.70	5.85
T_4	2.46	6.00	5.95	6.75	6.90	7.50
T_5	2.60	5.70	5.80	6.60	7.10	7.70
T_6	2.15	7.35	8.05	9.70	9.80	11.55
T_7	2.70	7.70	7.75	9.60	9.60	11.20
T_8	2.30	4.68	5.76	5.92	8.73	9.69
T_9	1.17	4.20	5.61	6.22	8.55	11.54
T_{10}	1.37	5.50	6.97	11.42	11.96	13.78
T_{11}	1.33	5.25	8.06	9.81	11.06	13.49
T_{12}	1.30	3.55	4.50	4.45	5.65	5.75
T_{13}	1.80	2.90	3.90	5.30	6.15	10.50
T_{14}	0.65	1.65	2.45	2.75	2.95	3.05
SEm (±)	0.33	0.45	0.52	0.55	0.38	0.62
CD (0.05)	1.008	1.390	1.585	1.682	1.172	1.880

DAT - Days After Transplanting

From 60 DAT onwards T_1 (HDP) was very poor in root spread compared to all other treatments.

4.2.4 Root volume

Data relating to root volume at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT as influenced by INM practices and summer irrigation are presented in Table 15.

Effect of treatments on root volume was found to be remarkable at all stages of growth. T_3 (HDP + LOM) on par with T_7, T_5, T_4 and T_8 and T_7 (HDP + LOM + azospirillum + B + Mg) on par with T_6 showed greater value of 3.3 cm^3 and 7.7 cm^3 at 45 and 75 DAT respectively. At 75 DAT the performance of the treatment T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) was found superior. It was on par with T_6, T_7 and T_{10}. The treatment T_{10} (HDP + NPK + azospirillum + B +Mg+ summer irrigation at 30 mm CPE) registered highest root volume at 90, 105 and 120 DAT. At the time of final harvest (120 DAT), T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) was found to be on par with T_{11} and both the treatments were found to be significantly superior to all other treatments. Broadcasting resulted in significantly lower root volume from 90 DAT onwards.

4.2.5 Fresh root weight per plant

Observations recorded on fresh root weight per plant as influenced by INM practices and summer irrigation at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are depicted in Table 16.

Significant influence of treatment on fresh root weight was observed at all stages of growth. The treatment T_3 (HDP + LOM) on par with T_4, T_5, T_8 and T_7 at 45 DAT, T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_7 at 60 DAT and T_{11} (HDP) on par with T6 and T7 at 75 DAT registered the highest fresh root weight per plant. From 90 DAT onwards T_{10} (HDP + NPK + azospirillum + B +

Table 16. Fresh root weight (g plant^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	1.42	5.00	6.50	7.50	8.00	11.00
T_2	1.95	7.75	8.75	9.25	10.50	10.75
T_3	5.50	6.90	8.00	9.00	9.50	9.75
T_4	4.10	8.75	9.75	11.25	11.50	12.50
T_5	4.00	8.65	9.50	10.90	12.00	12.80
T_6	3.00	10.50	11.50	13.85	14.00	16.50
T_7	3.85	9.75	11.05	13.50	13.75	15.90
T_8	3.90	7.80	9.60	10.38	11.64	12.12
T_9	1.95	7.00	8.02	8.88	11.40	14.43
T_{10}	2.31	8.80	9.96	16.32	16.54	17.22
T_{11}	2.04	8.40	13.44	14.02	15.80	16.86
T_{12}	2.00	6.00	7.50	7.50	8.00	8.25
T_{13}	2.96	4.50	6.50	8.75	10.00	15.00
T_{14}	0.94	2.50	3.50	4.00	4.00	4.35
SEm (±)	0.54	0.42	0.83	0.85	0.47	0.90
CD (0.05)	1.667	1.303	2.535	2.597	1.447	2.729

Table 17. Dry root weight (g plant^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	0.45	2.39	3.19	3.68	3.90	5.48
T_2	0.66	3.80	4.28	4.54	5.08	5.28
T_3	1.44	3.32	3.87	4.41	4.66	4.87
T_4	0.95	4.34	4.80	5.52	5.69	6.17
T_5	0.86	4.23	4.77	5.38	5.84	6.23
T_6	1.03	5.15	5.65	6.70	6.86	8.17
T_7	1.60	4.80	5.42	6.64	6.75	7.85
T_8	1.95	3.90	4.80	5.19	5.82	6.06
T_9	0.98	3.50	4.01	4.44	5.70	7.22
T_{10}	1.16	4.40	4.98	8.16	8.27	8.61
T_{11}	1.02	4.20	6.72	7.01	7.90	8.43
T_{12}	0.44	2.88	3.78	3.74	3.85	4.03
T_{13}	1.10	1.90	3.20	4.40	4.90	7.38
T_{14}	0.21	1.19	1.65	1.99	1.99	2.23
SEm (±)	0.28	0.23	0.41	0.43	0.24	0.44
CD (0.05)	0.849	0.691	1.250	1.326	0.739	1.336

DAT- Days After Transplanting

Mg + summer irrigation at 30mm CPE) showed remarkable influence on fresh root weight per plant and it was on par with T_{11} and T_6 at 90 DAT; T_{11} at 105 DAT and T_{11}, T_6, T_7 and T_{13} at 120 DAT. The treatment T_{14} (Broadcasting) resulted in lowest fresh root weight per plant at all stages of growth.

4.2.6 Dry root weight per plant

Effect of treatments on dry root weight per plant is given in Table 17.

Dry root weight per plant also showed significant difference due to treatment effect and it followed a similar trend as that of fresh root weight per plant.

4.2.7 Fresh and dry root yield per hectare

Data on fresh and dry root yield per hectare as influenced by INM practices and summer irrigation recorded at 120 DAT (at the time of harvest) are furnished in Table 18.

The remarkable influence of treatment on fresh and dry root production per hectare was observed at 120 DAT. The treatment T_{10} (HDP + NPK + azopirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_{11}, T_6, and T_7 recorded the highest fresh and dry root yield of 1377 and 688.8 kg ha^{-1} respectively. The lowest fresh and dry root yield of 600 and 295.2 kg ha^{-1} were recorded by T_{13} (NRP). Compared to T_{14} (Broadcasting) an increase in fresh and dry root productions were in the tune of 681 and 332 kg ha^{-1} respectively in T_{10}.

4.3 SEED PRODUCTION

Data on seed yield per plant and seed yield per hectare are furnished in Table 19.

Treatments had significant effect on seed yield per plant and T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_{10}, T_8, T_{11}, T_7, T_4, T_{13} and T_9

Table 18. Fresh and dry root yield (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Fresh root yield (kg ha^{-1})	Dry root yield (kg ha^{-1})
T_1	880.00	438.40
T_2	860.00	422.00
T_3	780.00	389.60
T_4	1000.00	493.20
T_5	1024.00	498.40
T_6	1320.00	653.60
T_7	1272.00	628.00
T_8	969.60	484.80
T_9	1154.40	577.20
T_{10}	1377.60	688.80
T_{11}	1348.80	674.40
T_{12}	660.00	322.00
T_{13}	600.00	295.20
T_{14}	696.00	356.00
SEm (±)	70.39	34.46
CD (0.05)	214.975	105.258

Table 19. Seed production of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Seed (g $plant^{-1}$)	Seed (kg ha^{-1})
T_1	3.80	304.00
T_2	5.30	424.00
T_3	5.00	400.00
T_4	6.15	492.00
T_5	5.00	400.00
T_6	6.75	540.00
T_7	6.25	500.00
T_8	6.25	500.00
T_9	5.75	460.00
T_{10}	6.70	536.00
T_{11}	6.25	500.00
T_{12}	4.20	336.00
T_{13}	6.15	376.00
T_{14}	2.25	360.00
SEm (±)	0.33	47.46
CD (0.05)	1.011	144.960

recorded the highest seed yield of 6.75 g seed per plant which was 66.67 per cent higher compared to T_{14} (Broadcasting).

Seed yield per hectare was also found to be significantly influenced by treatments. The treatment T_6 (HDP + NPK + azospirillum + B + Mg) recorded the highest seed yield per hectare was on par with T_{10}, T_8, T_{11}, T_7, T_4, T_9, T_2, T_5 and T_3.

4.4 PHYSIOLOGICAL PARAMETERS

4.4.1 Relative leaf water content

The data pertaining to relative leaf water content at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are presented in Table 20.

The treatments had no significant effect on relative leaf water content at any of the growth stages. However, with a range differ 69.49 % to 82.39 % at 45 DAT, 82.18 % to 90.42 % at 60 DAT, 83.23 % to 90.75 % at 75 DAT, 71.92 % to 95.52 % at 90 DAT, 63.50% to 76.67 % at 105 DAT and 40.55 % to 55.50 % at 120 DAT.

4.4.2 Leaf temperature

Mean data on leaf temperature recorded 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are given in Table 21.

Similar to relative leaf water content, treatments had no significant effect on leaf temperature at any of the crop growth stage. The highest and lowest leaf temperature was 35.65 to 39.10 ^{0}C at 45 DAT, 35.05 to 36.60 ^{0}C at 60 DAT, 34.05 to 38.10 ^{0}C at 75 DAT, 35.40 to 35.90 ^{0}C at 90 DAT, 34.10 to 38.20 ^{0}C at 105 DAT and 33.50 to 36.40 ^{0}C at 120 DAT were recorded. The treatments T_1, T_{14}, T_{12}, T_{11}, T_{12} and T_6 recorded the higher leaf temperature at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT respectively.

Table 20. Relative water content (%) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	74.49	90.12	89.78	87.41	69.08	45.40
T_2	69.49	86.97	87.55	81.17	76.34	55.50
T_3	72.39	90.42	90.75	86.30	76.67	52.90
T_4	80.59	84.64	85.33	93.52	69.68	45.50
T_5	76.95	88.37	88.93	82.99	70.79	50.45
T_6	74.00	88.73	88.88	91.56	68.60	47.88
T_7	80.95	86.15	87.38	79.02	68.58	50.50
T_8	75.07	84.19	84.68	85.30	76.08	55.38
T_9	78.86	83.83	84.45	74.92	63.11	40.55
T_{10}	80.99	88.31	88.43	73.34	71.84	50.35
T_{11}	80.60	87.79	88.38	82.63	69.29	47.68
T_{12}	82.39	90.42	90.63	84.00	68.39	52.75
T_{13}	82.01	88.53	88.50	80.92	63.50	45.35
T_{14}	77.69	82.18	83.23	80.82	67.01	47.73
SEm (±)	3.05	2.48	1.86	5.18	4.41	2.98
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 21. Leaf temperature (^{0}C) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	39.10	36.08	36.25	35.40	36.25	35.85
T_2	37.55	35.45	36.10	35.54	36.30	35.90
T_3	37.35	35.45	34.05	35.73	34.10	34.95
T_4	37.75	36.05	35.35	35.58	35.60	35.25
T_5	36.30	35.60	35.30	35.40	35.15	34.75
T_6	36.35	35.60	35.60	35.57	35.55	36.40
T_7	35.75	35.05	35.30	35.40	35.30	35.00
T_8	38.40	35.50	35.75	35.63	34.05	33.50
T_9	39.00	35.68	34.95	35.40	34.70	34.50
T_{10}	38.30	36.20	37.00	35.50	37.30	36.00
T_{11}	37.90	36.15	37.60	35.90	37.50	35.65
T_{12}	36.25	35.60	38.10	35.45	38.20	35.50
T_{13}	36.70	36.50	34.60	35.70	34.10	34.50
T_{14}	35.65	36.60	35.55	35.50	36.00	34.50
SEm (±)	0.88	0.35	1.10	0.14	0.97	0.50
CD (0.05)	NS	NS	NS	NS	NS	NS

NS - Not significant, DAT - Days After Transplanting

4.4.3 Stomatal conductance

Mean data on stomatal conductance at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are presented in Table 22.

The treatments failed to exert significant influence on stomatal conductance at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT. The stomatal conductance ranged from 54.3 to 94.25 mmol m^{-2} s^{-1}, 92.2 to 134.55 mmol m^{-2} s^{-1}, 66.25 to 244 mmol m^{-2} s^{-1}, 67.7 to 180.5 mmol m^{-2} s^{-1}, 95.95 to 164.4 mmol $m^{-2}s^{-1}$ and 92.95 to 161.40 mmol m^{-2} s^{-1} at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT respectively. However, the treatment effect was remarkable at 90 DAT and the treatments T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) and T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) recorded higher stomatal conductance of 180.50 mmol m^{-2} s^{-1} compared to 67.70 mmol m^{-2} s^{-1} recorded by T_5.

4.4.4 SPAD chlorophyll meter reading

Mean data on SCMR recorded at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are given in Table 23.

The treatment effects on SCMR was insignificant at 45 DAT, 75 DAT, 90 DAT and 105 DAT. However, it was significant at 60 and 120 DAT. At 60 DAT it ranged from 45.94 to 63.06 and T_7 (HDP + LOM + azospirillum + B + Mg) showed the highest value. The treatment T_7 was on par with T_{13}, T_6, T_4, T_2 and T_{12}. At 120 DAT also the same trend was followed. The treatment T_7 (HDP + LOM + azospirillum + B + Mg) showed the highest value of 47.

Table 22. Stomatal conductance (mmol m^{-2} s^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	65.30	94.25	202.00	145.00	133.05	130.05
T_2	67.20	92.20	177.80	177.50	144.70	141.70
T_3	67.00	117.50	104.05	125.50	110.85	107.85
T_4	94.25	134.55	125.90	128.00	114.70	111.70
T_5	58.25	108.65	66.25	67.70	95.95	92.95
T_6	93.90	110.85	113.25	110.50	128.65	125.65
T_7	56.30	98.70	189.25	176.50	205.05	202.05
T_8	54.30	120.40	192.90	180.50	164.40	161.40
T_9	58.00	134.50	244.00	172.50	145.00	142.00
T_{10}	91.00	125.50	202.00	112.80	125.50	122.50
T_{11}	58.00	126.20	237.50	180.50	106.25	103.25
T_{12}	93.50	93.90	108.65	107.50	126.20	123.20
T_{13}	66.50	120.35	110.80	98.50	128.00	125.00
T_{14}	108.05	116.30	128.65	127.00	128.40	125.40
SEm (±)	18.24	24.36	36.44	20.56	31.05	31.05
CD (0.05)	NS	NS	NS	62.800	NS	NS

Table 23. SPAD chlorophyll meter reading of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	54.80	58.05	60.42	51.68	51.76	41.00
T_2	56.71	60.49	61.14	58.26	46.61	41.50
T_3	53.36	54.08	55.54	43.41	47.82	41.50
T_4	57.58	60.71	61.02	53.12	50.31	43.50
T_5	45.50	58.99	60.59	51.14	45.22	41.50
T_6	51.96	61.82	60.14	60.93	52.74	46.50
T_7	53.42	63.06	61.53	61.34	55.28	47.00
T_8	61.27	56.83	54.14	53.40	46.98	40.00
T_9	50.82	51.64	54.21	49.10	51.35	41.00
T_{10}	50.55	45.94	53.45	46.72	46.75	40.50
T_{11}	53.51	51.41	54.25	51.82	48.84	40.00
T_{12}	57.82	59.79	59.75	58.22	52.96	45.50
T_{13}	56.12	62.32	61.37	55.26	54.84	46.50
T_{14}	49.57	51.79	54.40	49.11	50.69	41.50
SEm (±)	2.94	1.11	2.14	3.73	2.98	1.32
CD (0.05)	NS	3.382	NS	NS	NS	4.046

NS - Not significant, DAT - Days After Transplanting

4.4.5 Dry matter production

Data on dry matter production at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT as influenced by INM practices and summer irrigation are depicted in Table 24.

Dry matter production showed significant difference at all stages of growth except at 45 DAT due to treatment effect. At 60 DAT, a highest dry matter production of 2.214 t ha^{-1} was recorded by T_7 (HDP + LOM + azospirillum + B + Mg) which was on par with T_{10}, T_6 and T_{11}. At 75 DAT, T_6 (HDP + NPK + azospirillum + B + Mg) on par with T_{11}, T_7 and T_{10} recorded highest dry matter production of 2.598 t ha^{-1}. From 90 DAT onwards, the treatment T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) showed higher values. The highest dry matter production of 3.13, 3.92 and 3.949 t ha^{-1} was registered by T_{10} at 90, 105 and 120 DAT respectively. However, T_{10} was on par with T_6 and T_{11} at 90 DAT; T_{11} at 105 DAT and T_{11} and T_6 at 120 DAT. At the time of harvest (120 DAT), increase in dry matter production in T_{10} was 47.63 per cent higher over T_{14} (Broadcasting).

4.4.6 Dry matter partitioning

Data on leaf dry matter production, stem dry matter production, root dry matter production and dry matter production of berries as influenced by INM practices and summer irrigation recorded at the stage of final harvest (120 DAT) are furnished in Table 25.

The treatment T_6 (HDP + NPK + azospirillum + B + Mg), T_{11} (HDP + LOM + azosprillum + B + Mg + summer irrigation at 30 mm CPE), T_{10} (HDP + NPK + azosprillum + B + Mg + summer irrigation at 30 mm CPE), T_6 (HDP + NPK + azospirillum + B + Mg) and T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) recorded the higher leaf, stem, root, berries and total dry matter production at the time of harvest. Dry matter production of 4.32 g,

Table 24. Dry matter production (t ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	0.23	0.83	1.17	1.49	1.78	1.91
T_2	0.26	0.97	1.44	2.92	3.41	3.42
T_3	0.55	1.01	1.33	1.94	2.33	2.35
T_4	0.26	1.83	2.27	2.91	3.39	3.43
T_5	0.37	1.15	1.44	2.75	3.19	3.22
T_6	0.51	2.16	2.60	3.25	3.76	3.86
T_7	0.51	2.21	2.55	3.08	3.60	3.69
T_8	0.58	1.65	2.18	2.86	3.55	3.57
T_9	0.47	1.68	2.14	2.78	3.50	3.63
T_{10}	0.50	2.12	2.47	3.31	3.92	3.95
T_{11}	0.48	2.16	2.57	3.17	3.87	3.91
T_{12}	0.23	0.74	1.41	1.85	2.16	2.18
T_{13}	0.18	0.58	0.78	1.50	1.74	1.84
T_{14}	0.26	0.90	1.64	2.00	2.03	2.07
SEm (±)	0.13	0.11	0.21	0.08	0.04	0.06
CD (0.05)	NS	0.281	0.264	0.187	0.118	0.154

Table 25. Dry matter partitioning of ashwagandha into leaf, stem, root and berry and total dry matter production (g plant^{-1}) as influenced by INM practices and summer irrigation

Treatments	Leaf	Stem	Root	Berries	TDMP
T_1	4.10	8.51	5.48	5.80	23.88
T_2	3.06	27.14	5.28	7.30	42.78
T_3	3.74	13.77	4.87	7.00	29.37
T_4	3.78	24.77	6.17	8.15	42.87
T_5	4.10	22.91	6.23	7.00	40.23
T_6	4.32	27.03	8.17	8.75	48.27
T_7	4.10	25.91	7.85	8.25	46.10
T_8	3.60	26.65	6.06	8.25	44.56
T_9	3.69	26.66	7.22	7.75	45.32
T_{10}	3.60	28.45	8.61	8.70	49.36
T_{11}	3.78	28.47	8.43	8.25	48.93
T_{12}	3.20	13.81	4.03	6.20	27.23
T_{13}	4.01	26.55	7.38	8.15	46.08
T_{14}	1.98	4.47	2.23	4.25	12.93
SEm (±)	0.24	0.52	0.44	0.33	0.62
CD (0.05)	0.590	1.608	1.336	1.011	1.877

NS - Not significant, DAT - Days After Transplanting

28.47 g, 8.61 g and 8.75 g were recorded by leaf, stem, root and berries respectively. Total dry matter production was 49.36 which on par with T_{11} and T_6. It was 73.81 per cent higher compared to T_{14} (Broadcasting).

4.4.7 Per cent distribution of dry matter production

Data on per cent distribution of dry matter production into leaf, stem, root and berries estimated at the time of harvest (120 DAT) are given in Table 26.

Profound influence of treatment was observed on per cent distribution of dry matter into leaf, stem, root and berries. Partitioning of dry matter for leaf production ranged from 7.15 to 17.13 per cent and the treatment T_1 (HDP) on par with T_{14} (Broadcasting) contributed the maximum compared to all other treatment. Per cent distribution of dry matter for stem production ranged from 34.54 to 63.46 per cent and T_2 (HDP + NPK) on par with T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) recorded the maximum. The treatment T_1 (HDP) showed the highest distribution of dry matter for root production and it differed significantly from all other treatments. Distribution of dry matter for root production ranged from 12.33 to 22.79 per cent. Contribution of total dry matter production to production of berries varied from 16.89 to 32.86 per cent.

4.4.8 Root shoot ratio

Data on root shoot ratio worked out at different stages of crop growth (45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT) as influenced by INM practices and summer irrigation are furnished in Table 27.

Significant effect of treatments on root shoot ratio was found at all stages of growth. T_4 (HDP + NPK + azospirillum + B + Mg) was on par with all other treatment except T_{14} (Broadcasting) at 45 DAT. T_2 (HDP + NPK) recorded the highest root shoot ratio at 60 DAT and was on par with T_{12} and T_5. The treatment T_5 (HDP + LOM + azospirillum) showed the higher root shoot ratio at 75 DAT

Table 26. Per cent distribution of dry matter production of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Leaf	Stem	Root	Berries
T_1	17.13	35.66	22.79	24.42
T_2	07.15	63.46	12.33	17.06
T_3	12.72	46.90	16.58	23.81
T_4	08.81	57.81	14.38	19.01
T_5	10.17	56.95	15.49	17.39
T_6	08.95	56.00	16.91	18.14
T_7	08.88	56.19	17.03	17.90
T_8	08.07	59.81	13.60	18.52
T_9	08.14	58.84	15.90	17.11
T_{10}	07.29	57.65	17.44	17.62
T_{11}	07.72	58.14	17.25	16.89
T_{12}	11.71	50.84	14.69	22.76
T_{13}	08.69	57.63	16.00	17.68
T_{14}	15.37	34.54	17.23	32.86
SEm (±)	0.87	1.84	1.17	1.22
CD (0.05)	2.661	4.547	3.572	3.005

Table 27. Root shoot ratio of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	0.21	0.30	0.28	0.24	0.21	0.30
T_2	0.26	0.46	0.31	0.14	0.14	0.14
T_3	0.32	0.36	0.30	0.22	0.19	0.20
T_4	0.43	0.23	0.32	0.18	0.16	0.17
T_5	0.26	0.42	0.36	0.19	0.17	0.18
T_6	0.21	0.24	0.21	0.20	0.17	0.20
T_7	0.36	0.21	0.21	0.21	0.18	0.21
T_8	0.34	0.23	0.21	0.17	0.15	0.16
T_9	0.19	0.20	0.18	0.15	0.15	0.19
T_{10}	0.23	0.19	0.19	0.25	0.20	0.21
T_{11}	0.22	0.19	0.26	0.21	0.20	0.21
T_{12}	0.19	0.45	0.27	0.19	0.17	0.17
T_{13}	0.39	0.15	0.20	0.13	0.13	0.19
T_{14}	0.14	0.27	0.19	0.19	0.19	0.21
SEm (±)	0.08	0.02	0.02	0.02	0.01	0.03
CD (0.05)	0.239	0.043	0.038	0.039	0.023	0.056

DAT - Days After Transplanting

which was significantly different from all other treatment. At 90 DAT root shoot ratio of 0.246 was recorded by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) which was on par with T_1, T_3, T_{11} and T_7. The treatment T_1 (HDP) at later stages of growth that is 105 and 120 DAT registered higher values. It was on par with T_{10}, T_{11} and T_3 at 105 DAT. At the time of final harvest, the highest root shoot ratio of 0.30 was registered by T_1 (HDP) and differed significantly from all other treatments.

4.4.9 Leaf area index

Data on leaf area index as influenced by INM practices and summer irrigation are shown in Table 28.

The treatment T_1 (HDP) at 45 DAT and 90 DAT; T_{14} at 60 DAT; T_4 at 75 DAT and T_6 at 105 DAT and 120 DAT showed higher values of LAI of 0.58, 0.83, 1.06, 1.48, 0.60 and 0.46 respectively.

4.4.10 Leaf area ratio

Data on leaf area ratio recorded at different stage of crop growth as influenced by INM practices and summer irrigation are furnished in Table 29.

Treatments did not exert any significant effect on leaf area ratio at 45 DAT. From 60 DAT onwards the effects of treatments were evident on leaf area ratio. T_{14} (Broadcasting) on par with T_{12} at 60 DAT, T_{14} (Broadcasting) on par with T_3, T_1, T_{13} and T_{12} at 75 DAT, T_1 (HDP) at 90 DAT, T_{14} (Broadcasting) on par with T_1 at 105 DAT and T_1 (HDP) on par with T_{14} at 120 DAT recorded significantly higher leaf area ratio. The highest leaf area ratio of 122.43 $cm^2\ g^{-1}$ was observed at 60 DAT. From 60 DAT onwards there was gradual decline in leaf area ratio.

Table 28. Leaf Area Index of ashwagandha as influenced by INM and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	0.58	0.37	1.00	0.83	0.54	0.44
T_2	0.47	0.36	1.03	0.77	0.46	0.33
T_3	0.57	0.46	1.17	0.69	0.57	0.40
T_4	0.57	0.44	1.49	0.64	0.58	0.40
T_5	0.27	0.44	1.01	0.58	0.58	0.44
T_6	0.43	0.45	1.04	0.67	0.60	0.46
T_7	0.48	0.45	1.00	0.73	0.58	0.44
T_8	0.34	0.32	1.00	0.70	0.56	0.38
T_9	0.54	0.33	1.01	0.71	0.55	0.39
T_{10}	0.43	0.32	1.02	0.72	0.52	0.38
T_{11}	0.51	0.42	1.03	0.73	0.52	0.40
T_{12}	0.38	0.45	1.11	0.50	0.45	0.34
T_{13}	0.17	0.34	0.62	0.29	0.54	0.21
T_{14}	0.35	1.06	1.45	0.68	0.31	0.42
SEm (±)	0.04	0.02	0.08	0.06	0.04	0.02
CD (0.05)	0.138	0.060	0.240	0.172	0.108	0.080

Table 29. Leaf area ratio (cm^2 g^{-1}) of ashwagandha as influenced by INM and summer irrigation

Treatments	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
T_1	274.47	89.38	85.88	55.55	29.97	22.84
T_2	182.15	73.62	71.46	26.26	13.59	9.53
T_3	122.19	91.63	87.89	35.70	24.42	16.96
T_4	228.49	47.87	65.54	21.96	16.99	11.66
T_5	80.77	76.63	70.15	21.04	18.04	13.56
T_6	89.14	42.03	40.03	20.72	15.89	11.94
T_7	96.14	40.56	39.28	23.89	16.15	11.84
T_8	65.39	39.14	45.68	24.36	15.77	10.76
T_9	122.73	40.79	47.24	25.60	15.69	10.86
T_{10}	89.17	29.73	41.32	21.58	13.27	9.73
T_{11}	109.88	39.27	40.53	22.98	13.54	10.30
T_{12}	170.16	121.70	78.34	26.78	20.61	15.39
T_{13}	108.64	58.95	79.59	19.21	15.39	11.59
T_{14}	154.07	122.43	89.01	34.90	30.18	20.50
SEm (±)	40.25	8.54	5.72	2.47	1.70	1.19
CD (0.05)	NS	26.091	17.465	7.542	5.208	3.619

NS - Not significant, DAT - Days After Transplanting

4.4.11 Absolute growth rate

Data on absolute growth rate for height as influenced by INM practices and summer irrigation recorded at 60 DAT, 90 DAT, 105 DAT and 120 DAT are furnished in Table 30.

The treatments exerted profound influence on absolute growth rate at 60 DAT and 75 DAT. Absolute growth rate at 45 to 60 DAT ranged from 0.42 to 1.24 cm day^{-1} and T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_6, T_{14}, T_7, T_{12}, T_{11}, T_8, T_9, T_{13}, T_2 and T_1 recorded the highest absolute growth rate of 1.24 cm day^{-1}. At 2 to 75 DAT, the treatment T_{13} (NRP) was significantly different from all other treatments and recorded absolute growth rate of 1.42 cm day^{-1}. From 90 DAT onwards, absolute growth rate was insignificant due to treatment effect.

4.4.12 Crop growth rate

Mean data on crop growth rate estimated at 60 DAT, 75 DAT, 90 DAT, 105 DAT and 120 DAT are furnished in Table 31.

Remarkable influence of treatments on crop growth rate was observed at 45 to 60 DAT, 75 to 90 DAT and 90 to 105 DAT. However, the treatment effects were insignificant on crop growth rate at other stages of crop growth (60 to 75 and 105 to 120 DAT). At 45 to 60 DAT crop growth rate ranged from 2.83 to 12.15 g m^{-2} day^{-1} and the highest value was recorded by T_7 (HDP + LOM + azospirillum + B + Mg). At 75 to 90 DAT, T_2 (HDP + NPK) on par with T_5 registered the higher crop growth rate of 10.62 g m^{-2} day^{-1} which was 78.34 per cent higher compared to T_{14} (Broadcasting). At 90 to 105 DAT, T_9 (HDP + LOM + azospirillum + B + Mg + summer irrigation at 15 mm CPE) on par with T_{11}, T_8 and T_{10} recorded the highest crop growth rate of 5.21 g m^{-2} day^{-1} which was 90.40 per cent higher above T_{14} (Broadcasting).

Table 30. Absolute growth rate for height (cm day^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 to 60 DAT	60 to 75 DAT	75 to 90 DAT	90 to 105 DAT	105 to 120 MAT
T1	0.81	0.50	0.11	0.07	0.011
T2	0.83	0.50	0.13	0.08	0.010
T3	0.64	0.37	0.13	0.06	0.014
T4	0.56	0.20	0.17	0.07	0.011
T5	0.42	1.13	0.18	0.09	0.007
T6	1.20	0.22	0.14	0.14	0.014
T7	1.18	0.35	0.29	0.29	0.009
T8	1.02	0.40	0.07	0.21	0.011
T9	0.98	0.43	0.09	0.05	0.011
T10	1.24	0.38	0.14	0.23	0.011
T11	1.10	0.33	0.16	0.05	0.011
T12	1.17	0.50	0.07	0.08	0.013
T13	0.84	1.42	0.07	0.23	0.010
T14	1.18	0.41	0.37	0.13	0.004
SEm (±)	0.15	0.08	0.07	0.08	0.005
CD (0.05)	0.464	0.258	NS	NS	NS

Table 31. Crop growth rate (g m^{-2} day^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	45 to 60 DAT	60 to 75 DAT	75 to 90 DAT	90 to 105 DAT	105 to 120 MAT
T1	4.25	2.45	2.31	2.07	0.91
T2	5.09	3.33	10.62	3.45	0.11
T3	3.30	2.26	4.36	2.83	0.12
T4	11.18	3.12	4.57	3.47	0.47
T5	5.54	2.14	9.33	3.12	0.22
T6	11.78	3.13	4.64	3.63	0.75
T7	12.15	2.37	3.77	3.75	0.63
T8	7.66	3.80	4.80	4.93	0.14
T9	8.61	3.29	4.53	5.21	0.87
T10	11.94	2.10	6.05	4.35	0.19
T11	11.96	2.93	4.34	4.99	0.30
T12	3.63	4.83	3.12	2.24	0.33
T13	2.83	1.48	5.09	1.77	0.71
T14	4.56	5.27	2.30	0.50	0.27
SEm (±)	1.05	0.83	0.61	0.35	0.19
CD (0.05)	3.223	NS	1.858	1.064	NS

NS - Not significant, DAT - Days After Transplanting

4.5 BIOCHEMICAL PARAMETERS

Data on biochemical parameters namely crude alkaloid content, total sugar and total amino acid estimated at the time of harvest are furnished in Table 32.

Crude extract per cent ranged from 6.5 % to 10.4 %. The highest crude extract content of 10.54 % was registered by T_7 (HDP + LOM + azospirillum + B + Mg) which was on par with T_3, T_5, T_4 and T_{10}. Compared to T_{14} (Broadcasting) the per cent increase of crude extract in T_7 was 37.5 per cent higher. Other biochemical parameters namely total sugar and total amino acid content were not at all influenced by treatment effects. However, the total sugar content ranged from 0.70 to 0.95 % and T_7 (HDP + LOM + azospirillum + B + Mg) recorded the highest content. The total amino acid in different treatments were ranged from 0.31 to 0.64 mg L^{-1} and T_4 (HDP + NPK + azospirillum) registered the highest content.

4.6 MICROBIOLOGICAL STUDIES

Data on population of azospirillum enumerated at the time of harvest (120 DAT) are furnished in Table 33.

Remarkable influence of treatments on the population of azospirillum was observed. The population ranged from 11.5 x 10^5 to 64 x 10^5 per gram dry soil. The highest population of 64 x 10^5 per gram dry soil was registered by the treatments T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) and T_5 (HDP + LOM + azospirillum) which was on par with T_6, T_{11}, T_7, T_4, T_9 and T_{10}. Compared to broadcasting (T_{14}), the per cent increase in population in T_8 and T_5 was 82.03 per cent higher.

Table 32. Biochemical parameters of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Crude alkaloid content (%)	Total amino acid (mg L^{-1})	Total sugar (%)
T_1	7.15	0.31	0.85
T_2	8.00	0.54	0.85
T_3	10.20	0.57	0.75
T_4	9.35	0.64	0.90
T_5	9.75	0.56	0.85
T_6	9.00	0.59	0.95
T_7	10.40	0.61	0.75
T_8	9.00	0.57	0.70
T_9	8.75	0.58	0.75
T_{10}	9.20	0.57	0.80
T_{11}	8.75	0.52	0.90
T_{12}	7.00	0.54	0.85
T_{13}	7.40	0.38	0.90
T_{14}	6.50	0.49	0.12
SEm (±)	0.42	0.10	0.18
CD (0.05)	1.297	NS	NS

NS - Not significant, DAT - Days After Transplanting

Table 33. Azospirillum population per gram dry soil of ashwagandha as influenced by INM practices and summer irrigation

Treatments	*Azospirillum* population level (x 10^5/g soil dry wt.)
T_1	13.00 (6.12)
T_2	13.50 (6.13)
T_3	14.50 (6.12)
T_4	59.00 (6.77)
T_5	64.00 (6.81)
T_6	60.50 (6.78)
T_7	59.50 (6.77)
T_8	64.00 (6.81)
T_9	56.00 (6.75)
T_{10}	53.50 (6.73)
T_{11}	60.50 (6.78)
T_{12}	12.00 (6.08)
T_{13}	16.00 (6.21)
T_{14}	11.50 (6.06)
SEm (±)	0.05
CD (0.05)	0.153

Figures given in the parenthesis indicate the transferred values

4.7 SOIL MOISTURE STUDIES

Mean data on soil moisture studies before and after irrigation, seasonal consumptive use, mean daily consumptive use, crop water use efficiency, field water use efficiency and water productivity are furnished in Table 34 and 35.

Significant effects of treatment on soil moisture studies before irrigation were observed. Before irrigation, moisture content ranged from 10.30 to 13.35 % indicating the highest moisture content in T_9 on par with T_8. Moisture content in T_9 prior to irrigation was 22.85 per cent higher compared to T_{14}. However, treatments had no significant effect on moisture content after irrigation. However, T_7 (HDP + LOM + azospirillum + B + Mg) recorded the highest moisture content after irrigation and the lowest moisture content was noticed in and T_1 (HDP).

Seasonal consumptive use and mean daily consumptive use were found to be significantly influenced by treatments. Seasonal consumptive use ranged from 145.73 mm to 250.80 mm. the treatment T_{14} (Broadcasting) on par with T_{13}, T_{12}, T_7, T_5, T_2, T_4, T_3, T_6 and T_1 registered the highest seasonal consumptive use. The mean daily consumptive use ranged from 1.22 to 2.09 mm and the higher mean daily consumptive use was recorded by T_{14} (Broadcasting).

Crop water use efficiency, field water use efficiency and water productivity showed remarkable influence due to treatment effect. The highest crop water use efficiency of 474.78 g m^{-3} was recorded by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE). Crop water use efficiency was ranged from 121.43 to 474.78 g m^{-3}. Field water use efficiency varied from 84.46 to 222.31 g m^{-3} and the highest value of 222.31 g m^{-3} was recorded by T_6 (HDP + NPK + azospirillum + B + Mg) which was on par with T_7, T_{10} and T_{11}. T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) recorded the lowest value of 84.46 g m^{-3}.

Table 34. Soil moisture before irrigation (Mbi) and after irrigation (Mai), seasonal consumptive use and mean daily consumptive use of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Mbi (%)	Mai (%)	Seasonal Cu (mm)	Mean daily Cu (mm)
T_1	10.75	14.85	216.48	1.80
T_2	10.65	14.95	227.04	1.89
T_3	10.75	14.90	219.12	1.83
T_4	10.80	15.05	224.40	1.87
T_5	10.70	15.05	229.68	1.91
T_6	10.75	14.90	219.12	1.83
T_7	10.70	15.10	232.32	1.94
T_8	13.25	14.90	174.24	1.45
T_9	13.35	14.95	168.96	1.41
T_{10}	12.70	15.00	145.73	1.22
T_{11}	12.75	15.05	145.73	1.22
T_{12}	10.35	14.95	242.88	2.02
T_{13}	10.40	15.00	242.88	2.02
T_{14}	10.30	15.05	250.80	2.09
SEm (±)	0.13	0.13	11.02	0.10
CD (0.05)	0.409	NS	35.832	0.299

Table 35. Crop water use efficiency (CWUE), field water use efficiency (FWUE) and water productivity (WP) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	CWUE (g m^{-3})	FWUE (g m^{-3})	WP (g m^{-3})
T_1	177.03	130.350	649.795
T_2	186.07	143.540	1163.945
T_3	177.90	132.515	799.180
T_4	219.74	167.755	1166.395
T_5	217.05	169.725	1094.695
T_6	298.16	222.313	1313.470
T_7	270.32	213.605	1254.420
T_8	284.78	84.460	621.045
T_9	340.78	100.555	631.570
T_{10}	474.78	196.800	1128.230
T_{11}	471.01	192.685	1118.400
T_{12}	134.01	109.520	740.820
T_{13}	121.43	100.410	626.940
T_{14}	141.935	121.090	703.405
SEm (±)	31.37	14.34	16.40
CD (0.05)	95.823	43.767	50.087

The treatment which recorded highest value of field water use efficiency also registered the highest water productivity of 1313.467 g m^{-3} and it differed significantly from all other treatments. The treatment T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) recorded the lowest water productivity of 621.05 g m^{-3}.

4.8 NUTRIENT UPTAKE STUDIES

4.8.1 Plant nutrient status

Data on plant nutrient status (N, P, K, B and Mg) as influenced by INM practices and summer irrigation estimated at the time of harvest (120 DAT) are furnished in Table 36.

Significant effects of treatments were observed on plant nutrient status except for magnesium. Nitrogen content ranged from 1.3 to 2.75 %. The higher nitrogen content of 2.75 % was recorded by T_6 (HDP + NPK + azospirillum + B + Mg) which was on par with T_7, T_5, T_{10}, T_{13}, T_{12}, T_{11}, T_4 and T_1. The per cent increase in nitrogen content in T_6 over T_{14} was 52.73.

Phosphorus content also varied from 0.26 to 0.31 % and the highest content of 0.30 % was registered by T_8 (HDP + NPK + azospirillum + B + Mg + summer irrigation at 15 mm CPE) which was on par with T_6, T_4, T_7, T_9, T_3, T_{11}, T_2, T_5 and T_{13}. The increase in phosphorus content in T_8 over T_{14} was 16.13 per cent.

Potassium content was highest in T_9 (2.77 %) and ranged from 1.49 to 2.77 %. T_9 (HDP + LOM + azospirillum + B + Mg + summer irrigation at 15 mm CPE) was on par with T_4, T_3, T_6, T_{10}, T_8, T_2, T_{11}, T_1 and T_5. Compared to T_{14} the highest in potassium content in T_9 was 46.21 per cent.

Magnesium was ranged from 0.11 to 0.12 %. The lowest content of NPK and B and Mg were registered by T_{14} (Broadcasting) and T_{12} (HDP without polythene mulch) respectively.

Boron concentration varied from 5.09 to 10.44 mg L^{-1} and the highest content of 10.44 mg L^{-1} was registered by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) which was on par with T_6, T_9, T_3, T_7, T_{11}, T_4, T_{13}, T_8, T_2, T_1, T_{14} and T_5. Compared to T_{14}, the increase in boron concentration in T_{10} was in the tune of 51.25 per cent.

4.8.2 Plant nutrient uptake

Data on total nutrient uptake (N, P, K, B and Mg) estimated at 120 DAT (at harvest) are furnished in Table 37.

INM practices and summer irrigation remarkably influenced the total uptake of all the nutrients (N, P, K, B and Mg). Total uptake of nitrogen ranged from 26.85 to 106.07 kg ha^{-1} and the highest uptake was registered by T_6 (HDP + NPK + azospirillum + B + Mg) which was on par with T_7 and T_{10}. Phosphorus uptake varied from 4.94 to 11.85 kg ha^{-1} and the highest phosphorus uptake was registered by the treatment T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) which was on par with T_6, T_{11}, T_7 and T_8. Unlike nitrogen uptake the lowest phosphorus uptake was in T_{13} (NRP). The highest total uptake of potassium, boron and magnesium was registered by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE). Total potassium uptake ranged from 30.91 to 102.24 kg ha^{-1} and the highest uptake was by T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) which was on par with T_9, T_6, T_{11}, T_4, T_8 and T_2 which was 69.77 per cent higher compared to T_{14}. Boron and magnesium uptake varied from 10.79 to 41.15 g ha^{-1} and 2.08 to 4.68 kg ha^{-1} respectively. Boron and magnesium uptake by T_{10} were 73.77 and 55.52 per cent compared to T_{14} (Broadcasting).

Table 36. Plant nutrient status of ashwagandha as influenced by INM practices and summer irrigation

Treatments	N (%)	P (%)	K (%)	Mg (%)	B (ppm)
T_1	1.97	0.29	2.32	0.12	6.6
T_2	1.81	0.28	2.50	0.11	6.9
T_3	1.75	0.30	2.60	0.11	8.41
T_4	2.04	0.30	2.68	0.12	7.25
T_5	2.59	0.28	2.23	0.11	6.30
T_6	2.75	0.30	2.59	0.12	10.21
T_7	2.65	0.30	2.12	0.12	8.18
T_8	1.68	0.30	2.54	0.12	6.90
T_9	1.75	0.30	2.77	0.12	10.16
T_{10}	2.33	0.30	2.59	0.12	10.44
T_{11}	2.11	0.29	2.38	0.11	8.08
T_{12}	2.18	0.26	1.83	0.11	5.09
T_{13}	2.21	0.27	1.99	0.11	7.09
T_{14}	1.30	0.26	1.49	0.11	6.33
SEm (±)	0.24	0.01	0.18	0.004	1.84
CD (0.05)	0.727	0.033	0.548	NS	4.535

Table 37. Plant nutrient uptake of ashwagandha as influenced by INM practices and summer irrigation

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})	B (g ha^{-1})
T_1	37.85	5.52	44.45	2.23	12.71
T_2	62.10	9.69	85.60	3.85	23.17
T_3	41.25	6.93	61.12	2.63	10.79
T_4	70.12	10.34	91.99	4.05	24.82
T_5	83.19	9.09	71.74	3.62	20.28
T_6	106.07	11.70	99.96	4.79	39.44
T_7	97.74	10.88	78.19	4.52	30.15
T_8	59.71	10.88	90.66	4.23	24.60
T_9	63.31	10.69	95.37	4.41	36.63
T_{10}	92.30	11.85	102.24	4.68	41.15
T_{11}	82.41	11.36	92.88	4.40	31.58
T_{12}	47.61	5.64	39.77	2.42	10.96
T_{13}	40.61	4.94	36.61	2.08	13.01
T_{14}	26.85	5.30	30.91	2.34	13.10
SEm (±)	6.66	0.35	6.10	0.14	5.87
CD (0.05)	20.339	1.075	18.832	0.433	17.922

4.8.3 Soil nutrient status

Mean data on soil nutrient status (N, P, K, B and Mg) estimated on completion of experiment are furnished in Table 38.

INM practices and summer irrigation had remarkable influence on N, P, K, B and Mg status of soil after the experiment. Soil nitrogen ranged from 163.07 to 275.97 kg ha^{-1}. The highest nitrogen content was recorded by T_2 (HDP) on par with T_6, T_3 and T_{13}. Compared broadcasting (T_{14}), the per cent increase in soil nitrogen status was 40.91. Soil phosphorus ranged from 56.56 to 103.04 kg ha^{-1} and T_4 (HDP + NPK + azospirillum) registered the highest value which was significantly different from all other treatment. It recorded 45.12 per cent increase in phosphorus content compared to broadcasting (T_{14}). Potassium content ranged from 130.20 to 387.80 kg ha^{-1} and T_8 on par with T_9, T_{11}, T_7 and T_{10} recorded the highest value which was 66.43 per cent higher compared to T_{14} (Broadcasting). T_{11} (HDP + LOM + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_9, T_{10}, T_8, T_7 and T_6 registered the highest boron content of 6.910 g ha^{-1} and differed significantly from all other treatment. Compared to T_{14} (Broadcasting), the per cent increase in T_{11} was 58.03. Like other elements magnesium content was also varied significantly. T_7 (HDP + LOM + azospirillum + B + Mg) recorded the highest value and it was on par with all other treatments except T_{13} (NRP).

4.9 SCORING OF PEST AND DISEASE

4.9.1 Disease incidence

Minor incidence of fungal wilt, root rot, wet rot and leaf spot were observed during the crop period.

4.9.2 Pest occurrence

Infestation of Epilachna beetle was observed in nursery stage. Minor infestation of Sphingid larvae (*Dilephila nerii*) and red cotton bug (*Dysdercus cingulatus*) were also found at vegetative and reproductive stage respectively.

4.10 ECONOMIC ANALYSIS

Data on cost of cultivation, gross income, net income and benefit cost ratio as influenced by treatment effects are shown in Table 39.

Remarkable influences of treatments were observed on cost of cultivation, gross income, net income and benefit cost ratio. The treatment T_9 (HDP + LOM + azospirillum +B +Mg) on par with T_7 recorded the highest cost of cultivation of ₹ 58844 and T_{14} (Broadcasting) recorded the lowest. Gross income ranged from ₹ 124544 to ₹ 263296 and T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_{11}, T_6 and T_7 registered the highest value. Compared to T_{14} the per cent increase in gross income was 52.70. Net income was also showed a similar trend and it ranged from ₹ 47938 to ₹ 170088. The increase in net income in T_{10} compared to T_{14} was 71.82 per cent. The treatment T_{13} registered the lowest net income of ₹ 47938. Benefit cost ratio varied from 1.63 to 2.83. T_{10} (HDP + NPK + azospirillum + B + Mg + summer irrigation at 30 mm CPE) on par with T_6, T_{11} and T_7 registered the highest benefit cost ratio of 2.83 which was 42.40 per cent higher compared to T_{14}. Similar to net income, T_{13} also showed the lowest benefit cost ratio.

Table 38. Soil nutrient status (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

Treatments	N	P	K	Mg	B
T_1	200.70	70.67	166.00	74.54	3.25
T_2	275.97	56.56	245.00	68.26	3.45
T_3	244.61	77.95	217.00	71.90	3.49
T_4	169.34	103.04	217.00	71.40	3.88
T_5	194.43	73.75	196.00	74.65	3.78
T_6	275.97	68.88	259.00	72.07	6.48
T_7	188.16	75.32	289.80	79.63	6.63
T_8	175.62	80.53	387.80	70.67	6.71
T_9	219.52	58.80	322.00	72.24	6.75
T_{10}	181.89	60.76	288.40	68.54	6.73
T_{11}	200.7	63.50	316.40	68.15	6.91
T_{12}	206.98	84.00	175.00	70.00	3.41
T_{13}	232.06	66.30	130.20	65.35	2.90
T_{14}	163.07	73.86	172.00	77.73	3.04
SEm (±)	16.34	6.22	30.54	3.80	0.16
CD (0.05)	49.900	18.987	93.290	11.597	0.486

Table 39. Economic analysis of ashwagandha as influenced by INM practices and summer irrigation

Treatments	Total cost of cultivation (₹)	Gross income (₹)	Net income (₹)	BC ratio
T_1	90607	164608	74000	1.83
T_2	92027	168960	76932	1.84
T_3	94607	156672	62064	1.66
T_4	92127	197184	105056	2.15
T_5	94707	191488	96780	2.03
T_6	93457	252352	158894	2.71
T_7	96037	240960	144922	2.51
T_8	94457	195136	100678	2.07
T_9	97037	221504	124466	2.29
T_{10}	93207	263296	170088	2.83
T_{11}	95787	255808	160020	2.67
T_{12}	76607	129920	53312	1.69
T_{13}	76605	124544	47938	1.64
T_{14}	69210	142720	73510	2.06
SEm (±)	358.97	11656.40	11717.90	0.14
CD (0.05)	1096.390	35601.434	35789.282	0.443

Price of seed – ₹ 80 per kg, Price of dried root – ₹ 320 per kg

Discussion

5. DISCUSSION

The results of the experiment presented in the previous chapter are discussed in the following paragraphs.

5.1 MORPHOLOGICAL PARAMETERS

Integrated nutrient management practices and summer irrigation significantly influenced morphological parameters *viz*., plant height, number of functional leaves, leaf area and number of branches throughout the period of crop growth. In general, vigorous crop growth in respect of plant height, number of functional leaves, leaf area and number of branches were observed when high density planting of azospirillum inoculated ashwagandha was carried out in trenches mulched with polythene and filled with enriched growing medium followed by basal dressing of recommended dose of NPK and B and Mg application (T_6) (Fig. 2 and 3). Broadcasting in trenches filled with enriched growing medium without bottom and side mulching with polythene resulted in shorter plants with less leaf number and leaf area besides lesser number of branches.

Biometric characters *viz*., plant height, functional leaf number, leaf area and number of branches indicate the photosynthetic capacity of ashwagandha and the transpirational area that are related to field establishment, further growth and development. Plant growth is influenced by the metabolic activities which needs sufficient amount of nutrients and water. High density planting of azospirillum inoculated ashwagandha seedlings in trenches and application of recommended dose of NPK, secondary nutrient Mg and micronutrient B are beneficial for maintaining optimum moisture, nutrients and oxygen regime in the rhizosphere. Mulching the sides and bottom of trenches with polythene prevents the loss of nutrients and water through lateral movement and percolation beyond the root zone. So there is better conservation and efficient utilization of both rain and irrigation water and nutrients due to treatment effects which might have resulted in better plant growth in terms of morphological characters of ashwagandha in

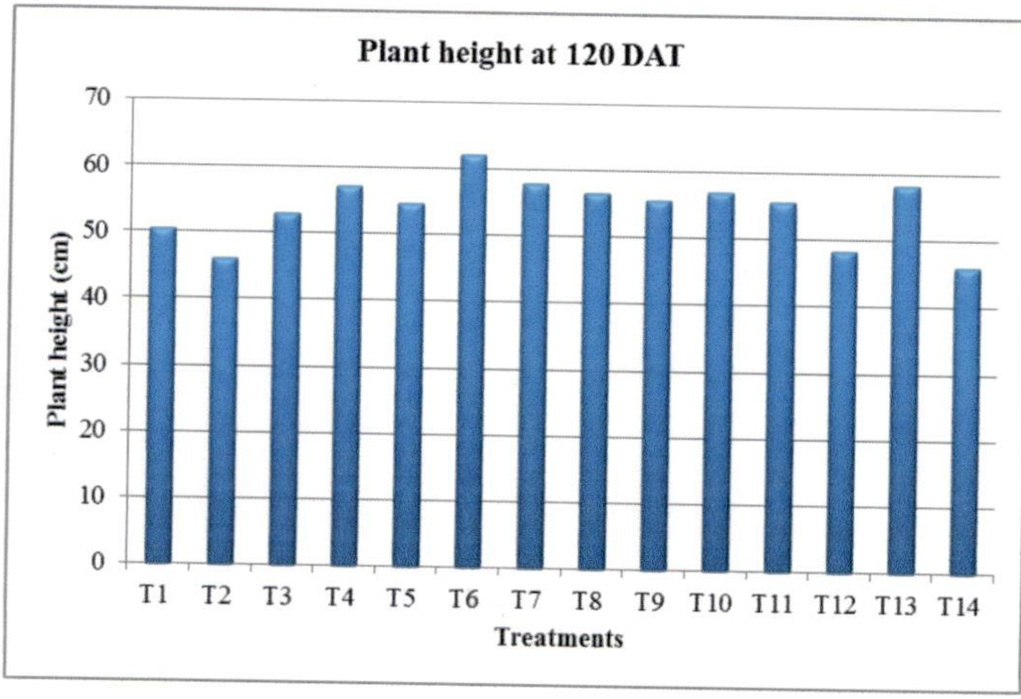


Fig. 2. Plant height (cm) of ashwagandha as influenced by INM practices and summer irrigation

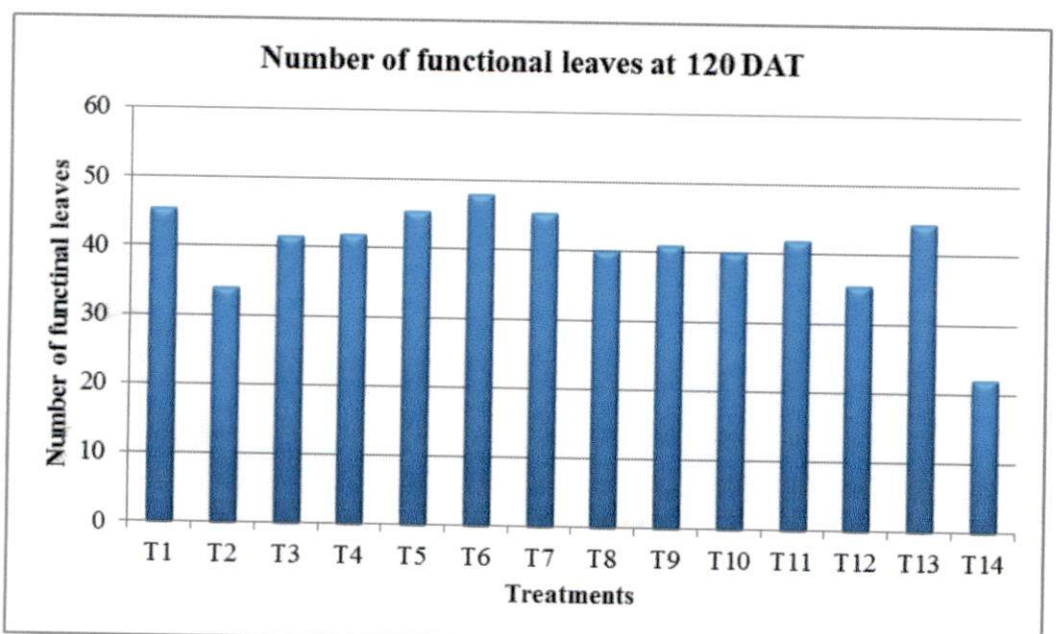


Fig. 3. Number of functional leaves of ashwagandha as influenced by INM practices and summer irrigation

polythene mulched trenches combined with the application of azospirillum, boron and magnesium. This could also be due to improved physical and chemical condition of soil and increased population of microorganisms by incorporation of organic manures which enhanced the uptake of nutrients which resulted in better plant growth.

Broadcasting in trenches filled with enriched growing medium showed reduction in crop growth in terms of plant height, number of functional leaves, leaf area and number of branches. Poor crop growth under this condition is mainly due to higher plant population. Method of crop establishment followed in T_{14} (Broadcasting in trenches filled with enriched growing medium) was quite different from T_6 (High density planting of azospirillum inoculated ashwagandha was carried out in trenches mulched with polythene and filled with enriched growing medium followed by basal dressing of recommended dose of NPK and B and Mg application). Broadcasting was followed in T_{14} (Broadcasting in trenches filled with enriched growing medium) whereas seedlings were transplanted at regular spacing in T_6. Mutual competition is avoided in T_6. Competition for space, nutrients, water and light existed in T_{14} on account of higher plant population. Moreover, physiological processes, *viz.*, cell division, cell expansion, cell elongation and photosynthesis were adversely affected due to several constraints.

Similar situation has been reported in several crops by Begg and Turner (1976). Nutrient and moisture stress have adversely affected cell elongation, which was primarily due to reduction in turgor pressure. Reduced turgor pressure due to nutrient and moisture stress also adversely affected cell expansion (Nath, 1993). Moisture and nutrient stress inhibition of cell division, cell elongation and further development might have resulted in reduced functional leaf number. Reduction in leaf area helps plants to reduce transpiration loss of water under stress environment.

It has been reported by FeiBo *et al.* (1998) and Sawan *et al.* (2001) that N, P and K nutrients have the largest effect on the physiology and yield of crops as

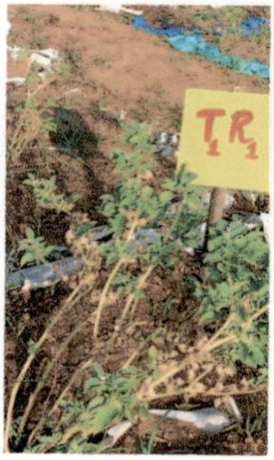
Plate 2. Different stages of crop growth

a. Nursery- emerging seedlings

b. Seedlings ready for transplanting

c. 60 days after transplanting

d. 75 days after transplanting



e. 90 days after transplanting

f. 120 days after transplanting - seed crop they are essential for photosynthesis and dry matter production. The observed positive effects of N and P application on the growth parameters of ashwagandha are in conformity with earlier workers (Shetty *et al.,* 1990; Maitra *et al.*, 1998; Maryada *et al.*, 2001; Kaushal *et al.*, 2002; Aishwath, 2004; Pandey *et al.*, 2006).

5.2 ROOT CHARACTERS

Below ground part of the plant behaved in a different manner due to different integrated nutrient management practices and summer irrigation. Variation in root parameters *viz*., number, length, weight, spread and volume was conspicuous due to treatment effects. T_{10} (high density planting of azospirillum inoculated seedlings of ashwagandha in trenches followed by basal dressing of recommended dose of NPK and B and Mg application with summer irrigation at 30 mm CPE) and T_{11} (high density planting of azospirillum inoculated seedlings of ashwagandha in trenches followed by sequential application of liquid organic manure and B and Mg application with summer irrigation at 30 mm CPE) were very effective in promoting root proliferation (Fig. 4, 5, 6 and 7). In general, high density planting of azospirillum inoculated seedlings in trenches mulched with polythene and filled with enriched rooting medium was found to improve all the root parameters studied compared to broadcasting in trenches filled with enriched growing medium but without mulching. Basal dressing of recommended dose of NPK or sequential application of vermiwash, fermented plant juice and panchagavya, inoculation with azospirillum, B and Mg application and summer irrigation provided a favourable situation for root development even during early phase of development.

The enriched growing medium physically supports the root system and supply water, nutrients and oxygen. Better the medium better will be the establishment and early development of a healthy root system. Enriched growing medium filled in the trenches consisted of a mixture of FYM, composted coir pith, leaf litter and soil which served as an excellent medium for efficient growth. The characteristics of the different component of the enriched growing medium have a

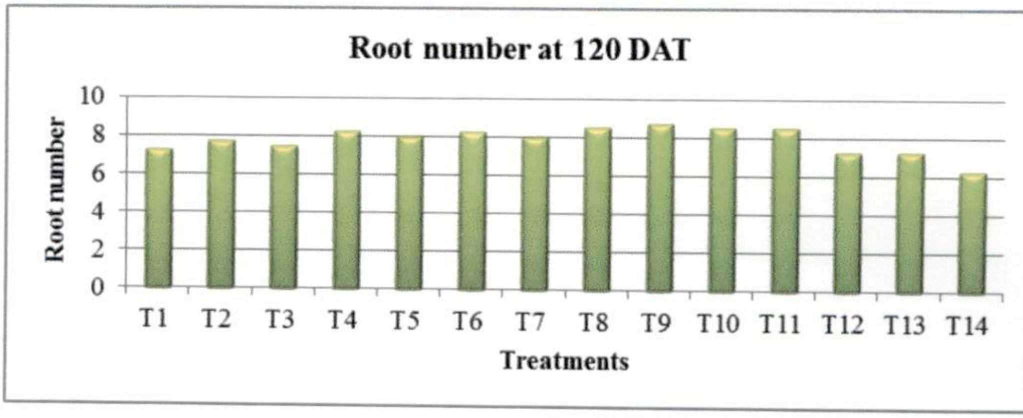


Fig. 4. Root number of ashwagandha as influenced by INM practices and summer irrigation

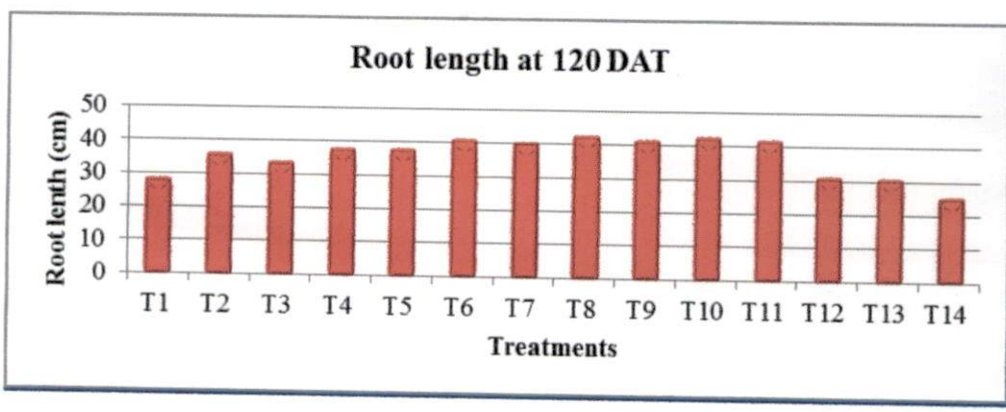


Fig. 5. Root length (cm) of ashwagandha as influenced by INM practices and summer irrigation

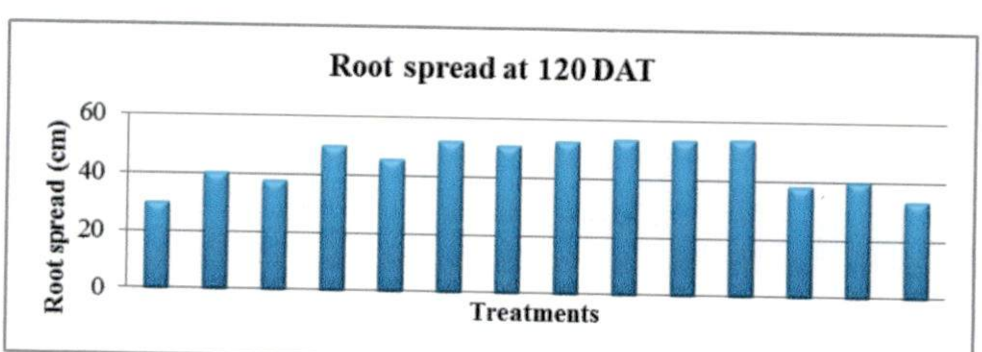
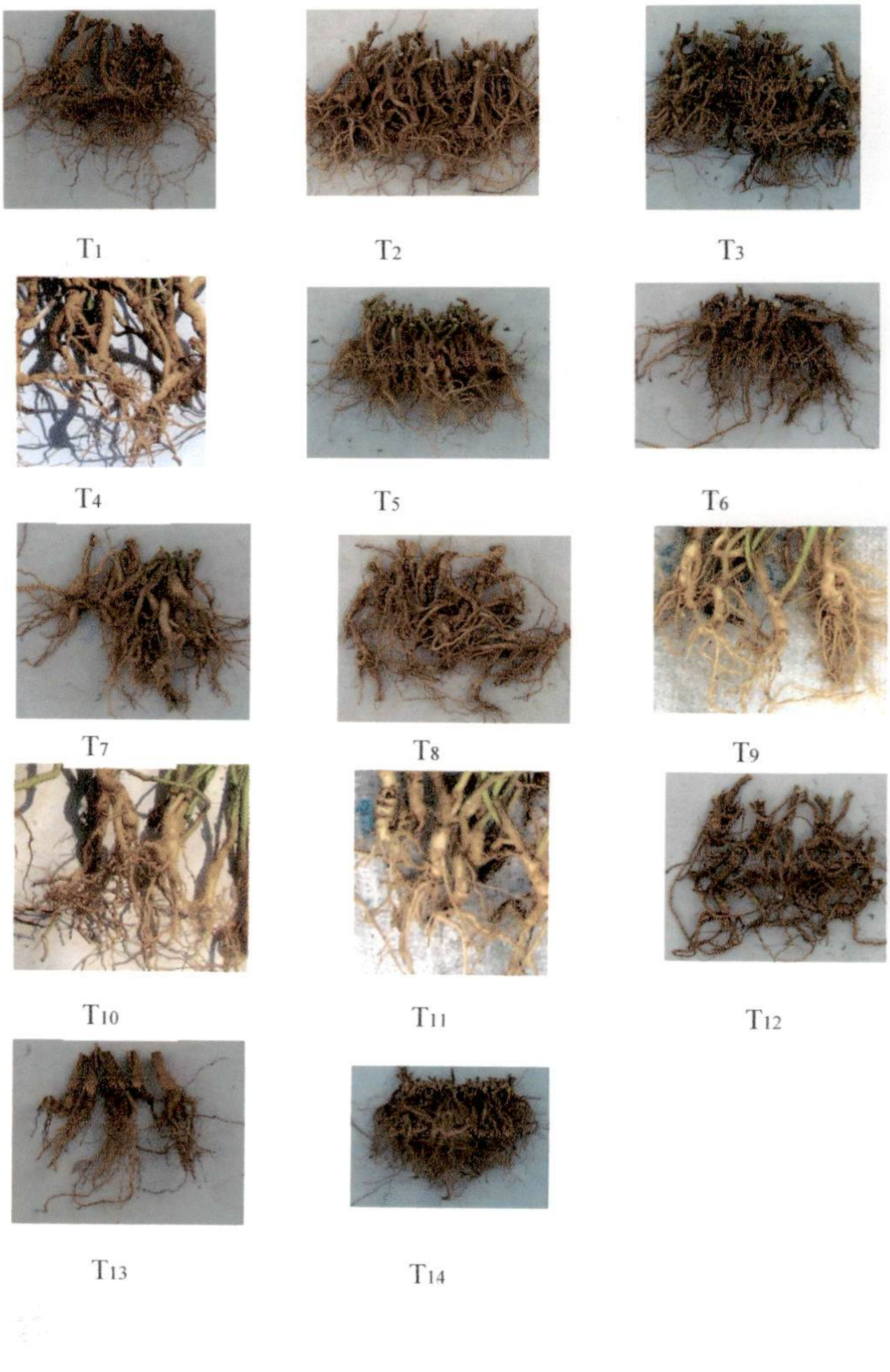


Fig. 6. Root spread (cm) of ashwagandha as influenced by INM practices and summer irrigation

Plate 3. Effect of treatments on root growth



catalytic effect in root growth promotion. It contains significant quantities of available nutrients, beneficial microorganisms, biologically active metabolites particularly gibberellins, auxins, cytokinin and group B vitamins. High surface area, low bulk density, low thermal conductivity and high porosity of coir pith make it a desirable component of the growing medium for enhancing moisture holding capacity. There are several reports about its suitability for moisture conservation (Salam *et al.*, 2004; Venkitaswamy and Khan, 2004).

Azospirillum application by seedling dip method at the time of transplanting promoted root proliferation. There are many papers related to the screening and advantages of azospirillum particularly in rice, maize and sugarcane but a few on ashwagandha.

Edaphic factors *viz.,* nutrient levels, soil moisture, penetrability and porosity play an important role in the development of root system. Appropriate combination of different sources of nutrients with organic and or inorganic sources, biofertilizers like azospirillum, secondary nutrient Mg and micro nutrient B and summer irrigation provided an ideal habitat for the accelerated development of root system.

5.3 PHYSIOLOGICAL PARAMETERS

Physiological parameters *viz.*, leaf area index, SPAD chlorophyll meter reading, root shoot ratio and stomatal conductance were significantly influenced by treatment effects. However, relative leaf water content and leaf temperature were unaffected by integrated management practices and summer irrigation.

Leaf area index is an important parameter determining crop productivity and efforts should therefore be directed towards enhancing LAI. High density planting of azospirillum inoculated ashwagandha in trenches mulched with polythene and filled with enriched growing medium followed by basal dressing of recommended dose of NPK and B and Mg application (T_6), high density planting of azospirillum inoculated ashwagandha in trenches mulched with polythene and filled with enriched growing medium followed by sequential application of vermiwash, fermented plant juice and panchagavya and B and Mg application (T_7) and high density planting of ashwagandha in trenches mulched with polythene and filled with enriched growing medium (T_1) recorded highest leaf area index, SPAD chlorophyll meter reading and root shoot ratio respectively (Fig. 8). The treatment T_6 recorded the highest leaf area index because of higher number of functional leaves and leaf area as evident from Tables 7, 8 and 28. The reasons attributed for higher functional leaf number and leaf area under sections 4.1.2 and 4.1.3 are applicable for higher leaf area as well. Highest SPAD chlorophyll meter reading was observed when liquid organic manure was substituted for recommended dose of NPK in the above treatment. Sequential application of vermiwash, fermented plant juice and panchagavya was carried out in above treatment.

Variation in leaf area index is due to changes in leaf number and or leaf size. Leaf number depends up on shoot length and rate of leaf production. Leaf size is determined by leaf number and size of cells by which the leaf is built and is influenced by light, moisture regimes and supply of nutrients (Gupta, 1975). The effect of soil moisture on rate of leaf production and leaf size is remarkable.

In general high density planting in trenches mulched with polythene and filled with enriched growing medium were found favourable for enhancing root shoot ratio towards the later stages of growth. Root shoot ratio is a function of root yield and shoot weight and variation in these parameters as influenced by treatment effects cause difference in root shoot ratio which is evident from Table 27. The reasons attributed for variations in root and shoot weight as described in sections 4.2.6 and 4.4.6 are applicable for higher root shoot ratio also. Root shoot ratio is an indication of the ability of plants for survival even under nutrient and moisture stress situations by strengthening its root system without proportionate development of shoot system. It is evident that nutrients and moisture present in the root zone decide the ratio.

Stomatal conductance was unaffected by treatment effects except at 90 DAT. Treatments exerted no significant influence on leaf temperature. However, leaf temperature varied from 34.1 ^{0}C to 39.1 ^{0}C at different growth stages. The elevation in leaf temperature could be due to decreased transpiration rate caused by water stress as against a well-watered plant which transpires at optimum level and makes the leaves cool. Increase in leaf temperature was observed by Mtui *et al.* (1981) due to moisture deficit situation. Such situation could lead to a reduction in photosynthesis resulting in lowering of total dry matter production. Nevertheless, leaf temperature alone cannot be considered as a good indicator of water stress as there was no consistent pattern of variation.

Growth indices *viz.*, crop growth rate, leaf area ratio and absolute growth rate were influenced by treatment effect at several stages of growth. T_2 (high density planting of ashwagandha seedlings in trenches mulched with polythene, T_{14} (broadcasting in trenches filled with enriched growing medium) and T_{10} (high density planting of azospirillum inoculated seedlings of ashwagandha in trenches followed by basal dressing of recommended dose of NPK and B and Mg application with summer irrigation at 30 mm CPE) in general showed higher crop growth rate, leaf area ratio and absolute growth rate respectively. Difference in these parameters were due to variations in the availability and absorption of solar radiation apart from water and nutrient intake. Leafiness is more in T_{14} due to closer spacing and consequent high population as evident from Table 29.

Chlorophyll is said to be an index of productivity, hence any alteration in chlorophyll concentration may change the morphological, physiological and biochemical behavior of the plant. The photosynthetic capability of plant increased with chlorophyll concentration.

The biomass accumulation in crop relies on inter regulation of multiple physiological processes. To regulate these processes efficiently, crops need an adequate supply of resources. Sufficient supply of nutrients stimulates metabolic activities and development so as to adapt efficiently to the nutritional status. The results reveal that applied nutrients resulted in positive responses for all the biochemical characteristics. Nitrogen is a constituent of many important biomolecules, e.g. nucleic acids, proteins certain hormones and chlorophyll. Since, large amount of chlorophyll per unit area is needed to capture solar energy efficiently, nitrogen is intimately related to photosynthesis (Lawlor, 2002). Lower rates of photosynthesis under conditions of nitrogen limitation are often attributed to the reduction of chlorophyll content (Verhoeven *et al.*, 1997; Toth *et al.*, 2002). Also, a positive correlation has been reported between nitrogen and chlorophyll content by several authors (Evans and Terashima, 1988; Menghini *et al.*, 1998). Similarly, phosphorus is an integral component of important compounds of plant cells, including the sugar-phosphate intermediates of respiration and photosynthesis and the phospholipids that constitute the plant membranes. It is also an important component of ATP (used in energy metabolism), DNA and RNA (Taiz and Zeiger, 2006). It promotes regulation of ribulose 1, 5-bisphosphate (Rao and Terry, 1989; Fredeen *et al.*, 1990), biosynthesis of ribulose-1, 5- bisphosphaste carboxylase and adenosine triphosphate (Dietz and Foyer, 1986) and assimilation of carbondioxide (Longstreth and Nobel, 1980). Thus, directly or indirectly N is helpful in enhancing the photosynthetic process of the plants. A significant increase in chlorophyll content due to nitrogen and phosphorus application has infact, been observed by Thapar *et al.*, (1990), Lopez Cantarero *et al.* (1994), Shubhra *et al.* (2004) and Prsa *et al.* (2007) in several plants suggesting that the biosynthesis of the pigment molecules was dependent on the uptake of N and P within optimum limits.

5.4 TOTAL DRY MATTER PRODUCTION

Treatment effects on biomass accumulation were found remarkable. Leaf, stem, root, berries and total dry matter production were found to be significantly influenced by integrated nutrient management practices and summer irrigation. High density planting of azospirillum inoculated ashwagandha seedlings in trenches mulched with polythene and filled with enriched growing medium and combined with recommended dose of NPK and B and Mg and summer irrigation

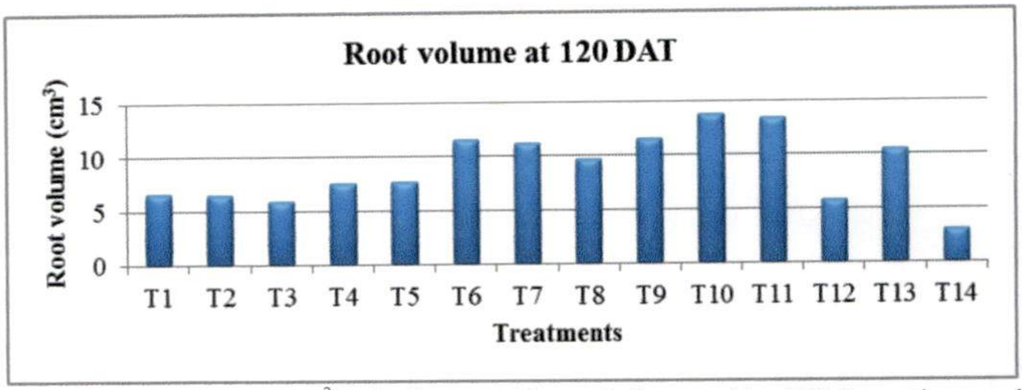


Fig. 7. Root volume (cm^3) of ashwagandha as influenced by INM practices and summer irrigation

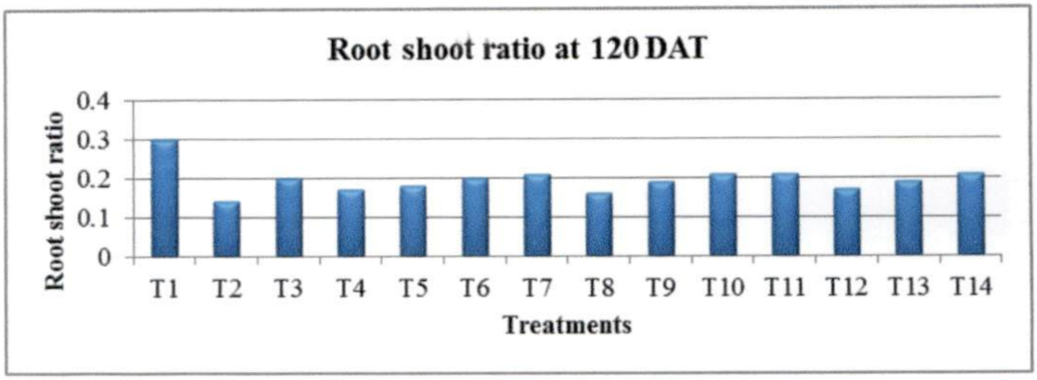


Fig. 8. Root shoot ratio of ashwagandha as influenced by INM practices and summer irrigation

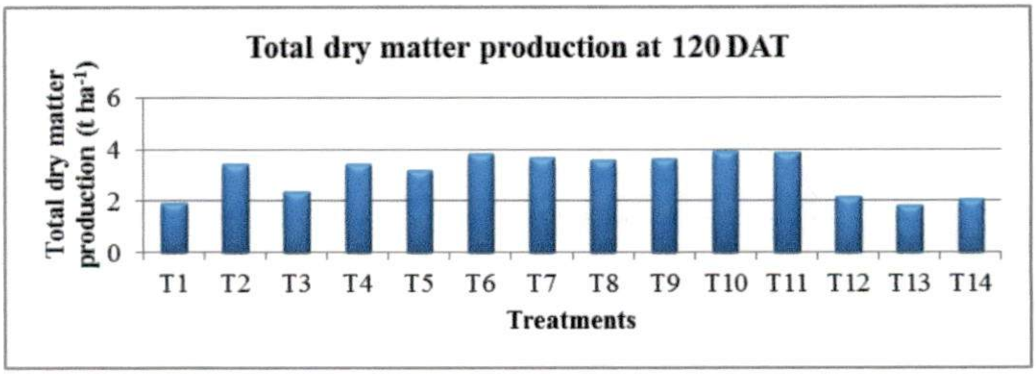


Fig. 9. Total dry matter production ($t\ ha^{-1}$) as influenced by INM practices and summer irrigation

at 30 mm CPE resulted in higher total dry matter production to the tune of 3.95 t ha^{-1} which was 47.59 per cent higher compared to broadcasting in trenches filled with enriched growing medium (T_{14}) (Fig. 9).

The influence of geometry of planting on total dry matter production was considerable in T_{10} (high density planting of azospirillum inoculated seedlings of ashwagandha in trenches followed by basal dressing of recommended dose of NPK and B and Mg application with summer irrigation at 30 mm CPE) compared to T_{14} (broadcasting in trenches filled with enriched growing medium) and the increase in total dry matter production was the tune of 1.88 t ha^{-1}. Available evidence indicate the significance of high density planting coupled with azospirillum inoculation, N, P, K, B and Mg incorporation and summer irrigation at wider interval in enhancing total dry matter production. Application of azospirillum in high density planting combined with N, P, K, Band Mg incorporation contributed to increased plant height, number of functional leaves, leaf area, leaf area index, number of branches etc. as evident from Tables 6, 7, 8, 28, 9 and sections 4.1.1, 4.1.2, 4.1.3, 4.4.9 and 4.1.4. This has resulted in a corresponding increase in the number of functional leaves which in turn increased the leaf area index. Higher leaf area index equipped the inoculated plants for better utilization of solar energy for growth and development which again contributed to higher production. Azospirillum, a micro-aerophilic bacterium is known to enter into associative symbiosis and lives inside the cortical cells and xylem vessels of plants and thus serve as an *in situ* nitrogen fixer (SubbaRao, 1979).

Increase in leaf, stem and root dry matter could be attributed to the effective functioning of azospirillum which produced bio-active substances showing similar effect as that of growth regulators, which helped in better uptake and utilisation of nutrients for promoting plant growth. The results are in conformity with the findings of Ramesh Babu (1996) in ashwagandha, Ravi (2004) in coleus and Velmurugan *et al.* (2008) in turmeric. The highest total dry weight per plant could be attributed to the promotion of growth and yield attributes due to greater uptake of nutrients into the plant system under the influence of biofertilizers. These are similar to the findings of Mahendran and Kumar (1998) in potato, Mahantesh (2002) in onion and Suja *et al.* (2005) in cassava.

Combined application of manures and fertilizers exhibited highest nutrient uptake. Improvement of soil physical condition due to addition of organic manures might have resulted in better root growth so that the roots could explore more volumes of soil and ultimately higher uptake of nutrients. In addition, use of bio fertilizers may also favourably influence the root, root growth, crop stand and crop maturity to a certain extent. The higher yield due to integration of organic manures could be due to the higher yield attributing characters like root length, girth, higher dry matter production and higher supply of nutrients, favourable physical and biological environment in the soil leading to better root activity and nutrient absorption (Krishnappa *et al.,* 1999; Mehra, 2004). As ashwagandha is a root crop, improvement of soil physical environment might have helped in better development of roots.

The dry matter production was reduced in T_{14} (broadcasting in trenches filled with enriched growing medium) due to the effect of nutrient and water stress consequent to higher plant population. Water deficit generally have negative effects on dry matter production in plants as it impairs many of the physiological process which determine growth. The reduction in dry matter production could be due to the decrease in plant characters like leaf area, leaf dry weight, stem dry weight, root dry weight etc. which are positively correlated with total dry matter production.

The growth of a plant is influenced by metabolic activities which require adequate amount of nutrients and moisture. Growth characters, root attributes and physiological parameters revealed that ashwagandha responded very well to different management practices.

The increase in vegetative growth with the optimum dose of fertilizers might be due to the effective role of the balanced amount of the nutrient elements in enhancing plant growth and development. It is well known that the root and shoot morphogenesis of plant species is affected by the level and form of the fertilizer applied (Albregts *et al.*, 1991). The positive effects of N and P may be explained on the basis of the fact that N, in addition to its important role in cell division and cell expansion (Gastal and Lemarie, 2002) and functions as a necessary component in several key bio-macromolecules (Menghini *et al.*, 1998; Lawlor, 2002; Taiz and Zeiger, 2006). It is therefore, required by all parts of the plant, particularly the meristematic tissues and the metabolically active cells. Similarly, P is a constituent of cell membranes, a number of proteins, all nucleic acids and nucleotides. Besides, P is involved in controlling key enzyme reactions and in the regulation of metabolic pathways (Theodorou and Plaxton, 1993; Schachtman *et al.*, 1998).

Yield is the final manifestation of several intricate morphological and physiological traits, which initiate at germination and terminate at harvest. Thus, better yields are obtained by encouraging vegetative growth which is influenced by various management practices, including efficient use of fertilizers. In the present study, application of NPK or liquid organic manure, azospirillum and boron and magnesium proved effective in maximizing most of the yield attributing traits (Table 12, 13. 14, 15, 16 and 17 and Fig. 4, 5, 6, 7, 10 and 11).

Improvement in leaf area (Table 8), on the one hand and total leaf chlorophyll content (Table 23) on the other, seems to be mainly responsible for the observed parallel increase in the various yield characteristics studied. Apparently, the greater the surface area of the leaf, the better equipped it would be to harvest radiant energy and to produce more photosynthates and hence higher dry weight of the treated plants (Table 25). The sustained improvement in yield characteristics might have culminated in the maximization of sink (Table 17). Similar beneficial effect of nutrients have been reported by Murage *et al.* (1996), Maitra *et al.* (1998), Muthumanickam and Balakrishnamurthy (1999), Kaushal *et* *al.* (2002), Muthumanickam *et al.* (2002), Aishwath (2004), Puttanna *et al.* (2005) and Panchbhai *et al.* (2006). The agronomic manipulations and practices aimed at improving the yield of roots through optimizing source-sink ratio are of more practical significance.

Shukla and Shukla (2012) reported that the plant of ashwagandha is more efficient to use solar radiation and soil nutrient when it is planted at closer spacing. Pakkiyanathan *et al.* (2004) found that weight of dry root yield per plot and per hectare is significantly affected by plant geometry. The crop yield per unit area is a function of plant density and per plant yield. With increase in the number of plants per unit area, the crowding coefficient of plant community also increases which leads to decrease in freeness to the individual plant and increase in competition for growth factors from effective root zone. In the present investigation, higher root yield per unit area recorded in broadcasting (closer spacing) accrued primarily due to the increase in plant population, despite compromise in per plant yield. The differences in total biomass production among different treatments could be due to differential production of total dry matter (TDM) per plant.

In many plants, it is not only the total dry matter production which is of importance, but its partitioning in to the economic part is also significant. Partitioning of the photosynthates and the source-sink relationships and its controlling mechanisms are, therefore, of crucial importance in crop production. Dry matter production and its distribution in various plant parts differed significantly due to treatment effects at all the stages (Fig. 12).

5.5 QUALITY

Total crude alkaloid content (Table 32 and Fig. 13) was found favorably influenced by INM practices and summer irrigation. Nitrogen is an essential constituents of alkaloids, enzymes etc. Similarly, phosphorus is an essential constituent of majority of enzymes and is involved in the transformation of energy. The observed advantages of nutrient application on total alkaloid content

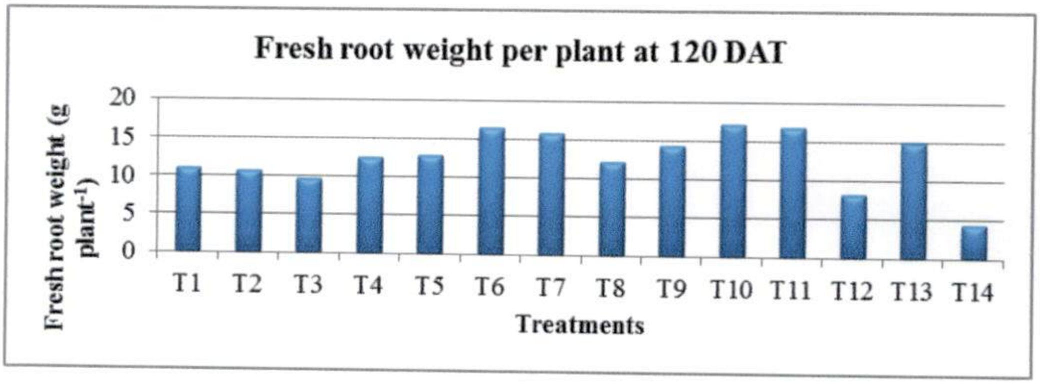


Fig. 10. Fresh root weight (g plant^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

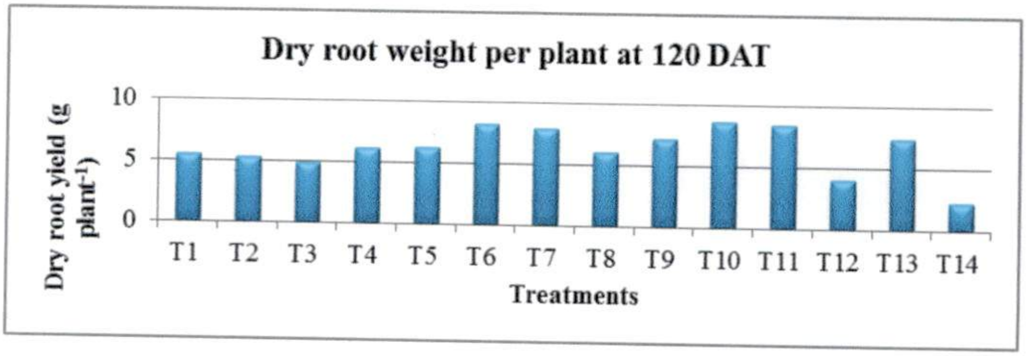


Fig.11. Dry root weight (g) of ashwagandha as influenced by INM practices and summer irrigation

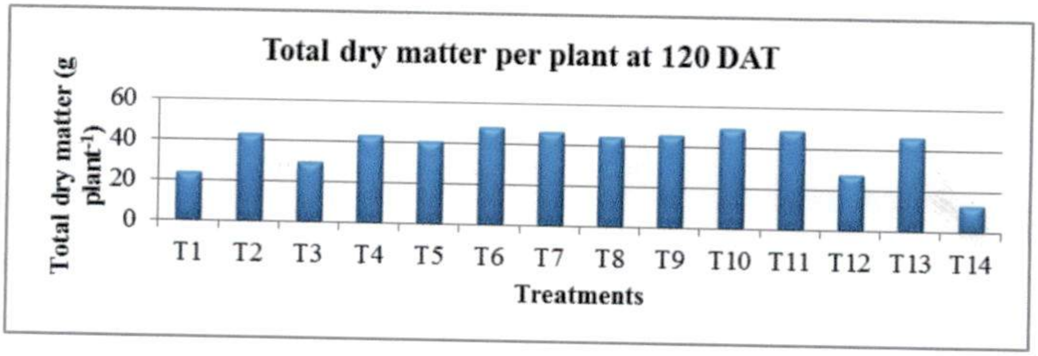


Fig. 12. Total dry matter (g plant^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

of ashwagandha are in conformity with the findings of earlier works in this regard (Shetty *et al.,* 1990; Maitra *et al.*, 1998; Ajay *et al.*, 2005; Panchbhai *et al.*, 2006).

5.6 SOIL MOISTURE STUDIES

Among the different planting methods high density planting of azospirillum inoculated seedlings with sequential application of liquid organic manures along with incorporation of B and Mg and summer irrigation at 15 mm CPE (T_9) recorded the highest soil moisture content before irrigation which was on par with T_8 where NPK was added instead of sequential application of organic manure (T_8). However, none of the treatments was effective in enhancing soil moisture content after irrigation.

Polythene mulching in trenches prevented percolation and seepage losses. Moreover the enriched growing medium provided favourable conditions for improving water holding capacity of the rooting medium. As there was conservation of stored moisture due to prevention of seepage and percolation and consequent improvement in water holding capacity, there was considerable increase in soil moisture storage which reflected in higher values. The beneficial effects of growing medium in improving soil moisture storage are discussed in detailed in section 4.7.

Seasonal consumptive use and mean daily consumptive use ranged from 145.73 mm to 250.80 mm and 1.22 mm to 2.09 mm respectively (Fig. 14 and 15). The highest values were recorded when ashwagandha was broadcasted in trenches filled with enriched growing medium. Mean daily consumptive use varied from 1.22 mm to 2.09 mm. Summer irrigation at 30 mm CPE resulted in higher yield because under irrigated condition, ashwagandha never faced water stress unlike rainfed condition. Water stress is likely to affect two vital processes of crop *viz*., cell division and cell enlargement resulting in poor growth under rainfed condition. The favourable influence of higher levels of irrigation might be due to stimulation of metabolic activities resulting in better growth of ashwagandha.

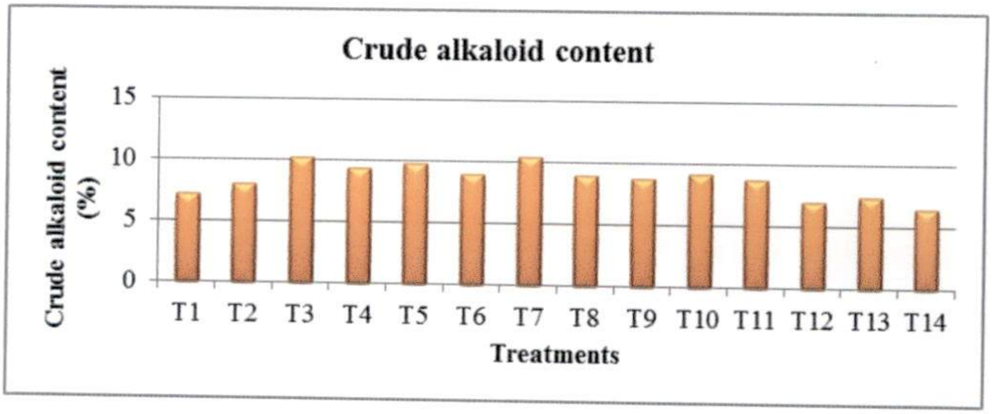


Fig. 13. Crude alkaloid content (%) of ashwagandhaas influenced by INM practices and summer irrigation

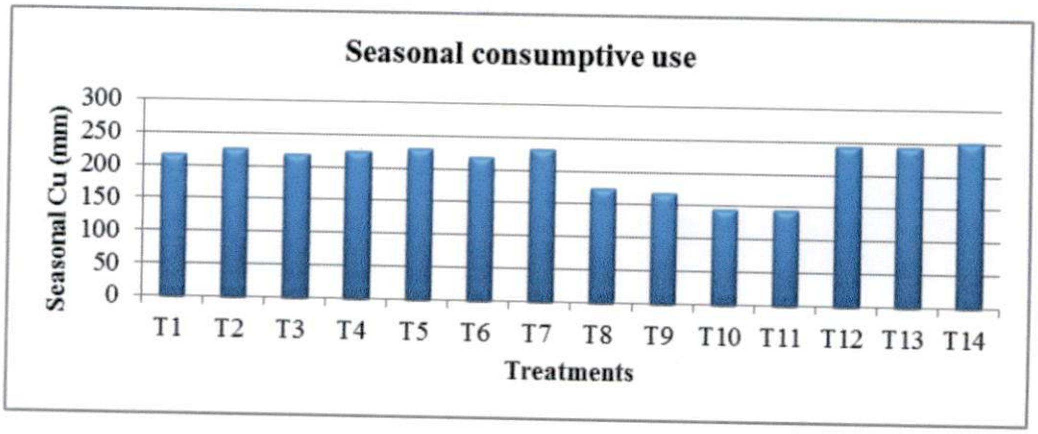


Fig.14. Seasonal consumptive use (mm) of ashwagandha as influenced by INM practices and summer irrigation

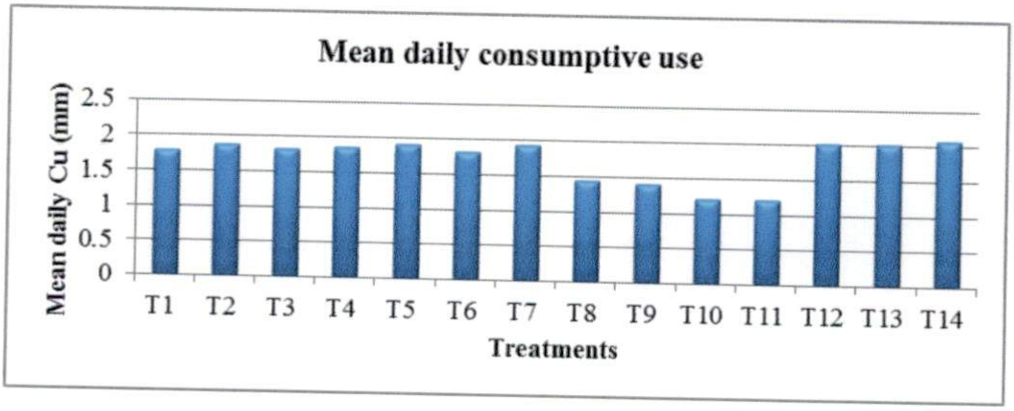


Fig. 15. Mean daily consumptive use (mm) of ashwagandha as influenced by INM practices and summer irrigatio

Irrigation at lower CPE tends to bring the soil to field capacity more frequently resulting favourable soil moisture regime for ashwagandha growth.

5.6.1 WATER USE EFFICIENCY

The results revealed the superior performance of the treatment T_{10} on par with T_{11} with respect to crop water use efficiency (Fig. 16). This was mainly due to the increase in yield and decrease in seasonal consumptive use when compared to other treatments. Water use efficiency decreased with increase in the level of irrigation. It is likely to increase with decrease in soil moisture supply until it reaches the maximum critical level because plant may actively try to economise water use in the range from minimum critical to optimum moisture level. Water above the optimum level may be lost in the form of excessive evaporation, transpiration or even as deep percolation.

5.7 CONTENT AND UPTAKE OF NUTRIENTS

Significant variations were observed with respect to N, P, K and B contents in the plant. N, P and K contents ranged from 1.3 to 2.75 %, 0.26 to 0.31 % and 1.49 to 2.77 % respectively. Boron concentration varied 5.09 to 10.44 mg L^{-1} and magnesium from 0.11 to 0.12 %. The highest values of N and P were observed when basal application of NPK was carried out as the part of integrated nutrient management strategy. Whereas sequential application of vermiwash, fermented plant juice and panchagavya was favourable for enhancing potassium uptake which indicate higher availability of potassium from the different organic sources. Boron application had profound influence in enhancing boron concentration in ashwagandha.

Quantitative expression of nitrogen uptake is the product of nutrient content of plant tissue and total dry matter. The highest nutrient status and uptake in plants were observed in T_6 (high density planting of azospirillum inoculated ashwagandha was carried out in trenches mulched with polythene and filled with

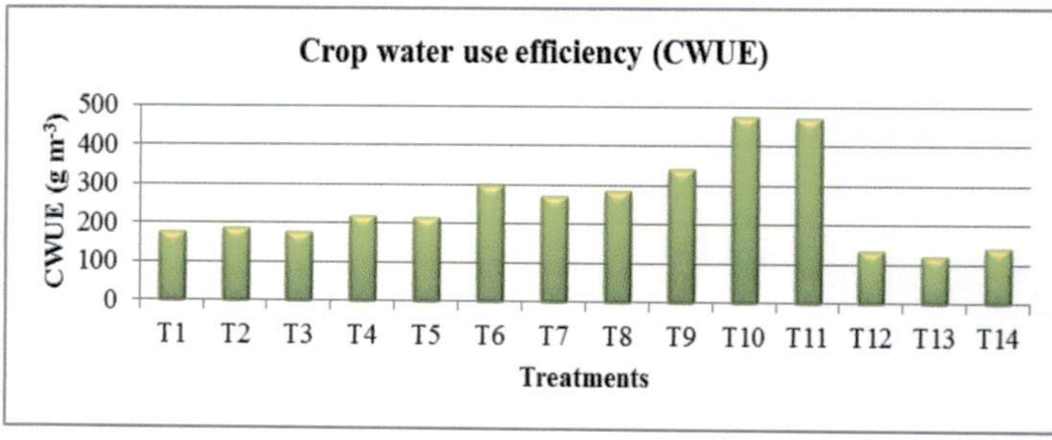


Fig. 16. Crop water use efficiency (g m^{-3}) of ashwagandha as influenced by INM practices and summer irrigation

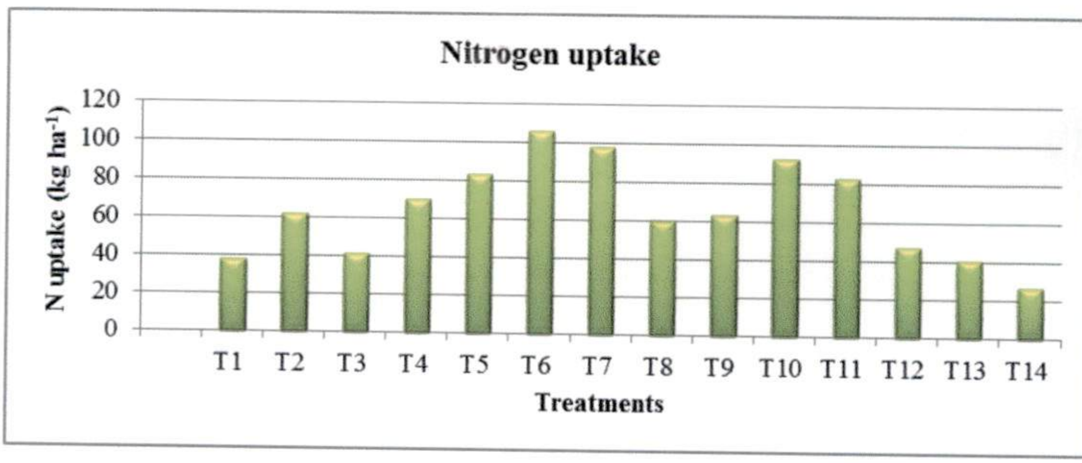


Fig. 17. Total nitrogen uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

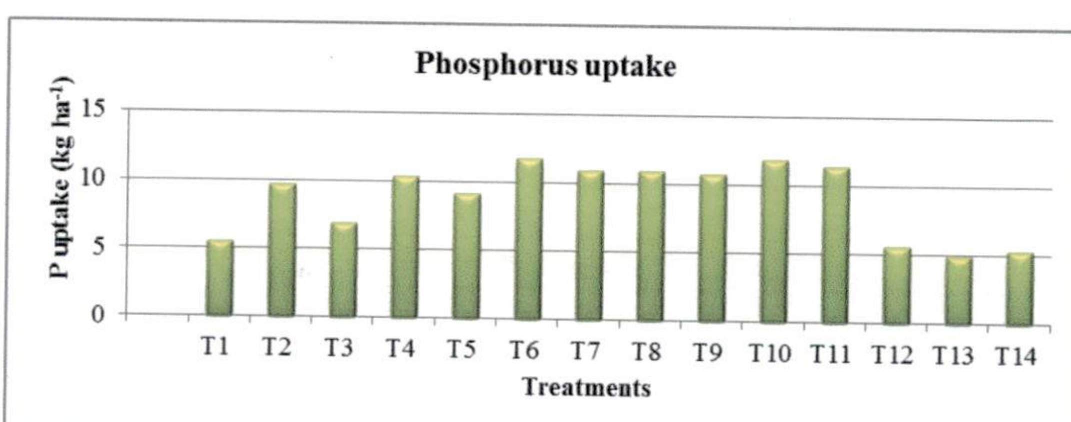


Fig. 18. Total phosphorus uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

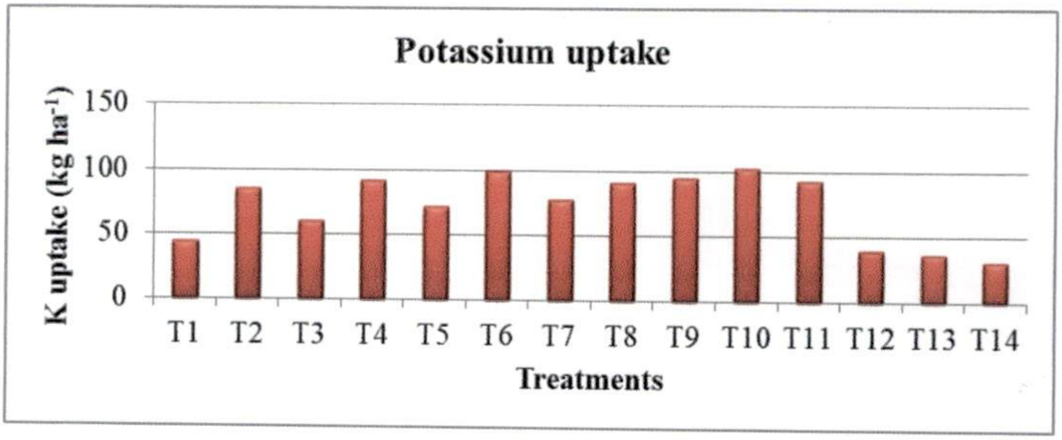


Fig. 19. Total potassium uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

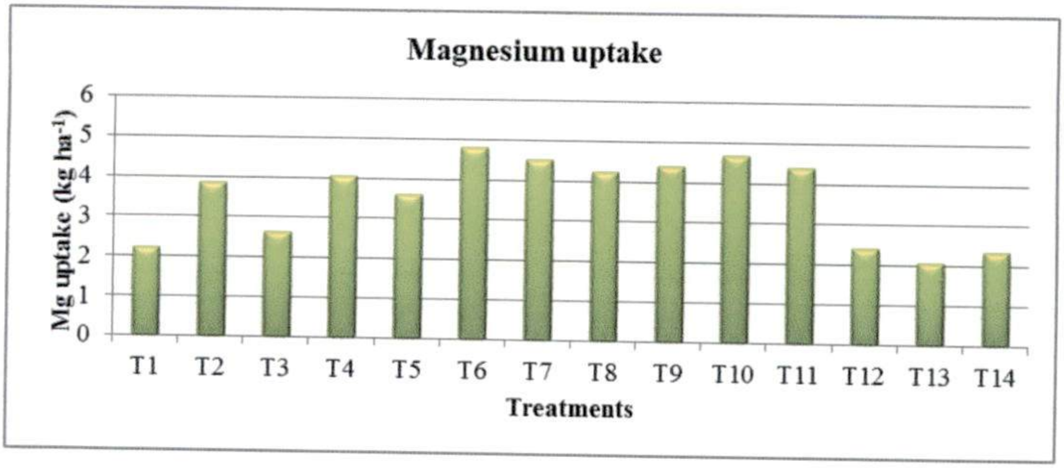


Fig. 20. Total magnesium uptake (kg ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation

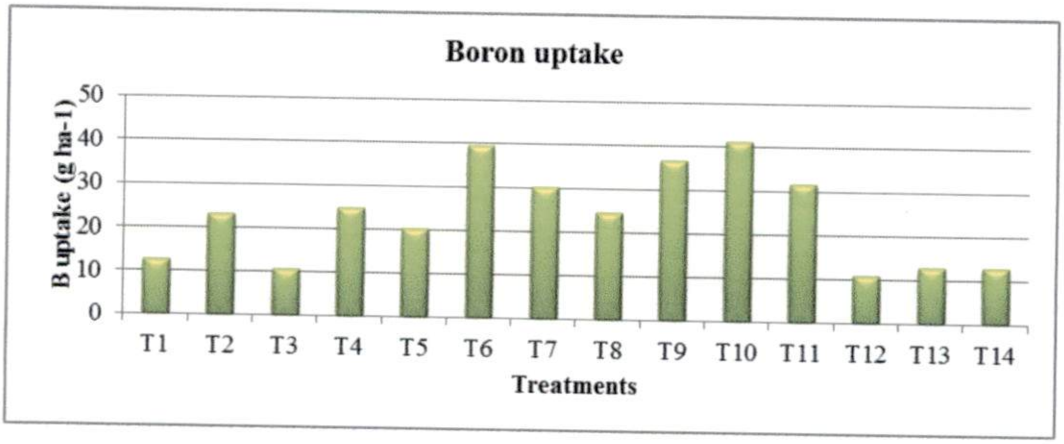


Fig. 21. Total boron uptake (g ha^{-1}) of ashwagandha as influenced by INM practices and summer irrigation.

enriched growing medium followed by basal dressing of recommended dose of NPK and B and Mg application) which helped in better availability and absorption of nutrients by the plants (Fig. 17, 18, 19, 20 and 21). The greater uptake of nutrients can also be related to higher dry matter production due to greater accumulation of metabolites. These results are in confirmation with the findings of Mahendran and Kumar (1998) in potato, Suja *et al.* (2005) in cassava and Kalyanasundaram *et al.* (2008) in sweet flag.

The positive effect of basal application of nutrients might be due to the adequate supply of these nutrients ensuring their continuous absorption by roots, followed by smooth translocation to the shoot. This would result finally in their satisfactory distribution throughout the foliage. An increase in the leaf N, P and K content as a result of application of fertilizers has also been noted by Singh and Ram (1992), Hayat *et al.* (1996), Hocking *et al.* (1997), Parmar *et al.* (1999), Alloush *et al.* (2000), Khan *et al.* (2000), Singh and Verma (2002), Khiriya and Singh (2003), Naeem and Khan (2005) and Naeem *et al.* (2009).

Summary

6. SUMMARY

An experiment entitled, 'Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)' was conducted at the Instructional farm attached to the College of Agriculture, Padannakkad during 2015-17 to study the effect of integrated nutrient management practices and summer irrigation for enhancing root production and quality constituents in ashwagandha. The experiment was laid out in RBD with 14 treatments. The treatments were T_1 - HDP in trenches mulched with polythene and filled with enriched growing medium, T_2 - T_1 + Recommended dose of NPK, T_3 - T_1 + Liquid organic manures, T_4 - T_2 + azospirillum, T_5 - T_3 + azospirillum, T_6 - T_4 + B and Mg, T_7 - T_5 + B and Mg, T_8 - T_6 + Summer irrigation at 15 mm CPE, T_9 - T_7 + Summer irrigation at 15 mm CPE, T_{10} - T_6 + Summer irrigation at 30 mm CPE, T_{11} - T_7 + Summer irrigation at 30 mm CPE, T_{12} - HDP in trenches filled with enriched growing medium, T_{13} - NRP in trenches filled with enriched growing medium, T_{14} - Broadcasting in trenches filled with enriched growing medium.

Important results obtained and conclusions drawn out from the investigations are summarized hereunder.

- Treatments significantly influenced plant height at all stages of growth. The treatment T_4 recorded significantly higher plant height at 45 DAT. T_6 registered higher plant height at all other stages of crop growth.
- Similar to plant height, significant effect of treatments on functional leaf number was observed throughout the period of crop growth. The treatment T_1 registered highest functional leaf number at 45 DAT. The treatments T_3, T_4, T_9 and T_1 showed higher values at 60, 75 and 90 DAT respectively. T_6 at both the stages 105 and 120 DAT recorded higher functional leaf number.
- INM practices and summer irrigation were found significantly influence the leaf area throughout the period of crop growth. T_1 at 45

DAT; T_3 at 60 DAT; T_4 on par with T_{13} at 75 DAT; T_1 at 90 DAT; T_6 at 105 DAT and T_6 at 120 DAT recorded significantly higher values.

- The treatments did not exert any significant effect on primary, secondary and tertiary branches at any of the growth stage. However higher number of primary branches were recorded by T_7
- The treatments had no significant on primary root number during early stages of growth (45 DAT and 60 DAT). However the treatments T_2, T_4 and T_6 and T_2 and T_6 recorded highest values of 2.75 and 3.75 at 45 DAT and 60 DAT respectively. The effect of treatments was evident from 75 DAT onwards. T_{10} at 75 DAT; T_9 at 90 DAT; and T_8, at 105 DAT and 120 DAT recorded higher primary root number.
- Root length was found to be significantly influenced by treatments at all growth stages of crop. T_6 recorded significantly higher value at 45 DAT. At 60, 75 and 90 DAT the longer root was showed by T_{10}. At 105 and 120 DAT, the treatment T_8 and T_{10} registered the greatest length.
- Significant influence of treatment on root spread was observed at all growth stages. The treatment T_6 at 45 DAT and 60 DAT recorded higher values. The performance of the treatment T_{11} was found to be significantly superior at 75 DAT, 90 DAT and 120 DAT.
- Effect of treatments on root volume was found to be remarkable at all stages of growth. T_3 showed greater value of 3.3 cm^3 and 7.7 cm^3 at 45 and 75 DAT respectively. At 75 DAT the performance of the treatment T_{11} was found superior. T_{10} registered highest root volume at 90, 105 and 120 DAT.
- Significant influence of treatment on fresh root weight was observed at all stages of growth. T_3 at 75 DAT registered the highest fresh root weight per plant. From 90 DAT onwards T_{10} showed remarkable influence on fresh root weight per plant.

- Dry root weight per plant also showed significant difference due to treatment effects and it followed a similar trend as that of fresh root weight per plant.
- The remarkable influence of treatment on fresh and dry root production per hectare was observed at 120 DAT. T_{10} recorded the highest fresh and dry rot yield of 1377 and 688.8 kg per hectare respectively. The lowest fresh and dry root yield of 600 and 295.2 kg ha^{-1} were recorded by T_{13}.
- Treatments had significant effect on seed yield per plant and T_6 recorded the highest seed yield of 6.75 g seed per plant which was 66.67 per cent higher compared to T_{14}.
- Seed yield per hectare was also found to be significantly influenced by treatment effects. The treatment T_6 recorded the highest seed yield per hectare.
- The treatments had no significant effect on relative leaf water content at any of the growth stages.
- Similar to relative leaf water content, treatments had no significant effect on leaf temperature at any of the crop growth stage.
- The treatment effect was remarkable at 90 DAT and the treatments T_8 recorded the highest stomatal conductance of 180.50 mmol m^{-2} s^{-1}.
- The treatment effect on SCMR was insignificant at 45 DAT, 75 DAT, 90 DAT and 105 DAT. However, it was significant at 60 and 120 DAT and T_7 showed the highest values.
- Dry matter production showed significant difference at all stages of growth except at 45 DAT due to treatment effect. At 60 DAT, highest dry matter production of 2.214 t ha^{-1} was recorded by T_7. From 90 DAT onwards the treatment T_{10} showed higher values. The highest dry matter production of 3.13, 3.92 and 3.949 t ha^{-1} was registered by T_{10} at 3, 3.5 and 120 DAT respectively.

- T_6, T_{11}, T_{10}, T_6 and T_{10} recorded higher leaf, stem, root, berries and total dry matter production at the time of harvest. Dry matter production of 4.32 g, 28.47 g, 8.61 g and 8.75 g were recorded by leaf, stem, root and berries respectively. Total dry matter production was 49.36 which on par with T_{11} and T_6. It was 73.81 per cent higher compared to T_{14}.
- Profound influence of treatment was observed on per cent distribution of dry matter into leaf, stem, root and berries. T_1 showed the highest distribution of dry matter for root production and it differed significantly from all other treatment. Distribution of dry matter for root production ranged from 12.33 to 22.79 per cent. Contribution of total dry matter production to berries varied from 16.89 to 32.86 per cent.
- Significant effect of treatments on root shoot ratio was found at all stages of growth. T_4 at 60 DAT showed the higher root shoot ratio. At 90 DAT root shoot ratio of 0.246 was recorded by T_{10}. T_1 at later stages of growth that is 105 and 120 DAT registered higher values.
- T_1 at 45 DAT and 90 DAT; T_{14} at 60 DAT; T_4 at 75 DAT and T_6 at 105 DAT and 120 DAT showed higher values of LAI of 0.577, 0.833, 1.061, 1.484, 0.597 and 0.461 respectively.
- Treatments did not exert any significant effect on leaf area ratio at 45 DAT. From 60 DAT onwards the effects of treatments were evident on leaf area ratio. T_{14} at 2 and 75 DAT, T_1 at 90 DAT, T_{14} at 105 DAT and T_1 at 120 DAT recorded significantly higher leaf area ratios. The highest leaf area ratio of 122.43 $cm^2\ g^{-1}$ was observed at 60 DAT. From 60 DAT onwards there was gradual decline in leaf area ratio.
- The treatments exerted profound influence on absolute growth rate at 60 DAT and 75 DAT. Absolute growth rate at 45 to 60 DAT ranged from 0.42 to 1.24 cm day^{-1} and T_{10} recorded the highest AGR of 1.24 cm day^{-1}. At 60 to 75 DAT, T_{13} was significantly different from all

other treatments. From 90 DAT onwards, absolute growth rate was insignificant due to treatment effect.

- At 45 to 60 DAT crop growth rate ranged from 2.83 to 12.15 g m^{-2} day^{-1} and the highest value was recorded by T_7. At 75 to 90 DAT, T_2 registered the highest crop growth rate of 10.62 g m^{-2} day^{-1}. At 90 to 105 DAT, T_9 recorded the highest crop growth rate of 5.21 g m^{-2} day^{-1}.
- Total crude alkaloid content ranged from 6.5 % to 10.4 %. The highest crude alkaloid content of 10.54 % was registered by T_7. Other biochemical parameters namely total sugar and total amino acid content were not at all influenced by treatment effects.
- Azospirillum population ranged from 11.5 x 10^5 to 64 x 10^5 per gram dry soil. The highest population of 64 x 10^5 per gram dry soil was registered by the treatments T_8.
- Before irrigation, soil moisture content ranged from 10.3 to 13.35 % indicating the highest moisture content in T_9. However, treatment had no significant effect on moisture content after irrigation.Seasonal consumptive use and mean daily consumptive use were found to be significantly influenced by treatment effect. Seasonal consumptive use and mean daily consumptive use ranged from 145.73 mm to 250.80 mm and 1.22 to 2.09 mm respectively and T_{14} registered the higher values.
- The highest crop water use efficiency of 474.78 g m^{-3} was recorded by T10. Field water use efficiency varied from 84.46 to 222.31 g m^{-3} and the highest value was recorded by T_6. The treatment which recorded highest value of field water use efficiency also registered the highest water productivity of 1313.467 g m^{-3} and it differed significantly from all other treatments.
- Nitrogen content ranged from 1.3 to 2.75 %. The highest nitrogen content was recorded by T6. Phosphorus content also varied from 0.26 to 0.31 % and the highest content was registered by T_8. Potassium content was highest in T_9 and ranged from 1.49 to 2.77 %. Magnesium

content ranged from 0.11 to 0.12 %. Boron concentration varied from 5.09 to 10.44 mg L^{-1} and the highest content was registered by T_{10}.

- INM practices and summer irrigation remarkably influenced the total uptake of all the nutrients (N, P, K, B and Mg). Total uptake of nitrogen ranged from 26.85 to 106.07 kg ha^{-1} and the highest uptake was registered by T_6. Phosphorus uptake varied from 4.94 to 11.85 kg ha^{-1} and the highest uptake was registered by T_{10}. The highest total uptake of potassium, boron and magnesium was registered by T_{10}.
- INM practices and summer irrigation had remarkable influence on N, P, K, B and Mg status of soil after the experiment. Soil nitrogen ranged from 163.07 to 275.97 kg ha^{-1}. The highest nitrogen content was recorded by T_2. Soil phosphorus ranged from 56.56 to 103.04 kg ha^{-1} and T_4 registered the highest value. Potassium content ranged from 130.20 to 387.80 kg ha^{-1} and T8 recorded the highest value. T_{11} registered the highest boron content of 6.910 g ha^{-1}. Like other elements, magnesium content also varied significantly. T_7 recorded the highest value.
- T_9 recorded the highest cost of cultivation of 58844 ₹ and T_{14} recorded the lowest. Gross income ranged from 124544 to 263296 ₹ and T_{10} registered the highest value. Net income also showed a similar trend and it ranged from 47938 to 170088 ₹. Benefit cost ratio varied from 1.63 to 2.83. T_{10} registered the highest benefit cost ratio of 2.83.

References

7. REFERENCES

Agarwal, M., Singh, P., and Agarwal, M.K. 2004. Effect of sowing dates and spacing on yield attributes and root yield of Ashwagandha. *J. Med. Plant Sci*. 26: 473-474.

Aishwath, O. P. 2004. Mineral nutrition and growth of *Withania somnifera*. *J. Trop. Med. Plants*. 5: 111–118.

Ajay, P., Ramesh, K., Reddy, K. S., Ramana, S. and Maji, B. 2005. Effect of nitrogen and farm yard manure on physiological parameters in ashwagandha (*Withania somnifera*) under vertisol soil type. *Indian J. Plant Physiol.* 10: 389–393.

Albregts, E.E., Howard, C.M., and Chandler, C.K. 1991. Slow release fertilizers for strawberry fruit production. *Proc. Florida State Hort. Sci.* 104: 244–245.

Al-Doghachi, E.H.A., Hassan, A.R.O., and Faris, N.N. 2016. Response of ashwagandha (*Withania somnifera* L.) to sowing dates and organic liquid fertilizer (Vit ORG). *Asian J. Plant Sci. and Res.* 6(1): 1-7.

Alexander, M. 1965. Most probable number method for microbial population. In: Black, C. A. (ed.), *Methods of Soil Analysis, Part 2 – Chemical and Microbial Properties*. American society of agronomy Inc. Madison, Wisconsin, U. S. A., pp.1462- 1472.

Allolli, T.B., Hulihalli, U.K., and Athani, S.I. 2008. Influence of in situ moisture conservation practices on the performance of dryland chilli. *Karnataka J.Agric.Sci.* 21(2): 253-255.

Alloush, G. A., Zeto, S. K., and Clark, R. B. 2000. Phosphorus source, organic matter, and arbuscular mycorrhiza effects on growth and mineral acquisition of chickpea grown in acidic soil. *J. Plant Nutr*. 23(9): 1351-1369.

Ansari, A.A. 2008. Effect of vermicompost and vermiwash on the productivity of spinach (*Spinacia oleracea*), onion (*Allium cepa*) and potato (*Solanum tuberosum*). *World J. Agric. Sci*. 4(5): 554-557.

Ansari, A.A. and Kumar, S. 2010. Effect of vermiwash and vermicompost on soil parameters and productivity of okra (*Abelmoschus esculentus*) in Guyana. *Curr. Adv. in Agric. Sci.* 2(1): 1-4.

Anusha, A. N. 2013. Multiple cropping and microsite enrichment in vetiver (*Chrysopogon zizanioides* (L.) Nash. MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 124p.

Araújo, A. P., TEIXEIRA, M. G., and ALMEIDA, D. L. D. (2000). Growth and yield of common bean cultivars at two soil phosphorus levels under biological nitrogen fixation. *Pesquisa Agropecuária Brasileira*. 35(4): 809-817.

Arumugan, T., Doraipandian, A., Premalakshmi, V., and Kumar, V. 2001. Studies on the effect of biofertilizer on biomass production in senna (*Cassia angustifolia* vahl.). *S. Indian Hort*. 49: 178-179.

Ayyobi, H., Hassanpour, E., Alaqemand, S., Fathi, S., Olfati, J.A. and Peyvast, G. 2014. Vermicompost Leachate and Vermiwash Enhance French Dwarf Bean Yield. *Int. J. Veg. Sci.* 20(1): 21-27.

Babu, N. 2002. Response of foliar application of boron on vegetative growth, fruit yield and quality of tomato var. Pusa Ruby. *Indian J. Hill Farming*. 15(1): 109-112.

Baby, U.I., Baliah, N.T., Ponmurugan, P., and Premakumar, R. 2002. Effect of *Azospirillum* on nursery grown tea plants. Proceedings of the 15th Plantation crops Symposium Placrosym XV, Mysore, India pp: 369-374.

Barche, S., Kirad, S.K., and Tomar, R.K.S. 2010. Response of Ashwagandha to organic manure and Biofertilizers. Abstracts 97th Indian Science Congress pp: 102.

Begg, J. E. and Turner, N. C. 1976. Crop water deficit. *Advan. Agron*. 28: 161-207.

Behera, M.S., Mahapatra, P.K., Verma O.P., Singandhupe, R.B., and Kumar, A. 2012. Productivity, quality and economics of Ashwagandha (Withania somnifera) as influenced by irrigation and fertility levels under drip irrigation system. Indian J. Agron. 57(2): 195-199.

Behera, M.S., Mahapatra, P.K., Singandhupe, R.B., Kundu, D.K., Kannan, K., and Singh, A. 2014. Effect of drip fertigation on growth,seed and root yield of ashwagandha [*Withania somnifera* (L.) Dunal]. *Indian J. Plant physiol.*19(3): 281-286.

Bhagavantagoudra, K.H. and Rokhade, A.K. 2002. Economics of *Azospirillum* inoculation to cabbage. *Karnataka J. Agric. Sci.* 15(2): 413-415.

Bingham, F.T., 1982. Boron. In: Page, A.L., Miller, R.H., and Keeney, D.R. (eds.), *Methods of Soil Analysis.* Part 2. Chemical and microbiological properties. Agronomy Monograph No. 9 (2nd Ed.). SSSA, Madison WI, USA, pp: 431-447.

Black, C.A. 1965. *Methods of Soil Analysis.* American society of Agronomy, Winconsin, USA, 128 p.

Bouyoucos, G.I. 1962. Hydrometer method improved for particle size analysis of soil. *J. Agron.* 54: 464-465.

Buckerfield, J. C., Flavel, T. C., Lee, K. E., Webster, K. A., Diazcozin, D. J., Jesus, J. B., Trigo D., and Garvin, M. H. 1999. Vermicompost in solid and liquid forms as a plant growth promoter. *Pedobiologia.* 43: 753-759.

Cakmak, I. 2013. Magnesium in crop production, food quality and human health. *Crop and Pasture Sci*. 66(12): 1-2.

Chandra, R., Kumar, D., Aishwath, O.P., and Jha, B.K. 2003. Response of *Chlorophytum borivilianum* to organic manure. *J. Trop. Med. Pl.* 4 (2): 261-264.

Chaudhari, S.R., Ingle, V.G., and chaudhari, R.S. 2013. Effect of sowing time and seed rate on total alkaloid content of ashwagandha (*Withania somnifera* Dunal). IOSR J. Agric. and Vet. Sci. 5(5): 1-2.

Chauhan, H.S., Aparbal, Singh,H.P., Singh, A.K., Singh, A., Chattopadhyay., Rajumari., and Prasad, A. 2005. Influence of FYM and NPK fertilizers on growth and yield of safed musli. *J. Med. and Arom. Plant Sci*. 27: 280-282.

Conty, A., Gonzales, C.I., and Iswaran, V. 1994. Effect of coating cabbage seedlings with *Azospirillum* and dicalcium phosphate on growth and their yield. *Philippine J. plant Industries*. 39: 159-162.

Dasthane, N.G. 1972. *A Practical Manual for Water Use Research in Agriculture.* Navabharat Prakashan, Poona, 120p.

Dietz, K. J. and Foyer, C. 1986. The relationship between phosphate status and photosynthesis in leaves. *Planta*. 167(3): 376-381.

Evans, J. R. and Terashima, I. 1988. Photosynthetic characteristics of spinach leaves grown with different nitrogen treatments. *Plant and Cell Physiol.* 29(1): 157-165.

Farooqui, A. A. and Sreenivas, B. S. 2001. Aromatic and Medicinal Plants. IBH Publications, New Delhi, 27-34pp.

FeiBo, W., LiangHuan, W., and FuHua, X. 1998. Chlorophyll meter to predict nitrogen sidedress requirements for short season cotton (*Gossypium hirsutum* L.). *Field Crop Res.* 56: 309–314.

Feleafel, M.N. and Mirdad, Z.M. 2013. Optimizing the nitrogen, phosphorus and potash fertigation rates and frequency for eggplant in arid regions. *Int. J. Agric. and Biol.* 15(4): 737-742.

Fredeen, A. L., Raab, T. K., Rao, I. M., and Terry, N. 1990. Effects of phosphorus nutrition on photosynthesis in *Glycine max* (L.) Merr. *Planta*. 181(3): 399-405.

Ganorkar, S.R., Barabde, N.P., Futane, N.W., Pote, S.R., and Wankhade, S.G. 2006. Nutrient uptake by safed musli as influenced by different levels of FYM and nitrogen. *J. Soils and Crops*. 16(2): 379-383.

Gastal, F. and Lemaire, G. 2002. N uptake and distribution in crops: an agronomical and ecophysiological perspective. *J. Exp. Bot.* 53(370): 789-799.

Ghosh, D.K., Bandopaddhyay, A., and Samanta, G. 2009. Studies on the influence of organic substitution of nitrogenous fertilizer on growth and yield of ashwagandha grown as intercrop in coconut plantation. *J. crop and weed.* 5(2): 149-150.

Goel, V and Duhan, B.S. 2014. Ashwagandha (*Withania somnifera* L. Dunal) crop as affected by the application of farm yard manure (FYM) and inorganic phosphorus in typic Torripsamment of Hisar. *Academic J.* 13(6): 743-748.

Gopal, H. and Natarajan, T. 2009. Microbial Inoculants for Enhancing the Biochemical Properties of *Withania somnifera* Variety Jawahar 20. Madras *Agric. J.* 96(7-12): 339-343.

Gopal, M., Gupta, A., Palaniswami, C., Dhanapal, R., and Thomas, G.V. 2010. Coconut leaf vermiwash: a bio-liquid from coconut leaf vermicompost for improving the crop production capacities of soil. Curr. Sci. 98(9): 1202- 1210.

Govindan, M. and Chandy, K. C. 1985. Utilization of the diazotroph, Azospirillum for inducing rooting in pepper cuttings (*Piper nigrum). Curr. Sci.* 54: 1186-1188.

Gupta, U. S. 1975. Physiological aspects of dry land farming. Oxford &IBH Publishing Co. New Delhi. 385p.

Gupta, R.P and Dakshinamoorthi, C. 1980. *Procedures of Physical Analysis of Soil and Collection of Agro Meteorological Data*. Indian Agricultural Research Institute, New Delhi, 280 p.

Gupta, R. and Banoo, Z. 2012. Enzyme and bacterial population as affected by Farm Yard Manure (FYM) and Vermicompost application in rhizosphere soils of *Withania somnifera* L. Dunal. *A J. Multidisciplinary Advance Res.* 1(2): 58-62.

Harborne, J.B. 1973. *Phytochemical Methods*. Chapman and Hall, London, 105p.

Hayat, S., Hussain, A., Khan, T., and Yahiya, M. 1996. Response of mustard to varied levels of nitrogen and phosphorus. *New Agriculturist*. 7: 187–189.

Hocking, P. J., Randall, P. J., and DeMarco, D. 1997. The response of dry land canola to nitrogen fertilizer: partitioning and mobilization of dry matter and nitrogen, and nitrogen effects on yield components. *Field Crops Res.* 54(2):201-220.

Jackson, M.L. 1958. *Soil Chemical Analysis* (Indian Reprint, 1967) Prentice Hall of India, New Delhi, 498p.

Jackson, M.L. 1973. *Soil Chemical Analysis* (2nd Ed.). Prentice Hall of India, New Delhi, 498p.

Jadhav, P.B., Kireeti, A., Patel, D.J., Dekhane, S.S., Patil, N.B., and Patil, S.J. 2015. Utilization of vermiwash spray on growth and yield of radish cv. Local Variety. *Int. J. For. and Crop Improv.* 6(1): 30-34.

Jana, S.M. and Subrata Debnath B K 1998 Response of plant nutrient on growth and alkaloid content of ashwagandha. *Journal of Interacademicia.* 2: 4, 243-246.

Jat, R.S., Reddy, R.N., Bansal, R., and Manivel, P. 2015. *Good agricultural practices for ashwagandha.* ICAR-Directorate of Medicinal and Aromatic Plant Research, Boriavi, Anand, Gujarat, 18p. Available : http://www.dmapr.org.in/Publications/Bulletine/Good%20Agricultural%20Practices%20for%20Ashwagandha.pdf [12 Nov. 2015].

Joy, P.P., Savithri, K.E., Mathew, s., and kurien, K. 2005. Effect of sole and combined application of FYM and fertilizer on growth yield and quality of black musli. 27: 454-461.

Kalyanasundaram, B., Kumar, T. S., Kumar, S., Swaminathan, V. 2008. Effect of N, P, with biofertilizers and vermicompost on growth and physiological characteristics of sweet flag (*Acorus calamus* L.). *Adv. Plan. Sci.* 21(1): 323-326.

Kambizi, L., Adebola, P.O., and Afolayan, A.J. 2006. Effect of temperature, prechilling and light on seed germination of *Withania somnifera*; a high value medicinal plant. *S. Afr. J. Bot.* 72: 11-14.

Karad, S.R, Khade, P.D, Kubde, A.U., and Jadhav, S.R. 2009. Effect of plant density and fertilizer levels on seed yield and seed quality in Ashwagandha. *Int. J. Plant Sci.* 4(2): 396-398.

Kattimani, K. N., Reddy, Y. N., and Rao, B. R. 1999. Effect of pre-sowing seed treatment on germination, seedling emergence, seedling vigour and root yield of Ashwagandha (*Withania somnifera* Daunal.). *Seed sci. and technoL.* 27(2): 483-488.

KAU [Kerala Agricultural University]. 2009. *The adhoc Package of Practices Recommendations for Organic Farming.* Kerala Agricultural University, Thrissur, 209p.

KAU [Kerala Agricultural University]. 2011. *Package of Practices Recommendations: Crops* (14 Ed.). Kerala Agricultural University, Thrissur, 360p.

Kaushal, S.K., Kumar, S., and Upadhyay, R.G. 2002. Response of nitrogen and phosphorus on growth, development and seed yield of ashwagandha under mid-hill conditions of Himachal Pradesh. *Res. on Crops*. 3(2): 376-379.

Khan, M. M. A., Afaq, S. H., and Afridi, R. M. 2000. Response of black nightshade (Solanum nigrum L.) to phosphorus application. *J. Agron. and Crop Sci.* 184(3): 157-163.

Khanna, P.K., Kumar, A., Ahuja, A., and Kaul, M.K. 2006. Effect of Biofertilizers on the Morphology, Root yield and Biochemical parameters of *Withania somnifera* (L) Dunal. *J. Plant biol.* 33(1&2): 163-167.

Khiriya, K. D., and Singh, B. P. 2003. Effect of phosphorus and farmyard manure on yield, yield attributes and nitrogen, phosphorus and potassium uptake of fenugreek (*Trigonella foenum-graecum*). *Indian J. Agron.* 48(1):62-65.

Kinje, J.W., Barker, R., and Molden, D. 2003. *Water Productivity in Agriculture: Limits and Opportunities for Improvement.* CABI publ. 210p.

Kirnak, H., Kaya, C., Tasi, I., and Higgs, D. 2001. The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. *Bulg. J. Plant Physiol.* 27(3-4): 34-46.

Kothari, S.K., Singh. C.P., Vijaykumar, Y. and Singh, K. 2003. Morphology, yield and quality of ashwagandha (*Withania somnifera* L. Dunal) roots and its cultivation economics as influenced by tillage depth and plant population density. *J. Hort. Sci. and biotech.* 78(3): 422-425.

Krishnappa, K. S., Gowda, M. C., Reddy, N. S., and Anjanappa, M. 1999. Effect of varying levels of fertility on dry matter accumulation and uptake of nutrients by radish varieties. *Karnataka J. Agric. Sci.* 12(1/4): 230-233.

KSPB [Kerala State Planning Board]. 2013. Soil fertility assessment and information management for enhancing crop productivity in Kerala. In: Rajasekharan, P., Nair, K.M., Rajasree, G., Sureshkumar, P., and Narayanankutty, M.C. (eds), Kerala State Planning Board, Thiruvananthapuram, 514p.

Kubsad, V.S., Palled, Y.B., Mansur, C.., Channal, H.T., Basavaraj, N., and Koti, R.V. 2009. Performance of ashwagandha as influenced by dates of sowing and stages of harvesting. *Karnataka J. Agric. Sci.* 22(5): 1001-1005.

Kubsad, V.S., Palled, Y.B., Mansur, C.P., and Alangundagi, S. C. 2010. Influence of spacing and fertilizer levels on growth and dry matter production in ashwagandha. *Madras Agric. J.* 97(7-9): 212-215.

Kumar, T.S., Swaminathan, V., and Kumar, S. 2009. Influence of nitrogen, phosphorus and biofertilizers on growth, yield and essential oil constituents in ratoon crop of davana (*Artemisia pallens* wall.). *Electronic J.Environ. , Agric. and Fd Chem.* 8(2): 86-85.

Kumar, N., Kumar, V., and Singh, M.C. 2012. Response of bioorganic nutrition on growth, yield and quality of ashwagandha (*Withania somnifera Dunal.*). *HortFlora Res. Spectrum.* 1(3): 208-214.

Kumar, R., Sood, S., Sharma, S., Kasana, R.C., Pathania, V.L., Singh, B., and Singh, R.D. 2014. Effect of plant spacing and organic mulches on growth, yield and quality of natural sweetner plant Stevia and soil fertility in Western Himalayas. *Int. J. Plant Production.* 8(3): 311-332.

Kumar, R. 2015. Thesis. Effect of fertilizers, biofertilizers and micronutrients on growth, yield and quality of brinjal (*Solanum melongena* L.) *cv.* Pusa Purple Round. Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur,College of AgricultureTikamgarh, (M.P.). 82p.

Kumari, M. and Upadhyay, R.G. 2012. Effect of Spacing, Organic Manures and Time of Transplanting on Growth and Yield of Ashwagandha (*Withania somnifera* Dunal) under Mid Hill Zone of Himachal Pradesh. *Environ. And Ecol.* 30(4): 1272—1275.

Lawlor, D. W. 2002. Limitation to Photosynthesis in Water-stressed Leaves: Stomata vs. Metabolism and the Role of ATP. *Ann. Bot.* 89(7): 871-885.

Longstreth, D. J. and Nobel, P. S. 1980. Nutrient influences on leaf photosynthesis. *Plant Physiol.* 65(3): 541-543.

Lopez-Cantarero, I., Lorente, F. A., and Romero, L. 1994. Are chlorophylls good indicators of nitrogen and phosphorus levels? 1. *J. Plant Nutr.* 17(6): 979-990.

Madhavi, Y. 2007. Effect of organic manures and biofertilizers on nutrient uptake in palak. *Orissa J. Hort.* 23(2) : 31-33.

Mahantesh, B. 2002. Evaluation of onion varieties/hybrids and effect of biofertilizers with levels of NPK on growth, yield and quality of onion (cv. Bellary Red) in central dry zone of Karnataka. Ph.D. thesis, University of Agricultural Sciences, Bangalore.

Mahendran, P. P. and Kumar, N. 1998. Effect of biofertilizers on tuber yield and certain quality parameters of potato cv. Kufri Jyoti. *South Indian Hort.* 46(1&2): 97-98.

Maheshwari, S.K. and Yadav, S. 1981. Response of *Withania somnifera* (ashwagandha) to variable levels of N and P under rainfed condition. A paper presented in the IV All India Workshop on Medicinal and Aromatic Plants held at Madurai during 31st August to 3rd September, pp. 11-12.

Maheshwari, S.K, Sharma, R.K., and Gangrade, S.K. 2000. Response of ashwagandha to organic manures and fertilizers in shallow black soil under rainfed conditions. *Indian J. Agron.* 45 (1): 214-216.

Maitra, S., Jana, B. K., and Debnath, S. 1998. Response of plant nutrients on growth and alkaloid content of ashwagandha (*W. Somenifera*). *J. Interacademicia*, 2: 243-246.

Mallick, D.K. and Sawhney, S. 1998. Experimental regulation of flowering in chickpea. The photo period Gibberillin interaction. *Indian J. Plant Physiol.* 3(3): 223-225.

Manhas, S. S., Gill, B. S., Khajuria, V., and Kumar, S. 2011. Effect of planting material, mulch and farmyard manure on weed density, rhizome yield and quality of turmeric (*Curcuma longa*). Indian J. Agron. 56(4): 393-399.

Manohar, S., Choudhari, M.R., Yadav, B.L., Dadheech, S., and Singh, S.P. 2012. Analyzing the efficacy of organic and inorganic sources of nitrogen and phosphorus on growth of ashwagandha (*Withania somnifera* Dunal.). *J. Hortl. Sci.* 7(2): 161-165.

Maryada, S.K., Kaushal., and Kaistha, B.P. 2001. Response of ashwagandha (*Withania somnifera* Dunal) to nitrogen fertilization under mid hill conditions of Himachal Pradesh. *Himachal J. Agric. Res.* 27(1&2): 77-80.

Meghvansi, M.K., Khan, M.H., Gupta, R., Gogoi, H.K., and Singh, L. 2012. Vegetative and yield attributes of okra and naga chilli as affected by foliar sprays of vermiwash on acidic soil. *J. Crop Improv.* 26(4): 520-531.

Mehra, R. K. 2004. Text book of Soil Science. Published by Directorate of information and Publications of Agriulture, ICAR, New Delhi.

Menghini, A., Pocceschi, N., Venanzi, G., and Palladini, B. T. 1998. Effect of nitrogen fertilization on photosynthesis rate, nitrogenous metabolites and α-and β-asarone accumulation in triploid *Acorus calamus* L. leaves. *Flavour and fragrance J.* 13(5): 319-323.

Mishra, A. 1992. Nutritional requirements of some important medicinal and aromatic plants for higher productivity. *Curr. Res. on Med. and Arom. Pl.* 14(2): 121-132.

More, S., Deshmukh, S., Prashant, S., and Vishal, D. 2013. Effect of integrated nitrogen management with vermiwash in corn (*Zea mays* L.) on growth and yield. *Afr. J. Agric. Res.* 8(38): 4761-4765.

Mostafa, E.A.M., Saleh, M.M.S., and Abdi El Migeed, M.M.M. 2007. Response of banana plants to soil and foliar applications of magnesium. *Am. Eurasian J. Agric. and Environ. Sci.* 2(2): 141-146.

Mtui, T.A., Kanemasu, E.T., and Wassom, C. 1981. Canopy temperatures, water use, and water use efficiency of corn genotypes. *Agronomy J. 73*(4): 639-643.

Murage, E. N., Chweya, J. A., and Imungi, J. K. 1996. Changes in leaf yield and nutritive quality of the black nightshade (*solarium nigrum*) as influenced by nitrogen application. *Ecol. food and nutr*. 35(2): 149-157.

Muthumanickam, D. and Balakrishnamurthy, G. 1999. Studies on nutritional requirement of ashwagandha (*Withania somnifera* Dunal) in Shevroy hills of TamilNadu. *J. Spices and Arom. Crops*. 8: 179-183.

Naeem, M., and Khan, M. M. A. 2005. Growth, physiology and seed yield of Cassia tora (syn. *Cassia obtusifolia*) as affected by phosphorus fertilization. *J Med. Arom. Plant Sci*. 27:4-6.

Naeem, M., Masroor, M., Khan, A., and Khan, M. N. 2009. Promotive effects of phosphorus on crop productivity, enzyme activities, anthraquinone and sennoside content in *Cassia tora* L.–a medicinal herb. *J. Plant Interactions*. 4(1): 49-57.

Nasir, S. and Khan, M.A. 2012. Critical dose of nitrogen and phosphorus enhanced growth, yield and alkaloid content in *Withania somnifera* L. *J. Pl. Nutr.* 35(11): 1705-1724.

Natarajan, S. 2003. Studies of different organic manures and nitrogen fertilizers on soil fertility and sustained productivity in rice based cropping system. Ph. D. thesis, Tamilnadu Agricultural University, Coimbatore.

Nath, R. 1993. Modern Plant Physiology, Kalyani Publishers, NewDelhi. p.605.

Nigam, K.B., Rawat, G.S., and Bhagawatprasad. 1984. Effects of methods of sowing, plant density and fertility levels on ashwagandha. *S. Indian Hort*. 32: 356-359.

Niyaz, A. and Siddiqui, E. N. 2014. Seed germination of *Withania somnifera* (L.) Dunal. *Eur. J. Med. Plants*. *4*(8): 920.

Okon, Y., Heytler, P. G., and Hardy, R. W. F. 1983. N2 fixation by *Azospirillum brasilense* and its incorporation into host *Setaria italica*. *Appl. Environ. Mirobiol.* 46: 694-697.

Pakkiyanathan, K., Pasha, Y.N., Narayan , R. Y., and Arun, S. 2004. Effect of spacing and phosphorus levels on growth and root yield of Ashwagandha (*withania somnifera Dunal.*). *Indian J. of Hort*. 61(2): 195-197.

Panchbhai, D. M., Bachkar, B. R., Jogdande, N. D., Deokar, P. L., and Wankhade, S. G. 2006. Effect of nitrogen and phosphorus levels on root yield and quality of ashwagandha (*Withania somnifera Dunal*). *Ad. Plant Sci.*, 19: 89-92.

Pandey, S. T., Singh, P., and Pandey, P. 2006. Site specific nutrient management for *Withania somnifera* at subtropical belt of Uttaranchal. *Int. J. Agric. Sciences*. 2: 626–628.

Panwar, J. and Tarafdar, J.C. 2006. Distribution of three endangered medicinal plant species and their colonization with arbuscular mycorhizal fungi. *J. Arid Environ*. 65(3): 77-79.

Parmar, D. K., Sharma, T. K., Saini, J. R., and Sharma, V. 1999. Response of French bean (*Phaseolus vulgaris*) to nitrogen and phosphorus in cold desert area of Himachal Pradesh. *Indian J. Agron.* 44(4): 787-790.

Patel, D.H. 2001. Effect of methods of sowing, nitrogen levels and time of harvesting on yield and quality parameters of ashwagandha var. WS-100. Ph.D. thesis, Gujarat Agricultural University, Anand, 198p.

Patel, D.H., Upadaya, P.N., Patel, K.V., Patel, J.B., and Patel, B.K. 2004 Effect of method of sowing, time of harvesting and nitrogen application on dry root yield of ashwagandha (*Withania somnifera* Dunal). *J. Med. and Arom. Plant Sci.* 26: 288-292.

Patil, S.V., Halikatti, S.I., Hiremath, S.M., Babalad, H.B., Sreenivasa, M.N., Hebsur, N.S., and Somanagouda, G. 2012. Effect of organics on growth and yield of chickpea (*Cicer arietinum* L.) in vertisols. *Karnataka J. Agric. Sci.* 25(3): 326-331.

Patil, S.R., Kattimani, K.N., and Polaiah, A.C. 2014. Integrated nutrient management in ashwagandha (*Withania somnifera* Dunal.). *Pl. Arch.* 14(1): 373-377.

Pratibha,G., Korwar, G.R., and Yadav, S.K. 2010. Productivity, quality, nutrient use efficiency and economics of senna (*Cassia angustifolia*) as influenced by FYM and fertilizer nitrogen under rainfed conditions. *Indian J. Agron.* 55(1): 79-83.

Priyadarshani, N. D. N., Amarasinghe, M. K. T. K., Subasinghe, S.,Palihakkara, I. R., and Kumarasinghe, H. K. M. S. 2013. Effect of organic and inorganic fertilizers on biomass production , oil yield and quality of vetiver (*Vetiveria zizanioides* L.). *J. Agric. Sciences.* 8(1): 28-35.

Prsa, I., Stampar, F., Vodnik, D., and Veberic, R. 2007. Influence of nitrogen on leaf chlorophyll content and photosynthesis of 'Golden Delicious' apple. *Acta Agriculturae Scandinavica Section B-Soil and Plant Sci.* 57(3): 283-289.

Puttanna, K., Rao, E. P., Chandrashekhara, R. S., and Rao, R. G. 2005. Organic and inorganic nutrition for *Withania somnifera*. *J. Trop. Med. Plants*. 6(2): 215.

Radford, P. J. 1967. Growth analysis formulae-their use and abuse. *Crop science*, 7(3): 171-175.

Raj, A.K. and Kumari, G. 2001. Effect of organic manures and *Azopsirillum* inoculation on yield and quality of okra. *Vegetable Sci.* 28 (2): 179-181.

Raja, G. and Veerakumari, L. 2013. Influence of vermicompost on the yield and alkaloid content of *Withania somnifera.* Dunal. *Int. J. Advanced Biological Res.* 3(2): 223-226.

Ramesh Babu, T.I. 1996. Nutritional studies in ashwagandha. M.Sc. (Agri.) thesis Tamil Nadu Agricultural University, Coimbatore. 130p.

Rao, I. M. and Terry, N. 1989. Leaf phosphate status, photosynthesis, and carbon partitioning in sugar beet I. Changes in growth, gas exchange, and Calvin Cycle enzymes. *Plant Physiol.* 90(3): 814-819.

Rao, B.R. and Rajput, D.K. 2011. Response of palmarosa [*Cymbopogon martini* (Roxb.) Wats. *var. motia* Burk.] to foliar application of magnesium and micronutrients. *Ind. Crops and Products.* 33(2): 277-281.

Ravi, P. 2004. Efficacy of integrated nutrient management for growth and yield of medicinal coleus (Coleus forskohlii Briq.). M. Sc.(Agri.) thesis, Tamil Nadu Agriculture University.

Ravikumar, M., Venkatesha, J., Niranjana, K. S., and Gurumurthy, B. R. 2012. Effect of Integrated Nutrient Management on Tuber Yield and Quality and Nutrient Uptake in *Coleus forskohlii* Briq. *J. Root Crops.* 38(2): 142-146.

Ravikumar, M., Venkatesha, J., Niranjana, K. S., and Gurumurthy, B. R. 2013. Effect of integrated nutrient management on yield and economics of coleus (Coleus *forskohlii* Briq.). *Karnataka J. Agric. Sci.* 26(1): 119-123.

Reddy, G.S., Susila, T., and Kumar, M.K. 2011. Effect of seed rate and spacing on yield of aswagandha (*Withania somnifera* Dunal). *Progressive Hort.* 43(1): 18-19.

Rekha, G. S., Valivittan, K., and Kaleena. P. K. 2013. Studies on the Influence of Vermicompost and Vermiwash on the Growth and Productivity of Black Gram (*Vigna mungo*). *Adv. in Biolo. Res.* 7(4): 114-121.

Salam, S. A., Geetha, D., and Yadav, P. 2004. Sustainable production of coconut through biomass recycling. *Indian Coconut J.* 35(1): 16-17.

Sarkar, D. and Mandal, B. 2007. Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. *Pl. Soil.* 301: 77-85.

Sawan, Z. M., Hafez, S. A., and Basyony, A. E. 2001. Effect of nitrogen fertilization and foliar application of plant growth retardants and zinc on cottonseed, protein and oil yields and oil properties of cotton. *J. Agron. and Crop Sci.* 186: 183–191.

Schachtman, D. P., Reid, R. J., and Ayling, S. M. 1998. Phosphorus uptake by plants: from soil to cell. *Plant Physiol.* 116: 447–453.

SentilKumar, T., Kalyansundaram, B., Swaminathan, V., and Kumar, S. 2006. Studies on the effect of nitrogen and phosphorus along with biofertilizers on growth and nutrient uptake of davana (*Artemisia pallens* wall.). International Conference on Globalization of Traditional, Complementary and Alternative System of Medicine, Coimbatore: March 16-18, Poster Abstract 89: 97.

Sharma, S. K. 1995. Response of boron and calcium nutrition on plant growth, fruit and seed yield of tomato. *Vegetable Sci.* 22: 27-29.

Sharma, S. K., Singh, H., and Kohli, U. K 1999. Influence of boron and zinc on seed yield and quality in radish. *Seed Res.* 27: 154-158.

Shetty, S., Farooqi, A. A., and Subbaiah, T. K. 1990. Effect of nitrogen, phosphorus and potassium on herbage yield and alkaloid content in *Datura stramonium* L. *Crop Research Hisar*, 3: 294–298.

Shimi, G. J. and Anilkumar, A. S. 2014. Planting methods, subsurface drip fertigation and bioinoculants on growth and pro- ductivity of vetiver [*Vetiveria zizanioides* (L.) Nash]. J. Spices and Arom. Crops. 23(2): 276-279.

Shinde, A., Gahunge, P., Singh, P., Rath, S.K., and Khemani, N. 2013. Effect of inorganic fertilizers and organic manures on growth, quality and yield of ashwagandha (*Withania somnifera* Dunal) cv. Jawahar Ashwagandha-20. *Ann. Pharmacy and Pharmaceutical Sci.* 4(1&2): 13-16.

Shivsubramanian, K. and Ganeshkumar, M. 2004. Influence of vermiwash on biological productivity of Marigold. *Madras Agric. J.* 91(4-6): 221-225.

Shravankumar, C.S. and Datta, S. 2014. Effect of pre-sowing treatment with organic amendment on germination of varieties of *withania Somnifera* (l.) Dunal. Wld. J. Pharmacy and Pharmaceutical Sci. 3(12): 1158-1166.

Shrivastava, A. K. and Sahu, P. K. 2013. Economics of Yield and Production of Alkaloid of *Withania somnifera* (L.) Dunal. *American J. Plant Sci.* 4: 2023-2030.

Shrivastava, D.K. and Srivastava, S.C. 2015. Cultivation of Aswagandha (*Withania somnifera* Dunal) during *rabi* season is more economical as compared to *kharif* season. *Med. Plant.* 6(3): 181-184.

Shubhra, D. J., Goswami, C. L, and Munjal, R. 2004. Influence of phosphorus application on water relations, biochemical parameters and gum content in cluster bean under water deficit. *Biol. Plant.* 48: 44.

Shukla, H.Y and Shukla, P.K. 2012. Effect of stand geometry and plant growth regulators on root yield and alkaloid content of Ashwagandha. (*Withania somnifera* Dunal.). *Int. J. Med. and Aromat. Plants.* 2(3): 390-95.

Singh, A. R., Singh, B., and Singh, A. 1990. Efficacy of nitrogen and boron on the growth, yield and quality of potato (*Solanum tuberosum* L.) Var Kufri Chamtkar. *Progressive Hort.* 22: 104-107.

Singh, P. N., and Ram, H. 1992. Effect of phosphorus and sulphur on concentration and uptake of N, Ca and Mg in chickpea. *Indian J. plant physiol.* 35: 109-109.

Singh, N. B., and Verma, K. K. 2002. Nitrogen and phosphorus nutrition of Frenchbean (*Phaseolus vulgaris* L.) grown in eastern Uttar Pradesh under late-sown condition. *Indian J. Agron.* 47(1):89-93.

Singh, R., Nilofer, A. K. S., and Singh, S. 2014. Optimization of plant population in Ashwagandha (Withania somnifera L. Dunal) under rainfed conditions. *CSIR-CIMAP.*, 188p.

Slatyer, R.O. and Barrs, H.D. 1965. *Methodology of plant Eco physiology.* United Nations Educational Scientific and Cultural Organisation, Rome. 468p.

Smita, S.R., Ingle, V.G. and Chaudhari, R.S. 2013. Effect of sowing time and seed rate on total alkaloid content of Ashwagandha (*Withania somnifera* Dunal). *J. Agric. and Vet. Sci.* 5(5): 1-2.

Srinivasappa, K.N., Anuradha, M.N., Farooqi, A.A., Kathiresan, C., Suresh, H.C., and Shivananda, T.N. 2007. Use of bio-fertilizers in cultivation of medicinal and aromatic plants – a review. Biomed. 2(3): 235-256.

Subba Rao, N. S. 1997. Soil Microorganisms and Plant Growth. New Delhi: Oxford and IBH Publishing Co.ISBN 81-204-0096-8, pp. 311.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* 25: 259-260.

Subbaiah, K. 1991. Studies on the effect of nitrogen and *Azospirillum* on Okra. *S. Indian Hort*. 39(1): 37-44.

Suja, G., Nayar, T.V.R., and Potty, V.P. 2005. Response of cassava (Manihot esculenta Crantz) to biofertilizers. *J. Root Crops*, *31*(2): 100-105.

Suvanthini, S., Mikunthan, G., Thurairatnam, S and Pakeerathan, K. 2012. Evaluation of *Withania somnifera* extracts on a storage pest Rice weevil, *Sitophilus oryzae. Ann. Biological Res*. 3 (11): 5050-5053.

Taiz, L., & Zeiger, E. 2006. Plant Physiology., 4th edn.(Sinauer Associates: Sunderland, MA.).

Thakur, N. S., Verma, K. S., and Rana, R. C. 2014. Growth and yield performance of ashwagandha (*Withania somnifera*) under agroforestry. *Indian J. Agric. Sciences.* 84(8): 937-941.

Thankamani, C.K., Srinivasan, V., Krishnamurthy, K.S., and Kandiannan, K. 2011. Effect of Azospirillum sp. and nutrients on yield of black pepper (*Piper nigrum* L.). *J. Spices and Aromat. Crops* 20(1): 9-13.

Thapar, S., Sekhon, B. S., Atwal, A., and Singh, R. 1990. Phosphorus assimilation i mycorrhizal moong (*Vigna radiata* L.) plants under different phosphorus levels. *Plant Sci.* 71(2): 209-214.

Theodorou, M.E. and Plaxton, W.C. 1993. Metabolic adaptations of plant respiration to nutritional phosphate deprivation. Plant Physiol. 101: 339-344.

Tien, T.M., Gaskens, M.H., and Hubbel, D.H. 1979. Plant growth substances produced by *Azospirillum brasilense* and their effect on growth of pearl millet (*Pennisetum americanum*). *Appl. Environ. Microbiol.* 3: 1016-1024.

Tiwari, S.C., Tiwari, B.K., and Mishra, R.R.1989. Microbial populations, enzyme activities and nitrogen-phosphorus-potassium enrichment in earthworm casts and in the surrounding soil of a pineapple plantation. *Biol. Fert. Soils.*8: 178.

Tóth, V. R., Mészáros, I., Veres, S., and Nagy, J. 2002. Effects of the available nitrogen on the photosynthetic activity and xanthophyll cycle pool of maize in field. *J. Plant Physiol.* 159(6): 627-634.

Tumbare, A.D. and Nikam, D.R. 2004. Effect of planting and fertigation on growth and yield of green chilli (*Capsicum annuum*). *Indian J. Agric. Sci.* 74(5): 242-245.

Udabal, N., Hunje, R., and Kote, P., 2014. Effect of organics and liquid fertilizers on plant growth and seed yield of sunflower (*Helianthus annum* L.). *Environ. and Ecolo*. 32(4A): 1437-1441.

Vajantha, B., Umadevi, M., Patnaik, M.C., and Rajmurkar, M. 2011. Effect of INM and Panchagavya on soil fetility status ofAshwagandha (*Withania somnifera* L.). *An Asian J. Soil Sci.* 6(1): 88-96.

Vajantha, B., Umadevi, M., Patnaik, M.C., and Rajkumar, M. 2014. Drymatter production, root characters and seed yield of ashwagandha (*Withania somnifera* L.) as influenced by panchakavya. *G. J. B. B.* 3 (4): 354-358.

Velmurugan, M., Chezhiyan, N., and Jawaharlal, M. 2008. Influence of organic manures and inorganic fertilizers on cured rhizome yield and quality of turmeric (*Curcuma longa* L.). *Int. J. Agric. Sci*. 4(1): 142-145.

Venkitaswamy, R and Khan. H. 2004. Drought management in coconut in Tamil Nadu. *Indian Coconut J.* 34 (10): 16-19.

Verhoeven, A. S., Demmig-Adams, B., and Adams III, W. W. 1997 Enhanced employment of the xanthophyll cycle and thermal energy dissipation in spinach exposed to high light and N stress. Plant Physiol. 113: 817–824.

Waghmode, B.R., Sonawane, S.V., and Tajane, D.S. 2015. Differential responses of yield and quality to organic manures in sweet corn [*Zea mays* (L.) *saccharata*]. *Int. J. Agric. Sci.* 11(2): 229-237.

Waller, G.R. and Nowacki, E.K. 1978. Alkaloid biology and Metabolism in Plants. Plenum Press, New York, 294p.

Watson, D. J. 1952. The physiological basis of variation in yield. *Adv. Agron*. 4: 101-145.

Yadav, B.D., Khandelwal, R.B., and Sharma, Y.K. 2005. Use of biofertilizer (*Azospirillum*) in onion. *Indian J. Hort*. 62(2): 168-170.

Yoo-Jeong, Y., Dungam, R.S., Ibekwe, A.M., Valenzuela-Solano, C., Crohn, D.M., and Crowley, D.E. 2003. Effect of organic mulches of soil bacterial communities one year after application. *Biol. Fertil. Soils*. 38: 273-281.

Zaller, J. G. 2006. Foliar spray of vermicompost extracts: effects on fruit quality and indications of late-blight suppression on field grown tomatoes. *Biol. Agric. Hortic.* 24: 165-180.

Abstract

RHIZOSPHERE MANAGEMENT FOR HIGHER ROOT PRODUCTION IN ASHWAGANDHA (*Withania somnifera* L. Dunal)

by

ASHIBA A

(2015-11-115)

Abstract of thesis
Submitted in partial fulfilment of the
requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY

COLLEGE OF AGRICULTURE

PADANNAKKAD, KASARGOD- 671 314

KERALA, INDIA

2017

ABSTRACT

The investigation entitled, "Rhizosphere management for higher root production in ashwagandha (*Withania somnifera* L. Dunal)" was carried out at the Instructional farm attached to the College of Agriculture, Padannakkad during 2015-17 to study the effect of integrated nutrient management practices and summer irrigation on growth promotion and root production in ashwagandha.

The experiment was laid out in RBD with 14 treatments replicated twice. The treatments were T_1 - HDP in trenches mulched with polythene and filled with enriched growing medium, T_2 - T_1 + Recommended dose of NPK, T_3 - T_1 + Liquid organic manures, T_4 - T_2 + azospirillum, T_5 - T_3 + azospirillum, T_6 - T_4 + B and Mg, T_7 - T_5 + B and Mg, T_8 - T_6 + Summer irrigation at 15 mm CPE, T_9 - T_7 + Summer irrigation at 15 mm CPE, T_{10} - T_6 + Summer irrigation at 30 mm CPE, T_{11} - T_7 + Summer irrigation at 30 mm CPE, T_{12} - HDP in trenches filled with enriched growing medium, T_{13} - NRP in trenches filled with enriched growing medium, T_{14} - Broadcasting in trenches filled with enriched growing medium. The results of the field experiment revealed that all growth parameters of ashwagandha were significantly influenced by treatment effects. In general, the treatment T_6 was found superior in enhancing vegetative growth. However, the treatments did not exert any significant effect on primary, secondary and tertiary branches at any of the growth stages.

The treatments had no significant effect on primary root number during early stages of growth (45 DAT and 60 DAT). The effect of treatments was evident from 75 DAT onwards. T_{10} at 75 DAT; T_9 at 90 DAT; and T_8 at 105 DAT and 120 DAT recorded higher primary root number.

With respect to root characters, T_8 recorded higher root number, T_8 and T_{10} recorded the greatest root length, T_{11} the highest root spread, and T_{10} the highest root volume at the time of harvest. The treatment T_{10}, recorded the highest fresh and dry root weight per plant and fresh and dry root production per hectare. The highest LAI and seed yield per plant and seed production per hectare were registered by T_6.

In general, relative leaf water content and leaf temperature were unaffected by treatment effects. Crude alkaloid content ranged from 6.5 % to 10.4 %. The highest crude alkaloid content of 10.54 % was registered by T_7. Other biochemical parameters namely total sugar and total amino acid content were not at all influenced by treatment effects. Azospirillum population ranged from 11.5 x 10^5 to 64 x 10^5 per gram dry soil. The highest population of 64 x 10^5 per gram dry soil was registered by the treatments T_8 and T_5.

Seasonal consumptive use and mean daily consumptive use ranged from 145.73 mm to 250.80 mm and 1.22 to 2.09 mm respectively and T_{14} registered the higher values. The highest crop water use efficiency of 474.78 g m^{-3} was recorded by T_{10}. Field water use efficiency varied from 84.46 to 222.31 g m^{-3} and the highest value was recorded by T_6. The treatment which recorded the highest value of field water use efficiency also registered the highest water productivity of 1313.47 g m^{-3}.

The highest nitrogen content was recorded by T_6. T_8, T_9 and T_{10} registered higher contents of phosphorus, potassium and boron respectively.

The treatment, T_{10} was found worthwhile for popularization with respect to higher fresh and dry root yield per plant and root production per hectare, dry matter production, crop water use efficiency, gross income, net income and BCR.

സംഗ്രഹം

"വേരുപടലം വിന്യസിക്കുന്ന മണ്ണിന്റെ പരിപാലന മുറകളിലൂടെ അമുക്കുരത്തിന്റെ ഔഷധയോഗ്യമായ വേരുത്പാദനം വർദ്ധിപ്പിക്കുക" എന്ന ഒരു പരീക്ഷണം 2015-17 കാലഘട്ടത്തിൽ പടന്നക്കാട് കാർഷിക കോളേജിനോട് അനുബന്ധിച്ചിട്ടുള്ള ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ നടത്തുകയുണ്ടായി. സംയോജിത വളപ്രയോഗവും വേനൽക്കാല നനയും അമുക്കുരത്തിന്റെ വേരുത്പാദനത്തിലും ഗുണനിലവാരത്തിലും ചെലുത്തുന്ന സ്വാധീനത്തെപ്പറ്റിയായിരുന്നു പഠനം.

റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ രൂപകൽപന ചെയ്യപ്പെട്ട പരീക്ഷണത്തിൽ 14 ട്രീറ്റ്മെന്റുകളും 2 റെപ്ലിക്കേഷനും ഉണ്ടായിരുന്നു. ട്രീറ്റ്മെന്റുകൾ താഴെ പറയുന്നവയാണ്. T_1- പോളിത്തീൻ കൊണ്ട് പുതയിട്ട പരിപോഷിത പോട്ടിംങ് മിശ്രിതം നിറച്ച ചാലുകളിൽ അതിസാന്ദ്രതാ നടീൽ രീതി, T_2- T_1 + രാസവള ശുപാർശ 40:40:40 കി. ഗ്രാം നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം പെർ ഹെക്ടർ. T_3- T_1 + ദ്രാവക രൂപത്തിലുള്ള ജൈവവളങ്ങൾ, T_4- T_2 + അസോസ്പൈറില്ലം, T_5 - T_3 + അസോസ്പൈറില്ലം, T_6 -T_4 + ബോറോൺ +മഗ്നീഷ്യം, T_7- T_5 + ബോറോൺ + മഗ്നീഷ്യം, T_8- T_6 + മൊത്തം ബാഷ്പീകരണം 15 മി .മി ആകുമ്പോൾ വേനൽക്കാല നന, T_9- T_7 + മൊത്തം ബാഷ്പീകരണം 15 മി .മി ആകുമ്പോൾ വേനൽക്കാല നന, T_{10} -T_6 + മൊത്തം ബാഷ്പീകരണം 30 മി .മി ആകുമ്പോൾ വേനൽക്കാല നന, T_{11}- T_7 + മൊത്തം ബാഷ്പീകരണം 30 മി .മി ആകുമ്പോൾ വേനൽക്കാല നന, T_{12}- പരിപോഷിത പോട്ടിംങ് മിശ്രിതം നിറച്ച ചാലുകളിൽ അതിസാന്ദ്രതാ നടീൽ രീതി, T_{13}- പരിപോഷിത പോട്ടിംങ് മിശ്രിതം നിറച്ച ചാലുകളിൽ സാധാരണ നടീൽ രീതി, T_{14}- പരിപോഷിത പോട്ടിംങ് മിശ്രിതം നിറച്ച ചാലുകളിൽ വിത്തു വിതറൽ .

അമുക്കുരത്തിന്റെ നിരീക്ഷിക്കപ്പെട്ട കായിക വളർച്ചയുടെ എല്ലാ സ്വഭാവങ്ങളെയും ട്രീറ്റ്മെന്റ്സ് കാര്യമായി സ്വാധീനിക്കുന്നതായി കണ്ടു..

വിളവെടുത്ത സമയത്തുള്ള വേരുപടലത്തിന്റെ സ്വഭാവത്തെപ്പറ്റി പഠിച്ചപ്പോൾ T_8 എന്ന ട്രീറ്റ്മെന്റ് മൊത്തം വേരിന്റെ എണ്ണത്തെയും, T_{10}

വേരിന്റെ നീളത്തെയും, T_{11} വേരിന്റെ പാർശ്വങ്ങളിലേക്ക് പടർന്നു വളരാനുള്ള കഴിവിനേയും, വ്യാപ്തത്തെയും കാര്യമായി വർദ്ധിപ്പിക്കുന്നതായി തെളിയുകയുണ്ടായി. T_{10} എന്ന ട്രീറ്റ്മെന്റ് ഓരോ ചെടിയുടെയും വേരിന്റെ തൂക്കത്തെയും വേരിന്റെ മൊത്ത ഉത്പാദനത്തെയും ഗണ്യമായി വർദ്ധിപ്പിക്കുന്നതായി കണ്ടു.

ഔഷധയോഗ്യമായ വേരിലടങ്ങിയിരിക്കുന്ന ക്രൂഡ് ആൽക്കലോയിഡിന്റെ അളവ് 6.5-10.4 ശതമാനമായി പരിശോധനയിൽ തെളിഞ്ഞു. T_7 എന്ന ട്രീറ്റ്മെന്റാണ് ഏറ്റവും കൂടുതൽ ക്രൂഡ് ആൽക്കലോയ്ഡ് ഉത്പാദിപ്പിക്കുവാൻ വഴി തെളിയിച്ചത്.

സീസണൽ കൺസംപ്റ്റീവ് യൂസും ദിവസേനയുള്ള ശരാശരി കൺസംപ്റ്റീവ് യൂസും T_{14} എന്ന ട്രീറ്റ്മെന്റിൽ ഉയർന്ന നിരക്കുകൾ രേഖപ്പെടുത്തുകയുണ്ടായി. ഏറ്റവും ഉയർന്ന ക്രോപ് വാട്ടർ യൂസ് എഫിഷ്യൻസി T_{10} എന്ന ട്രീറ്റ്മെന്റിലായിരുന്നു. ഏറ്റവും ഉയർന്ന ഫീൽഡ് വാട്ടർ യൂസ് എഫിഷ്യൻസിയും വാട്ടർ പ്രൊഡക്ടിവിറ്റിയും രേഖപ്പെടുത്തിയ ട്രീറ്റ്മെന്റ് ഒന്നു തന്നെയായിരുന്നു (T_6). ഉയർന്ന തോതിലുള്ള നൈട്രജൻ, ഫോസ്ഫറസ്,പൊട്ടാസ്യം, ബോറോൺ എന്നീ മൂലകങ്ങളുടെ അളവ് യഥാക്രമം T_6, T_8, T_9 , T_{10} എന്നീ ട്രീറ്റ്മെന്റുകൾ രേഖപ്പെടുത്തുകയുണ്ടായി.

പോളിത്തീൻ കൊണ്ട് ആവരണം ചെയ്യപ്പെട്ട ചാലുകളിൽ പരിപോഷിത പോട്ടിംഗ് മിശ്രിതം നിറച്ച് വേരുപടലം അസോസ്പൈറില്ലം സ്ലറിയിൽ മുക്കിയെടുത്ത ഒരു മാസം പ്രായമെത്തിയ തൈകൾ അതിസാന്ദ്രതാ രീതിയിൽ പറിച്ചു നട്ട് ഹെക്ടർ ഒന്നിന് 5 കി .ഗ്രാം ബൊറാക്സും 40 കി .ഗ്രാം മഗ്നീഷ്യം സൾഫേറ്റും അടിവളമായി നൽകി മൊത്തം ബാഷ്പീകരണം 30 മി .മി . ആകുമ്പോൾ വേനൽക്കാല നന അനുവർത്തിക്കുകയും ചെയ്യുമ്പോൾ ഔഷധയോഗ്യമായ വേരിന്റെ ഉത്പാദനക്ഷമതയിലും, മൊത്തം ഉത്പാദനത്തിലും, വിള അധിഷ്ഠിത ജല ഉപയോഗ ക്ഷമതയിലും, മൊത്തം വരുമാനത്തിലും, അറ്റാദായത്തിലും വരവു ചെലവ് അനുപാതത്തിലും പ്രത്യക്ഷവും അനുകൂലവുമായ മാറ്റം ഉണ്ടാകുന്നു (T_{10}).

Appendix

Appendix 1

Monthly weather data during the crop period

Period	Maximum temperature (^0C)	Minimum temperature (^0C)	Rainfall (mm)	Relative humidity (%)	Mean Daily Evaporation (mm)
December 2015	32.20	22.08	0.12	71.29	3.22
January 2016	32.25	19.57	0.00	56.58	3.67
February 2016	32.26	22.12	0.00	59.17	4.53
March 2016	33.59	24.58	0.00	61.07	5.34
April 2016	34.14	26.09	0.00	63.77	5.82