STANDARDIZATION OF AGRO-TECHNIQUES FOR ASHWAGANDHA (*withania somnifera* Dunal.) IN COASTAL DISTRICTS OF ANDHRA PRADESH

BY

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CERTIFICATE

Mr. D.VENKATA SWAMI has satisfactorily prosecuted the course of research and that the thesis entitled **"Standardization of Agro-techniques for Ashwagandha (*Withania somnifera* Dunal.) in coastal districts of Andhra Pradesh"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

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Chairperson of the Advisory Committee

CERTIFICATE

This is to certify that the thesis entitled **"STANDARDIZATION OF AGRO-TECHNIQUES FOR ASHWAGANDHA** (*Withania somnifera* Dunal.) **IN COASTAL DISTRICTS OF ANDHRA PRADESH "** submitted in partial fulfillment of the requirements for the degree of '**Doctor of Philosophy**' in the major field of **Horticulture** of the Acharya N.G. Ranga Agricultural University, Hyderabad is a record of the bonafide original research work carried out by **Mr. D.VENKATA SWAMI** under our guidance and supervision. The subject of the thesis has been approved by the Students Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part and all assistance and help received during course of investigation have been duly acknowledged by the author of the thesis.

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DECLARATION

I, **D.VENKATA SWAMI,** hereby declare that the thesis entitled **"STANDARDIZATION OF AGRO-TECHNIQUES FOR ASHWAGANDHA** (*Withania somnifera* Dunal.) **IN COASTAL DISTRICTS OF ANDHRA PRADESH"** submitted to the Acharya N.G. Ranga Agricultural University for the degree of **'Doctor of Philosophy'** in the major field of **Horticulture** is a result of original research work done by me. It is further declared that the thesis or part thereof has not been published earlier in any manner.

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ABSTRACT

Studies on "Standardization of Agro-techniques for Ashwagandha (*Withania somnifera* Dunal.) in coastal districts of Andhra Pradesh" was conducted at College of Horticulture,Venkataramannagudem, West Godavari district , Andhra Pradesh during late kharif seasons of 2009-10 and 2010-11. The studies include five experiments. The first experiment was on "Effect of seed rate on growth and yield of Ashwagandha *(Withania somnifera* Dunal. *)*" with treatments T_1: 6 kg of seed ha^{-1}, T_2: 8 kg of seed ha^{-1}, T_3: 10 kg of seed ha^{-1} and T_4: 12 kg of seed ha^{-1}. The experiment was laid out in a randomized block design with five replications. Among different seed rates, 12 kg of seed ha^{-1} had recorded highest plant height with longer roots, higher fresh and dry root yield and seed yield and was on par with seed rate of 10 kg of ha^{-1}. The growth attributes *viz.*, leaf area, number of branches per plant and root attributes like root girth, primary roots, secondary roots recorded higher at seed rate of 6 kg of seed ha^{-1} and was on par with 8 kg of seed ha^{-1}. Higher gross income was obtained with the seed rate at 12 Kg ha^{-1}. Further the seed rate at 6 Kg ha^{-1} was observed with lower dry root yield resulting in lower net income and BCR. The seed rate at 12 Kg ha^{-1} had recorded the maximum BCR followed by 10 Kg ha^{-1} seed rate.

Second experiment was on "Effect of spacing on growth and yield of ashwagandha (*Withania somnifera* Dunal.)" with treatments T_1: 30x30 cm, T_2: 30x10 cm, $T_{3:}$ 20x20 cm and $T_{4:}$ 20x10 cm. Plant height was highest with 20x10 cm which was on par with 30x10 cm. The leaf area and primary branches per

plant was recorded highest with 30x30 cm spacing resulted in higher root girth, primary and secondary roots. The treatment 20x10 cm recorded highest root length, fresh root yield, dry root yield and seed yield which was on par with 30x10cm. Higher gross income was observed with 20x10 cm spacing. Further lower dry root yield was observed at 30x30 cm resulting in lowest net income and BCR. The spacing 30x10 cm had recorded the maximum BCR followed 20x10 cm.

Third experiment was on "Influence of biofertilizers in combination with graded levels of P_2O_5 on growth and yield of ashwagandha (*Withania somnifera* Dunal)" with treatments T_1: P_2O_5 @ 30 kg ha^{-1}, T_2: P_2O_5 @ 40 kg ha^{-1}, T_3: P_2O_5 @ 50 kg ha^{-1}, T_4: Azatobactor + P_2O_5 @ 30 kg ha^{-1}, T_5: Azatobactor + P_2O_5 @ 40 kg ha^{-1}, T_6: Azatobactor + P_2O_5 @ 50 kg ha^{-1}, T_7: Phosphobacteria + P_2O_5 @ 30 kg ha^{-1}, T_8: Phosphobacteria + P_2O_5 @ 40 kg ha^{-1}, T_9: Phosphobacteria + P_2O_5 @ 50 kg ha^{-1}, T_{10}: Azatobactor, T_{11}: Phosphobacteria and T_{12}: Control. The maximum plant height, leaf area, leaf area index and primary branches per plant on par was recorded with Azatobactor + P_2O_5 @ 50 kg ha^{-1} was on par with Azatobactor + P_2O_5 @ 40 kg ha^{-1} . The other yield and yield attributes *viz.*, root length, root diameter, fresh root yield, dry root yield and seed yields recorded maximum with Azatobactor + P_2O_5 @ 50 kg ha^{-1} was on par with Azatobactor + P_2O_5 @ 40 kg ha^{-1} and found significantly superior to other treatments. Among the treatments, application of Azatobactor + P_2O_5 @ 50 kg ha^{-1} resulted in higher N, P and K uptake and was on par with Azatobactor + P_2O_5 @ 40 kg ha^{-1} . Application of biofertilizers alone (Azatobactor and Phosphobacteria) had resulted in low values for growth, yield and nutrient uptake and was on par with P_2O_5 @ 30 kg ha^{-1}. Higher gross income was obtained with, Azatobactor + P_2O_5 @ 50 kg ha^{-1} compared to Azatobactor + P_2O_5 @ 40 kg ha^{-1} owing to higher yield. Further the control treatment recorded lowest dry root yield resulting in lower net income and BCR. The treatment, Azatobactor + P_2O_5 @ 50 kg ha^{-1} had recorded the maximum BCR followed by Azatobactor + P_2O_5 @ 40 kg ha^{-1}.

The fourth experiment was on "Effect of time of harvesting on root yield and quality of ashwagandha (*Withania somnifera* Dunal.) with five treatments T_1: 120 days after sowing; T_2: 135 days after sowing, T_3: 150 days after sowing, T_4: 165 days after sowing and T_5: 180 days after sowing. Among different treatments, crop harvesting on 180 days after sowing recorded the highest root length, root girth, dry root weight and higher alkaloid content in roots. The roots obtained at maturity stage, *i.e.*, 180 DAS yielded higher per cent of 'A' grade roots, which was on par with roots harvested at 165 DAS. The crop harvested on 120 days after sowing recorded lower values for above parameters.

The fifth experiment was on "Effect of time of harvesting on quality of ashwagandha (*Withania somnifera* Dunal.) during storage" with five treatments *viz.*, storage of roots for 65 DAH, 90 DAH and 135 DAH harvested at 120 days after sowing (T_1), 135 days after sowing (T_2), 150 days after sowing (T_3), 165 days after sowing (T_4) and 180 days after sowing (T_5).with five treatments T_1: 120 days after sowing, T_2: 135 days after sowing, T_3: 150 days after sowing, T_4: 165 days after sowing and T_5: 180 days after sowing. The studies revealed that as the storage period advances, there was a reduction in the root quality characters like root girth, root weight and total alkaloid content. The dry root weight (g plant^{-1}) was reduced during storage irrespective of harvesting stage. The reduction in girth was almost linear upto

135 days of storage. The loss in weight was maximum in the stored roots harvested at 180 DAS after 135 storage. As the storage period advances, the moisture content of the stored roots increased irrespective of stage of harvest. The total alkaloid content (%) was degraded during storage irrespective of stage of harvest.

LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Per cent
@	:	At the rate of
^0C	:	Degree centigrade
BF	:	Biofertilizers
cc	:	Cubic centimetre
CD	:	Critical difference
cm	:	Centimeter
cm^2	:	Centimeter square
DAP	:	Days after planting
DAS	:	Days after sowing
DAH	:	Days after harvest
EC	:	Electrical conductivity
et al.,	:	And others/Associates
Fig.	:	Figure
FYM	:	Farm yard manure
g	:	Gram
g m^2	:	Grams per meter square
g $plot^{-1}$	:	Grams per plot
GA_3	:	Gibberelic acid
ha	:	Hectare
IAA	:	Indole Acetic Acid
i.e.,	:	That is
K_2O	:	Muriate of potash
kg	:	Kilogram
kg $plot^{-1}$	:	Kilogram per plot
kg ha^{-1}	:	Kilogram per hectare
l	:	**litre**
Lakh ha^{-1}	:	Lakhs per hectare
MAH	:	Months after harvesting

ml	:	Milli liter
mg	:	milligram
mm	:	Millimeter
Plants ha^{-1}	:	Plants per hectare
N	:	Nitrogen
NaOH	:	Sodium hydroxide
NS	:	Not significant
OC	:	Organic carbon
P_2O_5	:	Phosphorus pentoxide
pp	:	Page number / printed page number
ppm	:	Parts per million
PSB	:	Phosphate Solubilizing Bacteria
Q ha^{-1}	:	Quintal per hectare
RBD	:	Randomised Block Design
RH	:	Relative humidity
RDF	:	Recommended dose of fertilizers
Rs ha^{-1}	:	Rupess per hectare
S Em	:	Standard error mean
t ha^{-1}	:	Tonnes per hectare
VAM	:	Vesicular Arbuscular Mychorhiza
vol	:	Volume
viz.,	:	Namely
wt.	:	Weight

INTRODUCTION

CHAPTER I

INTRODUCTION

Medicinal plants encompasses a huge number of plant species that are used in homeopathy and various Indian systems of medicine such as folk medicine, Ayurveda, Siddha and Unani. About 4500 species are used in different folk medicines, 1700 in Ayurveda, 1000 in Siddha, 700 in Unani and 500 in Homeopathy. The demand for the products obtained from these plants such as phytochemicals, steroids, biologically active compounds, alkolids etc. is increasing in national and international market. To meet the demand, medicinal plants are being collected indiscriminately from forests resulting in dwindling supplies and endangering the survival of the species (Government of India, Planning Commission, 2000).

According to World Health Organisation (WHO) more than 1 billion people rely on herbal medicines to some extent. Recently WHO studies indicated that over 30 per cent of the world's plant species have at one time or another been used for medicinal purposes. Among 2,50,000 higher plant species available on the earth, more than 80,000 are medicinal. The products relating to about 20,000 higher plant species are being marketed world over. About 120 chemical compounds of plant origin have been developed into modern pharmaceuticals.

According to the convention of biological diversity report, there was US $ 62 billion sales of herbal medicines in the world and which is expected to increase to US $ 3 trillion by 2020.

Herbal plants are considered as one of the most important sources of medicines since the dawn of human civilization. According to one estimate of botanical survey of India,about 7,500 plants are used for medicinal purposes out of 15,000 plants of our country (Pushpagandan, 1995). There is growing demand for medicines of Ayurveda, Siddha, Unani and Homeopathy both for domestic consumption and export purposes. Out of 80,000 tonnes of medicinal plants imported by Western countries, India tops the list of exporters to USA and Europe with a share of over 10,000 tonnes (Praveenkumar *et al.*, 2007a). The values of trade in medicinal plants is about Rs. 5,000 crores, while the world trade is about US $ 62 billions.

India exports herbal products and medicines to the tune of Rs. 570.8 crores in 2009-10. A survey indicated that the use of herbal medicines will reach to the tune of US $ 5 trillion by 2050 (Ashok Kumar, 2003). Currently, the Ayurvedic and herbal products turnover is estimated to be Rs. 25,000 crores (Tikka and Jaimini, 2007).

In the changing world scenario, cultivation of medicinal plants has assumed greater importance due to the tremendous potential they offer in formulating newer drugs against many diseases and illnesses that affect human kind. The increasing demand for medicinal plant products is much felt by the people and the diversified agro-climate of India is a boon for cultivation and is rightly called the botanical garden of the world. India officially recognized over 3000 plants for their medicinal value. India being one of the 12 mega diversity centers in the world, with this bio-resource wealth, it ranks 10th in the world and 4th in Asia having 15 to 20 thousand plants species with medicinal value of which 30 per cent are considered as endemic to India. Currently, there are about 880 species of medicinal plants in all India trade (Praveenkumar *et al.*, 2007b).

Among the various medicinal plants, *Withania somnifera* Dunal (Wintercherry, Ashwagandha or Asgandh) is an important medicinal plant and its use in Ayurveda and Unani extends back over 3000 to 4000 years (Atal and Schwarting, 1961).

In Ayurveda, the roots of ashwagandha are known to possess health maintenance and restoration properties which are similar to ginseng roots, hence it is called as Indian ginseng. In European market, ashwagandha has recently acquired considerable significance on account of its large demand due to its reported male sex stimulating properties (Joshi *et al.*, 1981). It is an adoptogenic herb and its roots, seeds and leaves are used in Ayurvedic and Unani medicines. The root drug finds an important place in treatment of rheumatic pain, inflammation of joints, nervous disorders, female disorders, hiccup, cold, cough, as a sedative, ulcers, leprosy etc. The leaf paste is applied for carbuncles, inflammation and swellings and leaf juice is useful in conjunctivitis. Bark decoction is taken for asthma and applied locally to bed sores. Ashwagandha and its extracts are used in the preparation of herbal tea, powders, tablets and syrups (Nigam and Kandalkar, 1995).

Ashwagandha is cultivated over an area of 10,780 ha with a production of 8,429 tonnes in India. While the annual demand increased from 7028 tonnes (2001-02) to 9127 tonnes (2004-05) necessitating the increase in its cultivation and higher production. It stands third with annual growth rate of 9.1 per cent next to Amla and Ashoka. Among the traded medicinal plants in India, ashwagandha stands second in trading with a worth of Rs. 100-120 million next to Amla (Tripathi *et al.*, 1996). Due to increasing demand for roots in recent times and considering its future demand, there exists much scope for extensive cultivation of the crop in India.

It grows in dry and sub-tropical regions. Being hardy and drought tolerant species with its enormous biocompounds, its usage is forever regarded and continuous to enjoy the monopoly in many parts of India. The major Ashwagandha cultivating states are Madhya Pradesh, Rajasthan, Punjab, Uttar Pradesh, Haryana, Gujarath and Maharashtra among which Madhya Pradesh alone is having more than 4000 ha area (Misra *et al.*, 1997).

Withania somnifera Dunal (Winter cherry or Ashwagandha or Asgandh), belongs to Solanaceae family is a small woody shrub or herb that grows usually 30 to 50 cm height (maximum of 150 cm). It is an erect growing dicotyledonous plant with fleshy long tap roots. The stem and branches are covered with minute star shaped hairs. Leaves are simple upto 10 cm long, ovate, pedicillate and alternate. Plant bears small (1 cm long), greenish or yellow flowers borne together in short axillary clusters. The fruits or berries are smooth, spherical, red coloured with 6 mm diameter enclosed in an inflated and membranous calyx. The fruit has small kidney shaped yellow coloured seeds (Nigam and Kandalkar, 1995). Roots are fleshy, tapering, whitish brown. Compounds known as Withanolides are believed to account for the multiple medicinal applications of Ashwagandha and the alkaloid percentage in roots ranges from 0.13 to 0.40%.

This crop is generally grown in late *kharif* season only on conserved soil moisture and can be grown on any type of soils having good drainage with 7.5 to 8.0 pH. It requires dry climate for better growth and root development but winter temperatures are known to improve the root quality (Kahar *et al.*, 1991). The areas receiving 67-75 cm rainfall are best suited for its cultivation.

As the quality of root is an important parameter for its marketability, the factors affecting its quality need to be studied and optimized for making ashwagandha cultivation the most remunerative.

There is need to study the time and methods of sowing (direct seeding) to maintain the optimum plant stand (plant density) as both are the important factors for augmenting yield and quality of dry roots. The response of ashwagandha to varying plant densities from 6.6 to 15 lakh per ha was reported by Nigam and Kandalkar (1995). Besides this, the root quality is governed by alkaloid and starch content of root, which could be achieved by manipulating time of harvest. Harvesting of ashwagandha in the month of May end gave maximum root yield without deteriorating quality of the roots (Patel, 2001).

Generally, ashwagandha does not require any fertilizer and experimental evidences showed that indigenous cultivars do not respond to fertilizer application. But considering the need to augment the production of the dry roots to meet the trade requirements, this factor also needs to be attempted. The study conducted in Madhya Pradesh indicated that selection WS-100 gave positive response to nitrogen application at Mandsaur (Dahatonde *et al.*, 1983).

Presently, the crop is cultivated on marginal lands under conserved soil moisture during late *kharif* season resulting in lower root yields. The studies have shown that the use of inorganic fertilizers in appropriate quantity, form and stage of growth could upgrade the yields remarkably (Gupta and Pareek, 1981). Thus, the economic potential of the crop could be realized by expanding its cultivation to better agricultural lands with scientific production technologies.

In the semi-arid to arid central and southern states comprising Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu total area under cultivation is about 76-82% under rainfed agriculture. Successive years of deficit/delayed rainfall and or failure of monsoon affect 54.6 million farm holdings/families in this region (Sastry *et al.*, 2008).

In Andhra Pradesh agriculture is the mainstay of the livelihood of over 60% of the population. Andhra Pradesh with diverse agro-climatic conditions, large bio-diversity and strategic geographical location is likely to emerge a leading producer and supplier of medicinal plant species. Currently, medicinal plants are cultivated in about

10,000 acres of land, beside large area under forests where several medicinal plant species are found in abundance (Kothari *et al.,* 2001*).*

In Andhra Pradesh Medicinal plants are cultivated in isolated patches and each being grown in its favourable soil and agro-climatic conditions, e.g., Senna and Wintercherry are cultivated in dry areas as rainfed crops . Ashwagandha has been cultivated in Ananthapur district of Andhra Pradesh as rainfed crop. There is a lot of potential for cultivation of Ashwagandha in costal districts of Andhra Pradesh under rainfed conditions.

Literature pertaining to the performance of Ashwagandha and on its cultural practices being adopted and influence of biofertilizers on this medicinal crop is very scanty. Further the loss in the alkaloid content of Ashwagandha during storage also to be elucidated. Keeping these research gaps in view, the present investigation was undertaken during 2009-10 and 2010-11 at College of Horticulture, Venkataramannagudem, West Godavari district, A.P with the following objectives,

1. To find out the best method of sowing of ashwagandha.
2. To standardize the seed rate to maximize the root yield of ashwagandha.
3. To study the influence of biofertilizers at different levels of P_2O_5 on performance of ashwagandha in terms of growth and yield.
4. To study the effect of time of harvest on yield and quality of ashwagandha and to observe the changes in quality of roots during storage.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Ashwagandha (*Withania somnifera* Dunal.) is an important medicinal crop grown primarily for its roots. The leaves and seeds are also used in Ayurvedic and Unani medicines. The pharmacological activity of roots is attributed to the presence of several alkaloids specially withanin. The total alkaloid content of Indian ashwagandha roots has been reported to vary between 0.13 to 0.31 per cent (Anon., 1989). The wide variation in the alkaloid content might be due to soil factors, climatic factors and the production technology.

Though this crop has significant importance in the field of medicine, no systematic research efforts have been made to standardize agro-techniques to enhance the productivity. The crop is traditionally grown in marginal lands without application of any nutrients leading to low crop productivity as farmers are not aware of its response to fertilizer application.

In this chapter an attempt has been made to review the relevant research literature on ashwagandha and related medicinal crops with regard to their response to different seed rates, spacing, crop nutrition, stage of harvesting and the quality aspects.

2.1 RESPONSE TO SEED RATES

2.1.1 Effect on growth and yield components

At Hisar , two released varieties (JA-20 and JA-134) of ashwagandha were grown using four seed rates (6, 8, 10 and 12 kg ha^{-1}) to standardize the optimum seed rate and it was observed that the variety JA-134 out yielded(768 kg ha^{-1}) JA-20 in terms of dry root yield. Plant heights (48.1 cm), root diameter (1.73 cm), fresh and dry root weight (34.84 and 2.83 g palnt-1 respectively) were also significantly superior in JA-134. In both the varieties plant height and root yield increased with the increase in seed rate. Seed rate of 12 kg ha^{-1}produced maximum plant height (51.7 cm) and dry root yield (828 kg ha^{-1}). However, root diameter and root weight per plant decreased with higher seed rate. Maximum root diameter (1.72 cm) was found in seed rate of 6 kg ha^{-1} while thinnest (1.47 cm) root was produced with 12 kg ha^{-1}seed rate. Fresh and dry root yields were maximum (3542 and 828 kg ha^{-1}) with the seed rate of 12 kg ha^{-1}, however, these were on par with 10 kg ha^{-1}seed rate (NRCMAP, 2008).

It was observed at Udaipur that the highest root-shoot ratio (2.25:26.96) in ashwagandha was recorded with the use of 10 kg ha^{-1}seed in variety JA-20, while lowest root-shoot ratio (1.87:11.59) was observed in JA-134 with the seed rate of 6 kg ha^{-1} (NRCMAP,2005). In a similar study, five different seed rates (6, 7, 8, 9, and 10 kg ha^{-1}) were tried to optimise the seed requirement at Akola. It was found that plant height increased with increase in seed rate. The tallest (46 cm) and shortest plants (36.45 cm) were observed in seed rates of 10 kg ha^{-1} and 6 kg ha^{-1}, respectively. However, number of branches per plant decreased with increase in seed rate. Maximum root length (18.42 cm) was found in highest seed rate tested and thickness of root decreased with increased seed rates. Thickest root was obtained from seed rate of 6 kg ha^{-1} (0.72 cm) while lowest root girth data was observed in 10 kg ha^{-1} seed rate (NRCMAP, 2005).

In a experiment conducted at Hisar, it was observed that the ashwagandha plant population was more with increased seed rates and the root length was significantly increased in 8, 10 and 12 kg ha^{-1} seed rates compared to seed rate of 6.0 kg ha^{-1}, whereas the trend was reverse in case of root diameter and dry root weight $plant^{-1}$ (NRCMAP, 2008a).

The result of a field experiment conducted at Akola on ashwagandha revealed that the plant height was significantly influenced due to different seed rates and more plant height was recorded with the seed rate of 10 kg ha^{-1}, which was on par with

9 kg ha^{-1} and 8 kg ha^{-1}.The number of branches were significantly more due to lower seed rate *i.e*., 6 kg ha^{-1} and higher with 10 kg ha^{-1} seed rate(NRCMAP, 2008) .

From field experiments on the effect of seed rate on root yield and quality of Ashwagandha, Wankhade *et al.* (2009) observed that the highest plant height of 43.98cm was recorded with the seed rate of 10 kg ha^{-1}, and was on par with the seed rate of 9 kg ha^{-1}(43.05cm) and 8 kg ha^{-1} (42.26cm). They also observed the highest number of branches (6.25) with lower seed rate *i.e.,* 6 kg ha^{-1} and it was on par with 7 kg ha^{-1} and 8 kg ha^{-1} seed rate.

A field experiment was conducted at Herbal Garden, Rajendranagar, Hyderabad to find out the effect of spacing and variable seed rates on dry root yield of Aswagandha with the treatments consisted of broadcasting of seed with five different seed rates (10, 12.5, 15, 17.5 and 20 kg ha^{-1}) and seven different spacing (30x30 cm, 30x20 cm, 30x10 cm, 20x20 cm, 20x10 cm and 20x5 cm) and observed that the number of plants per unit area were highest in broadcasting of Aswagandha seed at the rate of 20 kg ha^{-1}. Length of root was significantly higher in broadcasting of seed @ 17.5 kg ha^{-1}. However, thickness of root and dry weight of root per plant were not influenced by method of sowing **(**Satyanarayana Reddy *et al.,* 2010**).**

2.1.2 Effect on yield

Nigam *et al.* (1984) observed that broadcasting was superior to line sowing for improved yield of Ashwagandha .The plant densities of 3.3 and 6.6 lakh ha^{-1} obtained by maintaining row to row distance of 30 cm recorded good dry yield.

A field experiment was conducted in Anand, Gujarat to determine the effects of seed rate (4, 6, 8 and 10 kg seeds ha^{-1}) and crop duration (90, 150 and 210 days) on the root yield and quality of ashwagandha by Patel *et al.* (2003) and revealed that the seed rates had no significant effects on all the parameters examined.

Significantly maximum root yield of ashwagandha (563 kg ha^{-1}) at Akola was obtained with a seed rate of 10 kg ha^{-1} which was at par with 9 kg ha^{-1}(524 kg ha^{-1}). Lowest root yield of 367 kg ha^{-1} was obtained from the seed rate of 4 kg ha^{-1} (NRCMAP, 2005).

The seed rate at 8 kg ha^{-1} produced significantly highest fresh (1290 kg ha^{-1}) and dry (465 kg ha^{-1}) root yields of ashwagandha at Udaipur (NRCMAP, 2005).

The total dry root yield of ashwagandha was not significantly influenced by method of sowing, however broadcasting of seeds @ 6kg ha^{-1} gave 40.4 % and 12.5% higher yields than transplanted and line sown crops respectively (Patel *et al.,* 2004).

Grade II and III root yields of ashwagandha were significantly increased to the extent of 83 and 60 per cent under broadcasting method over transplanting and line-sown crops respectively (Patel *et al.,* 2004).

A field experiment was conducted in Chhindwara, Madhya Pradesh, to determine the best method for the cultivation of Ashwagandha and the study revealed that direct seed sowing (broadcasting) is the best method for Ashwagandha cultivation as it yielded roots of better quality and recorded higher values for the economic parameters studied (Pandey and Shukla, 2007).

In a field experiment conducted at Akola and Hissar on ashwagandha, the results revealed that the root length was statistically increased in 8,10,12 kg ha^{-1} seed rates compared to lower one of 6 kg ha^{-1} whereas the trend was reversed in case of root diameter and dry root weight per plant. Dry root yield was at par between 10 and 12 kg ha^{-1} seed rates while 12 $kgha^{-1}$ seed rate produced 51.8 and 17.5 per cent higher dry root yield compared to 6 and 8 $kgha^{-1}$ respectively (NRCMAP, 2008).

More plant height was recorded with the seed rate of 10 kg ha^{-1} which was at par with 9 kg ha^{-1} and 8 kg ha^{-1} . The number of branches were significantly more due to lower seed rate *i.e.*, 6 kg ha^{-1} and higher with 10 kg ha^{-1} seed rate (NRCMAP, 2008b).

Highest root yield of ashwagandha was noticed with the seed rate of 10kg ha^{-1} in a trial conducted at Anand Agricultural University, Gujarat (NRCMAP, 2008b).

Dry root yield of ashwagandha was statistically at par between 10 and 12 kg ha^{-1} seed rates while 12.0 kg ha^{-1} seed rate produced 51.8 and 17.5% higher dry root yield compared to 6 and 8 kg ha^{-1}, respectively(NRCMAP, 2008b).

Significantly highest root length and root yield, GMR and NMR in ashwagandha was noticed with the seed rate of 10 kg ha^{-1}, however, it was at par with 9 $kgha^{-1}$ (Wankhade *et al.*, 2009).

The Non significant results were observed under the seed rate treatment trial at Anand, but numerically the highest dry root yield was noted at seed rate 8 $kgha^{-1}$ (NRCMAP, 2010)

Satyanarayana Reddy *et al.* (2010) reported that the maximum dry root yield per hectare of ashwagandha in broadcasting method of ashwagandha at the rate of 17.5 kg ha^{-1} and the line sowing treatments recorded significantly lower yields compared to broadcasting treatments.

2.1.3 Economics

The Incremental Cost Benefit Ratio (ICBR) ratio of ashwagandha cultivation was found higher with 9 kg seed per hectare (Wankhade *et al.*, 2009).

2.2 CROP RESPONSE TO SPACING

A plant would perform better only when it is provided with optimum environmental conditions. The establishment of adequate plant population per unit area is most important to realize the full yield potential of a genotype. Variation in plant population has been found to effect growth and dry matter accumulation due to differential availability of light, moisture and nutrients. Higher plant densities restrict the growth of branches per plant and number of reproductive parts per plant but may be compensated by increased population densities.

In Ashwagandha, root is the economic part of the plant. The agronomic manipulations and practices aimed at improving the yields of roots through optimizing source – sink ratio are of more practical significance. The line sowing provides space for easy interculturing, weeding, fertilizer application and other inputs apart from uniform plant stand ultimately resulting in better growth and development of crop compared to broadcasting method of sowing (Nigam and Kandalkar, 1995). The plant density to be used may depend on nature and fertility of soil and on the marginal lands, the population is kept high (Misra *et al.*, 1997).

2.2.1 Effect on growth and yield components

Veeraragavathatham *et al.* (1985) conducted a spacing trial at Coimbatore in coleus and reported that shoot weight per plant and tuber yield per plant were higher at wider spacing (60 cm x 30 cm) compared to closer spacing (60 cm x 20 cm).

Plant height, plant spread in North- South and East-West directions, branches per plant, leaves per plant, lamina length and breadth of coleus were affected significantly by different plant densities under Arabhavi (Karnataka) conditions (Shankargouda and Hulamani, 1999).

Working with diploid and autotetraploid *Solanum viarum,* Srinivasappa *et al.* (1999) reported inverse relation between the number of berries per plant and plant densities but dry weight per plant was unaffected. The diploid and autotetraploid responded differently to varying plant densities for plant height, leaf length and breadth, petiole length, fruits per node and internodal length.

Jayalakshmi (2003) in a field experiment on coleus at Coimbatore, observed better performance in terms of plant spread, branches, leaf area, stem girth, number of tuberous roots per plant, length and diameter at wider spacing (60 cm x 60 cm) and lower at closer spacing (45 cm x 30 cm).

Studying the optimum spacing requirement for ashwagandha at Jobner Manish 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).

In a field experiment on ashwagandha conducted at Hyderabad, Pakkiyanadhan *et al.* (2004) observed that the growth parameters like plant height, fresh weight of shoot and yield parameters like root length, number of lateral roots were maximum at closer spacing (30x10cm), while maximum number of leaves and fresh and dry weight of roots were observed with wider spacing (30x15cm).

The findings of a experiment conducted on Isabgol *(Plantago indica)* at NRCMAP, Anand to study the effects of different row spacings revealed significant influence of row spacings, maximum plant growth in terms of plant height, number of branches, shoot growth (fresh and dry weights) and leaf growth was observed in 50 cm spacing followed by 60 cm and 65 cm (NRCMAP, 2008C).

In an experiment on Kalmegh *(Andrographis paniculata)* at Akola, spacing of 30 x 15 cm recorded maximum plant height (52.06 cm) followed by 30 x 30 cm (51.85 cm) and 30 x 45 cm (47.15 cm). However, number of branches was maximum at a spacing of 30 x 45 cm (25.6 plant^{-1}). Spacing of 30 x 15 cm also produced significantly higher fresh (63.02 q ha^{-1}) and dry foliage yields (18.90 q ha^{-1}) and total yield of andrographolide (42.68 kg ha^{-1}) (NRCMAP, 2008a).

An experiment undertaken to study the effect of plant density and fertilizer levels on the growth, yield and quality characters in Ashwagandha indicated that wider spacing of 30x30 cm recorded early flowering, higher number of branches and berries per plant (Karad *et al.,* 2009).

Nigam *et al.* (1984) observed significant increase in root yield of ashwagandha at higher plant density of 6.6 lakh per ha (30 cm x 10 cm) compared to 4.4 lakh per ha (45 cm x 5 cm) and 2.2 lakh per ha (45 cm x 10 cm) under Mandsaur conditions.

The optimum spacing requirement for periwinkle was studied by Hegde (1985) at Bangalore (Karnataka). A spacing of 45 cm x 15 cm recorded the highest root, leaf and stem yields. Wider spacing gave significantly lower yields. While, in another experiment at Bhubaneshwar, the highest tuber yield (501.61 q ha^{-1}) was obtained at 40 cm x 45 cm spacing though the tuber weight per plant was more at wider spacings (Saxena and Dutta, 1985).

At Mandsaur on medium black soils, Nigam and Kandalkar (1985) found that the population of 8.0 lakh per ha (25 cm x 5 cm) was optimum for higher root yield of ashwagandha compared to wider spacings. In another study, the response of Ashwagandha to plant density was found upto 15 lakh plants per ha (Nigam, 1985).

Reddy *et al.* (1991) conducted an experiment on planting density and spacing arrangement for higher berry yield in *Solanum viarum* at Bangalore (Karnataka). A linear relationship was found between planting density (upto 49,000 plants ha^{-1}) and berry yield in square spacing. The plant population within a range of 6900 to 28,000 plants per ha with rectangular spacing (East to West) proved superior to square spacing for getting higher berry yields. Planting in the direction of East to West helped in better light interception.

The spacing requirement for *Solanum viarum* was studied by Reddy and Krishnan (1992) at Bangalore (Karnataka) and found that both diploids and tetraploids gave increased berries yield (6216 kg ha^{-1}) at high plant density of 49,000 plants ha^{-1} compared to lower plant densities of 18,000 and 28,000 ha^{-1}.

The results of an experiment conducted at Arabhavi (Karnataka) by Shankargouda and Hulmani (1999) on the effect of different plant densities in Coleus indicated that the highest marketable tuber yield (13.86 t ha^{-1}) was recorded at 1,11,111 plants ha^{-1} and the lowest (7.70 t ha^{-1}) at 27,778 plants ha^{-1}.

Performance of diploid and induced autotetraploid *Solanum viarum* at varying plant densities studied by Srinivasappa *et al.* (1999) at Bangalore (Karnataka) revealed the highest berry yield (9.95 t ha^{-1}) at higher density (1,11,000 plants ha^{-1}).

Farooqui and Sreenivas (2001) reported the optimum plant population of 20,000 to 25,000 per ha for harvesting higher root yield of Ashwagandha under Banglore conditions.

At Coimbatore on red sandy loam soils, Jayalakshmi (2003) reported the higher tuber yield of coleus at closer spacing (45 cm x 30 cm) and lower yield at wider spacing (60 cm x 60 cm).

A field experiment conducted at Uttar Pradesh by Saudan Singh *et al.* (2003) to evaluate the production potential of traditional monocropping systems vis-à-vis monocropping of ashwagandha at low (100 x 103 plants ha^{-1}) and high (200 x 103 plants ha^{-1}) plant density levels indicated 53.8 per cent and 66.7 to 73.3 per cent more roots at high plant density levels than grown at low plant density under monocropping and overlapping systems respectively. They also reported that growing ashwagandha is more economical at both population densities in monocropping systems under moisture stressed rainfed conditions. Overlapping cropping of ashwagandha is suggested as a way to improve the productivity and economic returns from resource constrained rainfed agriculture in sub-tropical North India.

Pakkiyanadhan *et al.* (2004) reported that ashwagandha planted at closer spacing of 30x5cm recorded maximum root yield followed by 30x10cm and 30x15cm. In another spacing trial, Chandrashekhar *et al.* (2007) also found the higher tuber yield of coleus at closer spacing compared to wider spacing.

Experiment on spacing and time of harvest of *Coleus* revealed that the closer spacing of 60cm x 20cm recorded significantly higher dry tuber yield over other spacings (Mastiholi *et al*., 2007).

In an experiment conducted on Isabgol *(Plantago indica)* at NRCMAP, Anand (NRCMAP, 2008c) with different row spacings maximum number of effective spikes plant $^{-1}$ (92.3) were recorded at 50 cm spacing followed by 60 cm spacing (90.3) and 65 cm spacing (77.8) and minimum being noticed in 80 cm spacing (62.9). Number of seeds per spike varied from 31.2 (80 cm spacing) to 53.1 (50 cm spacing).

In Chandrasur *(Lepidium sativum),* a spacing of 30 x 10 cm recorded maximum grain yield of 20.6 q ha^{-1}, whereas the lowest yield of 11.5 q ha^{-1} was obtained with spacing of 45 x 20 cm (NRCMAP, 2008a).

In a field experiment on Hypericum *(Hypericum perforatum)* at Solan, maximum plant height (50.15 cm) was observed with closer spacing of 45 x 30 cm followed by 60 x 30 cm (48.57 cm), but maximum herb yield (6.62 t ha^{-1}) was recorded in 30 x 30 cm spacing (NRCMAP, 2008b).

In a spacing trial conducted on Liquorice *(Glycyrrhiza glabra)* at Hisar, plant spacing of 90×30 cm was statistically at par with 75×45 cm in terms of dry stolon yield compared to 75×30 cm and 90×45 cm spacings (NRCMAP, 2008b).

An experiment was undertaken with a view to study the effect of plant density and fertilizer levels on the growth, seed yield, quality and yield-contributing characters in Ashwagandha and was found that the plant count at harvest, seed and root yield per hectare were maximum with the closer spacing of 30x10 cm than 30x20 cm and 30x30 cm (Karad *et al.,* 2009).

A field experiment conducted at Annigeri (Karnataka) to study the effect of spacings on ashwagandha yield indicated that the dry root yield, nutrient uptake and total withanolide content were significantly higher at a spacing of 15 cm x 10 cm when compared to other spacings of 15 cm x 5 cm, 30 cm x 10 cm and 45 cm x 10 cm (Kubsad *et al*., 2009).

In a field experiment conducted in Raichur, Karnataka, on the effects of planting date and harvesting stage of ashwagandha, Shamaraj Chandranath *et al*.(2010) reported that the harvesting of ashwagandha at the maturity stage resulted in the greatest length (14.04 cm) and diameter (1.44 cm) of roots, fresh (27.94 g per plant) and dry (6.20 g per plant) root weights, root to shoot ratio (0.103), and fresh (1714 kg ha^{-1}) and dry (837 kg ha^{-1}) root yields and the highest total withanolide content of roots was obtained with harvesting at the 50% flowering stage (0.62%).

In ashwagandha var WS-20, the dry root yield (426 kg ha^{-1}) and seed yield (260 kg ha^{-1}) were significantly higher at plant density of 8 lakh ha^{-1}, while the highest root yield (492 kg ha^{-1}) and seed yield (312 kg ha^{-1}) were recorded at 6 lakh ha^{-1} in WS-22 (Mohd Abbas *et al.*, 1994).

In a field experiment on clay alkaline soils at JNKVV, Mandsaur, Nigam *et al.* (1984) observed that application of 30:30:0 kg N, P_20_5 and K_20 per ha to ashwagandha at plant density of 6.6 lakh per ha recorded significantly higher root yield (812 kg ha^{-1}) compared to 4.4 and 2.2 lakh/ha at same fertilizer level.

2.2.2 Effect on nutrient uptake

In a spacing trial at Coimbatore on red sandy loam soils, Jayalakshmi (2003), reported higher N, P and K content in tuberous roots of coleus in wider spacing

(60 cm x 60 cm) than closer spacing (45 cm x 30 cm) while, closer spacing recorded the higher uptake of N, P and K (kg ha^{-1}) at 180 days after planting.

2.2.3 Effect on alkaloid, starch and essential oil content

The effect of spacing on Solasodine in *Solanum viarum* was studied by Patil and Laloraya (1981) at Indore (Madhya Pradesh) who observed the highest solasodine yield (106 kg ha^{-1}) at 45 cm x 60 cm spacing and lowest (72.4 kg ha^{-1}) at 90 cm x 120 cm spacing.

Rao *et al.* (1981) studied the spacing requirement of medicinal yam (*Dioscorea floribunda*) and reported that a spacing of 45 cm x 30 cm for one year crop and 60 cm x 45 cm for two year crop gave the highest diosgenin yields.

In a spacing trial at Jorhat, the maximum diosgenin yield (356.34 kg ha^{-1}) from *Dioscorea florifunda* was obtained by planting at 30 cm x 30 cm spacing (1,11,000 plants ha^{-1}) as reported by Singh *et al.* (1981). In another trial at Bhubaneshwar, Saxena and Dutta (1985) observed the highest diosgenin yield (528.70 kg ha^{-1}) at 40 cm x 45 cm spacing, but diosgenin content remained unaffected by plant spacing.

In a field experiment on planting density, at Bangalore (Karnataka), Reddy *et al.* (1991) reported that the plant densities within the range of 6,900 to 28,000 plants per ha with rectangular spacing (East to West) proved superior to square planting for obtaining higher solasodine yield in *Solanum viarum.*

Reddy and Krishnan (1992) in an experiment on effect of plant density on solasodine yields in *Solanum viarum* at Bangalore, reported higher solasodine yield (155.7 $kgha^{-1}$) at higher plant density (49,000 plants ha^{-1}) compared to lower plant density of 18,000 plants per ha (84.3 $kgha^{-1}$).

In a field trial conducted on the effect of plant densities at Arabhavi (Karnataka), Shankargouda and Hulmani (1999) reported the highest essential oil yield

(12.10 l ha^{-1}) at higher plant population (1,11,111 ha^{-1}) and lowest oil yield (8.67 l ha^{-1}) at 27,778 plant per ha in *Coleus forskohlii*.

The results of the experiment on effect of seed rate and crop duration on root yield and quality of ashwagandha conducted at GAU, Gujarath, by Patel *et al.* (2003) indicated that the seed rate of 4 kg/ha recorded significantly higher total alkaloid content of 0.944 and 0.907% in thin and thick roots respectively compared to seed rates of 6, 8 and 10 kg ha^{-1}.

2.2.4 Economics

In an experiment at Jobner (Madhya Pradesh), the highest net profit (Rs. 56,098 ha^{-1}) and B:C ratio (3.46) were obtained when ashwagandha was sown on 20th July at 20 cm x 7.5 cm spacing compared to other treatment combinations (Manish Agarwal *et al.*, 2003).

Jayalakshmi (2003) at Coimbatore realized the highest net returns (Rs. 82,192 ha^{-1}) and benefit : cost ratio (4.27) in closer spacing (45 cm x 30 cm) with 50 kg N per ha at 180 days after planting of coleus.

Saudan Singh *et al.* (2003) reported that growing ashwagandha proved to be more economical at high (200 x 103 plants ha^{-1}) and low (100 x 103 plants ha^{-1}) plant densities under monocropping and it is an ideal crop for moisture stressed rainfed conditions in subtropical North India.

Kubsad *et al.*(2009) reported that the maximum dry root yield of ashwagandha (1.55 t/ha), net returns (Rs 50,141/ha) and total withanolide content (0.62%) accrued when the crop was sown at 15 cm x 10 cm spacing along with fertilizer doze of 24-21.2 kg N-P/ha.

2.3 RESPONSE TO BIO-FERTILIZERS

Bio-fertilizers play a pivotal role in sustainable agriculture. They are cheaper when compared to chemical fertilizers and help in reducing the consumption of chemical fertilizers. They improve productivity of the soil and provide good soil health. Bio-fertilizers accelerate the microbial process of converting unavailable form of plant nutrients to available form (Sanjay Singh *et al.*, 2002). Bio-fertilizers are eco-friendly and provide better crop yields and uptake of plant nutrients. Bio-fertilizers *viz., Azospirillum* and *Azotobactor* are known to fix nitrogen, Phosphobacterium mobilize and solubilize phosphorus and increase the uptake of phosphorus, thereby cutting down the quantity of nitrogenous and phosphorus fertilizers to be used for raising good crops (Sanjay Singh *et al.*, 2002., Kamalakannan and Manivannan, 2003). These Bio-fertilizers contain living cells of different types of microorganisms, which have an ability to make the soil living and dynamic (Srinivasappa *et al*., 2007). Dash *et al.* (2008) reported that in all organic farming situations, addition of *Azospirillum* to package of practices will enhance the production of ginger.

The use of microbial inoculants to supplement nitrogenous and phosphatic fertilizers has gained immense importance owing to the energy and cost intensive manufacturing of chemical fertilizers. Moreover, the populations of beneficial micro-organisms present in the soil have been reduced due to excessive use of chemicals on the crops for different purposes especially to control pests and diseases, which necessitated supplying them artificially. Mohapatra *et al.* (2009) reported the free living nitrogen fixing bacteria *Azospirillum* and phosphate solubilizing bacteria (PSB) have been used as biofertilizer to increase the availability of N and P respectively.

2.3.1 Azotobactor

Azotobacter is gram negative bacteria, polymorphic *i.e.,* they are of different sizes and shapes .These are free living bacteria which grow well on a nitrogen free medium. These bacteria utilize atmospheric nitrogen gas for their cell protein synthesis. This cell protein is then mineralised in soil after the death of Azotobacter cells thereby contributing towards the nitrogen availability of the crop plants.

Old population of bacteria includes encapsulated forms and have enhanced resistance to heat, desication and adverse conditions. The cyst germinates under favourable conditions to give vegetative cells. They also produce polysachharides. Azotobacter spp., are sensitive to acidic pH, high salts, and temperature above 35^0C. There are four important species of Azotobacter viz. *A.viz.,chroococcum, A.agilis, A.paspali and A.vinelandii* of which A.*chroococcum* is most commonly found in our soils.

Most efficient strains of Azotobacter would need to oxidise about 1000 kg of organic matter for fixing 30 kg of N/ha. This does not sound realistic for our soils which have very low active carbon status. Besides, soil is inhabitated by a large variety of other microbes, all of which compete for the active carbon. Azotobacter also produces some substances which check the plant pathogens such as *Alternaria, Fusarium and Helminthosporium.* Hence Azotobacter also acts as a biological control agent.

Azotobacter naturally fixes atmospheric nitrogen in the rhizosphere. There are different strains of Azotobacter each has varied chemical, biological and other characters. However, some strains have higher nitrogen fixing ability than others.

Azotobacter uses carbon for its metabolism from simple or compound substances of carbonaceous in nature. Besides carbon, Azotobacter also requires calcium for nitrogen fixation. Similarly, a medium used for growth of Azotobacter is required to have presence of organic nitrogen, micro-nutrients and salt in order to enhance the nitrogen fixing ability of Azotobacter. Besides, nitrogen fixation, Azotobacter also produces, Thiamin, Riboflavin, Nicotin, indoleacetic acid and gibberellin. When Azotobacter is applied to seeds, seed germination is improved to a considerable extent, so also it controls plant diseases due to above substances produced by Azotobacter.

2.3.2 Effect of Azotobacter on growth and yield attributes

Khullar and Chahal (1977) reported that Azotobacter inoculation increased the yield by 15.8 per cent over control in carrot. Khullar *et al.* (1978) observed that Azotobacter inoculation increased the height of both brinjal and chillies by 63.4 and 42.2 per cent, respectively over uninoculated control.

Kolhe (1978) studied the performance of bio- fertilizers on the yield of leafy vegetables and observed that, shepu and palak vegetable crops showed response and have recorded 15.25 and 14.95 per cent more yield over untreated control with Azotobacter.

Maheshwari *et al.* (1988) reported that Azotobacter alone or in combination with nitrogen showed a sizable increase in total alkaloid content and yield of black henbane.

Meshram and Shende (1990) reported that Azotobacter inoculation in onion significantly increased the number of shoots per plant, height of shoot, root volume per plant and dry weight of roots per plant as compared to uninoculated control.

Thakre (1992) reported that seed inoculation with Azotobacter found superior over control in respect to height of plant, number of branches, weight of fresh fruit and yield of okra.

Jadhav (1998) observed that inoculation of Azotobacter gave maximum sprouting, length of vine, number of large tubers, weight of tubers and length of tuber over control in sweet potato.

An experiment was conducted on effect of FYM and biofertilizers on dry root and seed yield of Ashwagandha during 2000-2001 and 2001-2002. The results revealed that the inoculation of Azotobacter @ 10 kg ha^{-1} recorded root yield of 3.58 and 2.58 q ha^{-1} respectively during 2000-2001 and 2001-2002 than that of uninoculated control (NRCMAP, 2002).

Nandre (2003) observed that seedling inoculation of Azotobacter increased the plant height, girth of stem, number of branches and number of flowers per hectare in china aster over un inoculated control.

Yadav (2003) conducted a field experiment on potato to evaluate efficiency of Azotobacter with and without nitrogen and it was revealed that Azotobacter inoculations increased potato tuber yield from 5 to 14 per cent in absence the of nitrogen.

In a field experiment on *Hypericum perforatum* conducted at Y.S.Parmar University of Horticulture and Forestry,Solan, it was observed that the combination of vermicompost with Azotobacter recorded maximum plant height(55.8cm), number of branches (42.27), root length(46.35cm) fresh herb yield/plant(62.56g) and this treatment was followed by combination of vermicompost with VAM and PSB (NRCMAP,2008 a).

2.3.3 Phosphate solubilizing bacteria (PSB)

Isolates of phosphate solubilizing bacteria are able to improve phosphorus nutrition of plants and thus can stimulate plant growth under conditions of phosphorus deficiency (Domey and Lippmann, 1988).

Phosphate solubilizing bacteria such as *Bacillus* spp., *Pseudomonas striata and* phosphobacteria have the ability of solubilizing insoluble phosphorus. These bacteria secrete organic and inorganic acids such as malic acid, citric acid, formic acid, acetic acid etc., and they lower the pH and bring about the dissolution of bound form of phosphorus and make it available to plants (Sanjay Singh *et al.*,2002).

Phosphate solubilizing bacteria, apart from enhancing P availability also known to produce aminoacids, vitamins and growth promoting substances like, IAA, GA which help in better growth of plants (Anandan, 2000).

Phosphate solubilizing bacteria (PSB) was reported to increase the availability of phosphorus in turmeric (Mohapatra *et al.,* 2009).

2.3.4 Effect of PSB on growth and yield attributes

Kundu Gaur (1980) conducted experiment on potato var. Kufri Navjyoti. The yield of potato tuber was increased about 24 to 31 q ha^{-1} and 36 q ha^{-1} due to inoculation with single and mixed culture of Phosphobacteria respectively.

Kandasamy (1990) conducted an experiment on brinjal and chillies by treating seed with Phosphobacteria. They concluded that inoculation of Phosphobacteria and VAM resulted in maximum plant height and root length. They further stated that seed inoculation with Phosphobacteria increased plant height, seedling dry weight and root length than the uninoculated control both in brinjal and chillies.

Sharma and Bhalla (1995) reported that application of biofertilizers as PSB + Azospirillum showed superiority in growth parameters viz., plant height, leaves per plant and branches per plant as compared to control without any type of fertilizer in okra.

Dadhich *et al.* (2001) recorded increased plant height, branching, dry matter production, yield attributing characters and seed yield in cluster bean with PSB inoculation.

Gaiki *et al.* (2006) reported that application of *Azotobacter* and PSB along with 75 per cent recommended dose of fertilizers (100: 50: 100 N,P and K kg ha^{-1}) significantly increased the plant height, leaf number, bulb diameter, bulb weight and yield ha^{-1} in garlic.

2.3.5 Effect of FYM in combination with Azotobacter and PSB on growth and yield attributes

Naidu (1999) reported that application of 35 t FYM ha^{-1}+ Azospirillum + PSB showed more plant height, number of leaves, nodes per plant, girth of stem, number of fruits per plant, weight of fruits per plant and fruit yield over control in okra.

Kamala (2000) found that combined application of Azospirillum, Phosphobacteria and VAM each @ 2 kg ha^{-1} with farm yard manure @ 30 t ha^{-1} as soil application resulted in earliness, closer sex ratio, increased fruit size, number of fruits and mean tender fruit yield for two seasons in cucumber.

Application of FYM @ 5 t ha^{-1}+Azotobacter @ 10 kg $ha^{-1}$and PSB @ 10 kg ha^{-1} appeared to be beneficial for quality dry root yield and seed yield over control in Ashwagandha (NRCMAP, 2002).

Prabu (2002a) while working on integrated nutrient management in okra cv Parbhani Kranti, observed that the treatment combination of 2/3rd RDF + FYM + Azospirillum + PSB was found significant over all the treatments in respect of plant height, number of leaves, number of branches, root length and yield per plot.

Prabu (2002b) reported that the treatment 25 % RDF +FYM+ Azatobactor + PSB increased plant height, number of leaves, root length and yield per plot in coriander.

In a study on effect of different biofertilizers on aerial biomass of *Valeriana jatamansi* at Solan, it was recorded that the maximum aerial biomas, under ground biomas, root and rhizome yield per plant was maximum in combination of Azatobactor+PSB+VAM, which was statistically different from all other values. The nutrient uptake by aerial biomass as well as under ground biomass revealed that the organic carbon (0.13%), N (361.96kg/ha), P (38.28kg/ha) and K (187.20kg/ha) were maximum in Azotobactor + PSB + VAM combination as compared to other treatments. However, fresh aerial biomas/plant (g), fresh under ground biomass perplant (g) and fresh root yield/plant (g) were significantly higher with Azotobactor (10kg/ha), but significantly higher fresh rhizome yield/plant in PSB (10$kgha^{-1}$) treatment (15.91g) than Azatobactor (10 $kgha^{-1}$) treatment were reported (NRCMAP, 2006 a).

2.4 PHOSPHORUS

Phosphorus (P) is one of the most important elements for plant growth and metabolism. It plays key roles in many plant processes such as energy metabolism, the synthesis of nucleic acids and membranes, photosynthesis, respiration, nitrogen fixation and enzyme regulation (Raghothama, 1999). Adequate phosphorus nutrition enhances many aspects of plant development including flowering, fruiting and root growth.

2.4.1 Effect of Phosphorus on Growth Characters

Karnick (1978) studied the effects of application of fertilizer NPK (10:10:10) at different stages of plant growth in three crop seasons and the results revealed that fertilizer application at pre-flowering stage did not improve the growth of ashwagandha. But, Sandhya Singh *et al.* (1999) while compiling information regarding ashwagandha hypothesized that these results were of limited value, as there are contrary to the general phenomenon that fertilizer application during vegetative phase or up to pre-flowering stage only brings about desired results.

Mital and Saxena (1978) while reviewing cultivation aspects of black henbane reported that a supplementary basal application of 40 kg/ha phosphorus is desirable for better growth and productivity.

Stoltz (1982) concluded that addition of increasing P to the nutrient solution resulted in increased fresh weight of American ginseng upto a level of 1.5 times above the usual rate.

Mallick *et al.* (1989) carried out a field experiment at Mungpo, India with 3 levels of each of P_2O5, (0, 40 and 80 kg/ha), N (0, 50 and 100 kg/ha) and K_2O (0, 20 and 40 kg/ha) in *ipecac* and recorded highest shoot weight (10.75 g/plant) at 80 kg P_2O_5 + 50 kg N + 40 kg K_2O /ha; root weight (8.13 g) at 40 kg P_2O_5 combined with 50 kg N and 20 kg K_2O. Phosphorus did not show any influence on root : shoot ratio. They recorded highest root : shoot ratio (0.59) at zero P and K level with 50 kg N ha^{-1}.

Appropriate dose of P along with N and K fertilizer required for better growth of *Atropa* was also determined by Zaidi (1992). Further, Shylaja *et al.*(1996) studied the response of periwinkle to P and reported that application of P combined with N and K fertilization significantly increased growth and productivity.

Maitra (1998) investigated the effects of N, P and K fertilizers on the growth of *Vinca* and concluded that P concentration in the nutrient solution or shoot tissue had little or no effect on the shoot growth of seedlings, but shoot P levels increased with increasing P in the fertilizer solution (Luxury consumption).

The response of ashwagandha seedlings to various sources of nutrients viz., cow dung, bone meal, neem seed cake, sterameal (an organic fertilizer) a mixture of organic sources or 3 doses of NPK was observed by Maitra *et al.* (1998). They reported that application of P at the rate of 28 g per 1.3 sqm. along with 28 g each of N and K gave the best (significant) increases in vegetative growth, flowering and fruiting.

2.4.2 EFFECT OF PHOSPHORUS ON YIELD ATTRIBUTES

2.4.2.1 Root yield

Karnick (1978) studied the effects of application of fertilizer NPK (10:10:10) at different stages of plant growth in three crop seasons and the results revealed that fertilizer application at pre-flowering stage did not improve the growth and root yields of ashwagandha.

Sandhya Singh *et al.* (1999) while compiling information about ashwagandha stated that those results are contrary to the general phenomenon that fertilizer application during vegetative phase or upto preflowering stage only brings about the desired results. Maheshwari and Yadav (1981) reported highest root yield of ashwagandha at 40 kg $P_2O_5$and 20 kg N ha^{-1}.

Earlier reports by Nigam (1984) while reviewing profitability of growing ashwagandha in Madhya Pradesh stated that no response was observed on the root yield of the crop due to application of nitrogen and phosphorus.

In clayey soil with alkaline in reaction (pH 8.2) N: P: K levels of 30:30:0 (kg per hectare) recorded highest dry root yield of ashwagandha. But increasing levels of fertilizers (NPK) had no effect on the yield of dry roots (Nigam *et al.*, 1984).

Further, Singh and Mishra (1997) found 40 kg P_2O_5 + 15 kg N/ha responsible for increased crop production of ashwagandha.

Maitra (1998) found that the two NPK treatments *i.e.*, 28:28:28 and 42:42:42 g/1.3 m^2 as the best treatments for root yields of ashwagandha.

Muthumanickam and Balakrishnamurthy (1999) conducted fertilizer trials at Yercaud (Tamil Nadu) with the objective of increasing root yield and determining nutrient requirements of ashwagandha and reported that treatment of 60 kg P_2O_5/ha along with 40 kg N and 20 kg K_2O/ha gave the highest dry root yield of 770.37 kg/ha.

Maheshwari *et al.* (2000) conducted a two year field study during late rainy season under rain fed conditions in shallow black soil (depth 40-50 cm), belonging to Malwa plateau of Madhya Pradesh, having low available N (240 kg/ha), P (25 kg/ha) and K (570 kg/ha) and concluded that application of 25 kg P_2O_s recorded highest dry root yield along with 2.5 tonnes FYM and 12.5 kg N recorded highest dry root yield in ashwagandha.

2.4.2.2 Herbage yield

The dry matter production of periwinkle increased with the increasing level of fertilizer and was maximum at 20 kg P combined with 40 kg N and 20 kg K. Highest dry weight (g)/plant was obtained with the increasing levels of fertilizer and the value was maximum at N_{40} P_{20} K_{20} level. At N_0 P_0 K_0 and N20 P_{20} K_{2O} levels did not show any significant difference among themselves, although these values were significantly lower than that of $N_{40}P_{20}K_{20}$ level (Munsi 1985).

Maheshwari *et al.* (1989) reported that dry herbage yield of *Hyoscyanus albus* L. increased with increasing P rates from 16.29 q/ha at zero P to 18.24 q/ha at 80 kg P_2O_5/ha in a medium clay loam soil with initial contents of 81.6, 14.2 and 375 kg/ha of available N, P and K respectively.

Vitkare (1992) also found non significant influence on periwinkle foliage yield by varying levels of phosphorus.

Sharma *et al.* (1995) investigated the effects of 0, 40 or 80 kg $P_2O_5ha^{-1}$ in combination with 0, 40, 80 or 120 kg N ha^{-1} on production of Egyptian henbane in their field study and stated that fertilizer treatments had no significant effects on herbage yield.

2.5 RESPONSE TO STAGES OF HARVESTING

The stage of harvesting in any crop plays a vital role in harvesting maximum yield and also good quality products. If not harvested timely, the yield losses are to the great extent. The crop whose economic parts (roots) are below the ground, it is difficult to ascertain the right stage of harvesting though yellowing and leaf senescence may indicate to some extent the harvesting stage, but these changes could also be due to biotic and abiotic factors. In ashwagandha, the maturity of the crop is judged by drying of leaves and yellow-red berries. The crop is ready for harvest at 150-180 days after sowing depending on soil moisture status. It requires dry climate for better root growth but winters are known to improve the root quality (withanolide content) and root yield (Kahar *et al.*, 1991).

2.5.1 Effect on growth and yield components

In a study conducted in sandy loam soils of Hyderabad (Andhra Pradesh) on the effect of genotype and time of harvesting on yield and quality of periwinkle under irrigation, recorded the highest number of leaves per plant at 10 months after planting (Rao *et al.*, 1993).

The experiments conducted on loamy sandy soils during late *kharif* at GAU, Anand to study the effect of N levels and stages of harvesting on growth and yield of ashwagandha revealed that shoot length, root: shoot ratio, root diameter and dry matter production were not affected by stages of harvesting (Patel, 2001).

Jayalakshmi (2003) at Coimbatore reported higher growth (plant height, plant spread, number of laterals and leaf area per plant) and yield attributes (number of tuberous roots, length, diameter and tuberous root yield per plant) at 180 DAP in coleus.

The time of harvesting had no significant effect on plant heigh of Kalmegh *(Andrographis paniculata)* under Akola conditions. Significantly highest branches (23.66 plant^{-1}) and fresh and dry foliage yields (51.42 and 15.42 q ha^{-1}) were recorded with harvest at 60 days after 50% flowering. However, it was at par with harvest at 45days after 50% flowering (NRCMAP, 2008a)

The experiments at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra) indicated that significantly highest root yield was recorded with the harvesting at 100% flowering stage over all other treatments except berry ripening stage (Wankhade *et al.*, 2011)

The effect of planting material and time of harvesting on tuber yield in medicinal yam under irrigation was studied by Hegde *et al.*(1981) at Bangalore. Harvesting of tubers earlier than 15th February reduced the tuber yields and harvesting much later than 15th February had no additional advantage on yield. In another study at Hyderabad, Rao *et al.* (1993) observed that there was no significant effect of time of harvesting on root yield of perewinkle.

The root and seed yields of ashwagandha were not significantly affected by stage of harvesting under Anand conditions (Patel, 2001). However, a significant increase in the yield of both thin and thick roots (from 92.0 to 171.0 kg ha^{-1} and 25.9 to

43.6 kg ha^{-1} respectively) with the increase in days of harvesting from 90 to 210 DAS was reported by Patel *et al.* (2003).

Patel *et al.* (2004) studied the effect of time of sowing, time of harvesting and N application on dry root yield of ashwagandha at GAU, Anand and observed no significant effect of time of harvesting on root yield.

Mastiholi *et al*.(2007) while studying the effect of spacing and time of harvest on growth and yield of *Coleus* reported that the crop harvested at 180 or 160 DAP produced higher dry tuber yield (1.45and 1.39 t/ha respectively) .

In an experiment conducted at Akola on Kalmegh *(Andrographis paniculata)* to study the effect of harvesting times it was indicated that the seed yield was significantly highest with harvest at 45 days after 50% flowering (1.86 q ha^{-1}), which was at par with harvest at 30 days after 50% flowering (1.74 q ha^{-1}). The andrographolide content (2.36 %) from plants harvested at 15 days after 50% flowering and those harvested at 30 days after 50% flowering (2.33 %) were at par each other. (NRCMAP, 2008a).

2.5.2 Effect on uptake of nutrients

A study at Anand, Gujarat on the effect of stage of harvesting and N levels on nutrient uptake by ashwagandha indicated that N content of plant was significantly higher at 150 DAS (1.91%) compared to 210 DAS, while the uptake of N was significantly higher at 210 DAS (65.3 kg ha^{-1}) and P and K uptake were unaffected by stage of harvesting (Patel, 2001).

Kiruthikadevi (2002) reported decreased levels of N and P content of ashwagandha leaves with increased age of the plants , while the K content of leaf found to increase with increase in age (150 DAP).

Jayalakshmi (2003) at Coimbatore observed higher N and P content at 150 DAP and K at 180 DAP in coleus, while the uptake of N, P and K was found to be the highest at 180 DAP.

2.5.3 Effect on alkaloid content

Hegde *et al.* (1981) studied the effect of planting materials and time of harvesting on diosgenin content in *Dioscorea floribunda* under irrigated conditions at Bangalore (Karnataka) and found that harvesting of tubers earlier than 15th February, reduced the diosgenin yields. Whereas, harvesting later than 15th February had no effect on diosgenin content (2.81 – 3.75%).

In another experiment, Celyan and Kaya (1983) found that the alkaloid content in ashwagandha roots was highest at the beginning of flowering (0.132%) followed by post flowering (0.123%) compared to full bloom and fruiting stages. Rao *et al.* (1993) reported the highest root alkaloid yield (141.5 mg plant^{-1}) of periwinkle at 10 months after sowing.

The results from a field experiment on different seed rates of ashwagandha revealed that the maximum amount of alkaloids in roots was recorded at 4 kg seeds per ha when harvested at the end of May (Anon., 2000). Karthi Kumar (2000) observed higher alkaloid content in the roots of Ashwagandha at fruiting stage followed by flowering stage.

The studies of Patel (2001) revealed that the stage of harvest could not exert significant influence on total withanolides and starch content of ashwagandha roots .

Patel *et al.* (2003) studied the effect of seed rate and crop duration on root and quality of ashwagandha at GAU, Anand. They found that the alkaloid content was more in late harvested crop (210 DAS) compared to early harvested crop (90 and 150 DAS). A significant negative correlation between alkaloid and starch content (-0.4874) was reported. Further alkaloid content was more in root of different grades at a seed rate of 4 kg per ha. Variation in alkaloid content of ashwagandha with age of the crop was also reported by Baraiya *et al.* (2005).

In an experiment conducted to study the uptake of nutrients, root yield and quality of ashwagandha as influenced by harvesting period under Akola (Maharashtra) conditions, it was observed that the total alkaloids content was significantly highest at 50% flowering stage followed by 100% flowering stage, however the yield of total alkaloids was significantly highest with 100% flowering stage over all other treatments (Wankhade *et al.,* 2011)

A field experiment conducted on sandy loam soils of Anand during late *kharif* revealed that physical characters and dry root yield of ashwagandha in general were not significantly affected due to different seed rates (plant densities) and harvesting time, except total dry root yield which highest (227 kg ha^{-1}) when crop was harvested by May end (Anon., 2000).

2.5.4 Economics

The results of the experiment on method of sowing, harvesting time and N levels on yield and economics of ashwagandha indicated that harvesting the crop at 210 DAS recorded the highest gross returns (Rs. 65,940 ha^{-1}), net returns (Rs. 56,237 ha^{-1}) and B:C ratio (6.80) compared to harvesting at 150 DAS (Patel, 2001).

2.6 EFFECT OF STORAGE PERIOD ON QUALITY

Patel *et al.* (2009) studied the physico- chemical stability and biological activity of *withania somnifera* extract under real-time and accelerated storage conditions and observed that the significant decline in withaferin-A and withaferin-B both under real time and accelerated storage conditions. The decline of withaferin-A and withaferin-B continued from 0 to 6 months of storage. The study also revealed that the moisture content (w/w) of the samples were increased with increase in storage period both in real time and accelerated storage conditions.

In a storage study of ashwagandha at Hissar it was observed that the total alkaloid content (%) decreased from 0.7 to 0.417% in 12 months. The % decrease in total alkaloids content was 8.9, 14.5, 18.3, 25.8, 31.4 and 41.3% respectively from 2, 4, 6,8,10 and12 months after storage. (NRCMAP, 2006a).

In a field experiment at Jabalpur (M.P), Anubha Upadhyay (2011) observed the sennoside A and B of senna were magnificently reduced with increase in storage period from 1st month to till the sixth months. The losses of sennosides A and B in storage were found to be lowest in black polythene bags as compared to aluminum foil and transplant polythene bags.

Ram Chandra and Dinesh Kumar (2007) observed the Safed musli roots stored for six months in CFB boxes showed physiological loss on weight (ranging from 31.83 to 43.91%) in different genotypes and moisture content of 69.43% in CBI-13 genotype and 73.01% in CBI-2 genotype.

In a laboratory experiment at Akola while studying post harvest degradation of Saponia content in Satavar observed the highest moisture content during the storage period of 6 MAH (Months After Harvest) and was on par 8 and 10 MAH. The Saponin content decreased gradually with the increase in storage period and the lowest content was noticed at 12 MAH and was at per with 10 MAH. (NRCMAP, 2006)

MATERIAL AND METHODS

CHAPTER III

MATERIAL AND METHODS

Five experiments were conducted on **"Standardization of Agro-techniques for Ashwagandha (*Withania somnifera* Dunal) in coastal districts of Andhra Pradesh"** during late kharif seasons of 2009-10 and 2010-11 at College of Horticulture,Venkataramannagudem, West Godavari district , Andhra Pradesh. Details of the materials used and experimental techniques adopted during the investigation are described in this chapter.

3.1 GEOGRAHICAL LOCATION OF THE EXPERIMENTAL SITE

The College of Horticulture, Venkataramannagudem, West Godavari district, Andhra Pradesh comes under coastal belt and is situated at an altitude of 34 m above mean sea level. The geographical situation is 16^0 83^1N latitude and 81^0 50^1E longitude.

3.2 SOIL CONDITIONS OF THE EXPERIMENTAL SITE

Prior to preparatory cultivation, soil samples were collected at random from zero to 30 cm depth from the experimental field and a composite sample was analyzed for physico-chemical properties by following standard methods (Table 1). The experimental soil was red sandy loam in texture, neutral in reaction, low in organic carbon and available nitrogen, high in available phosphorus and medium in available potassium.

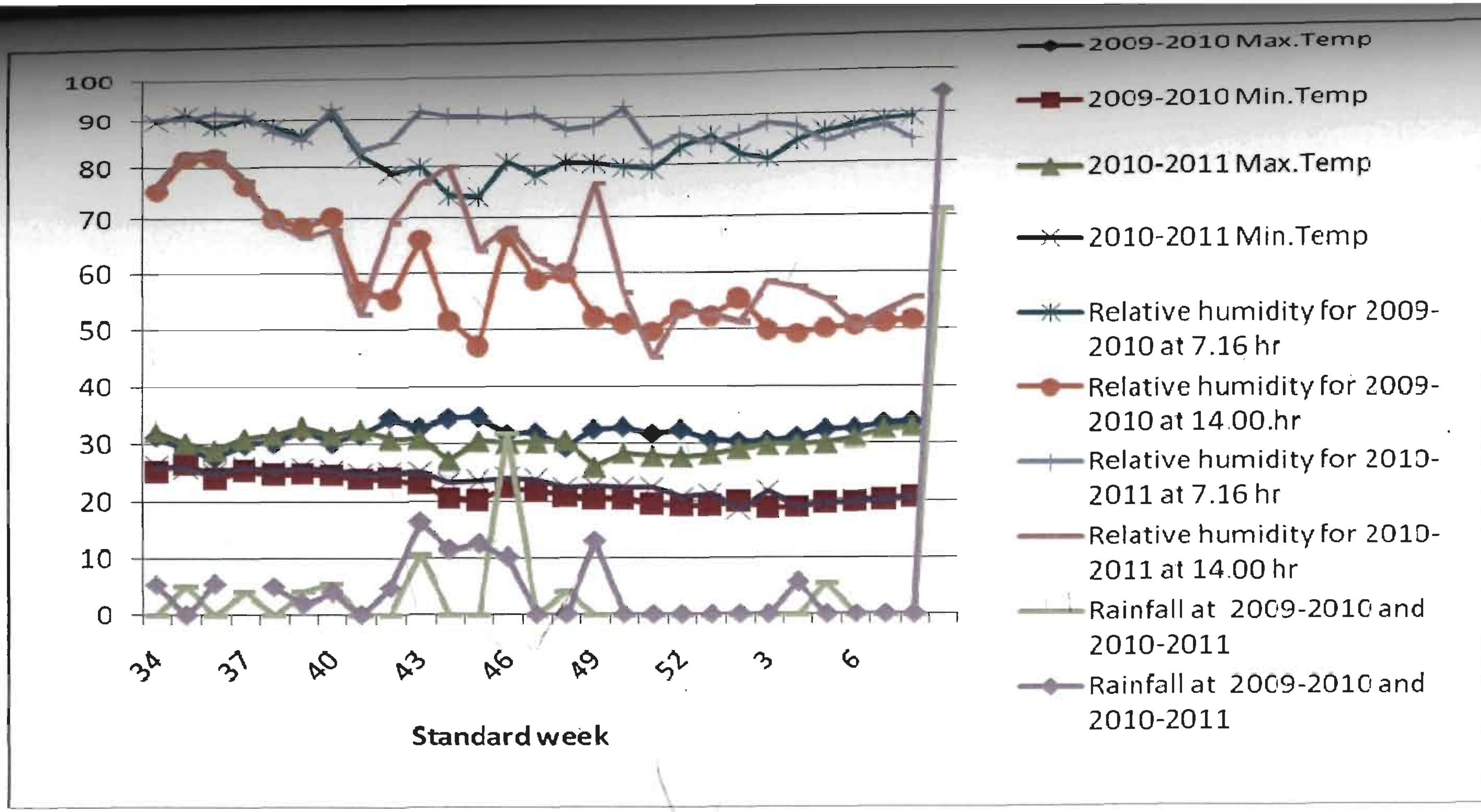


Fig. 1 Weekly meteorological data during the crop period (2009-10 and 2010-11)

Fig.1a: Layout plan of experiment on

ANDARDIZATION OF AGRO TECHNIQUES FOR ASHWAGANDHA *ithania somnifera* Dunal) IN COASTAL DISTRICTS OF ANDHRA ADESH

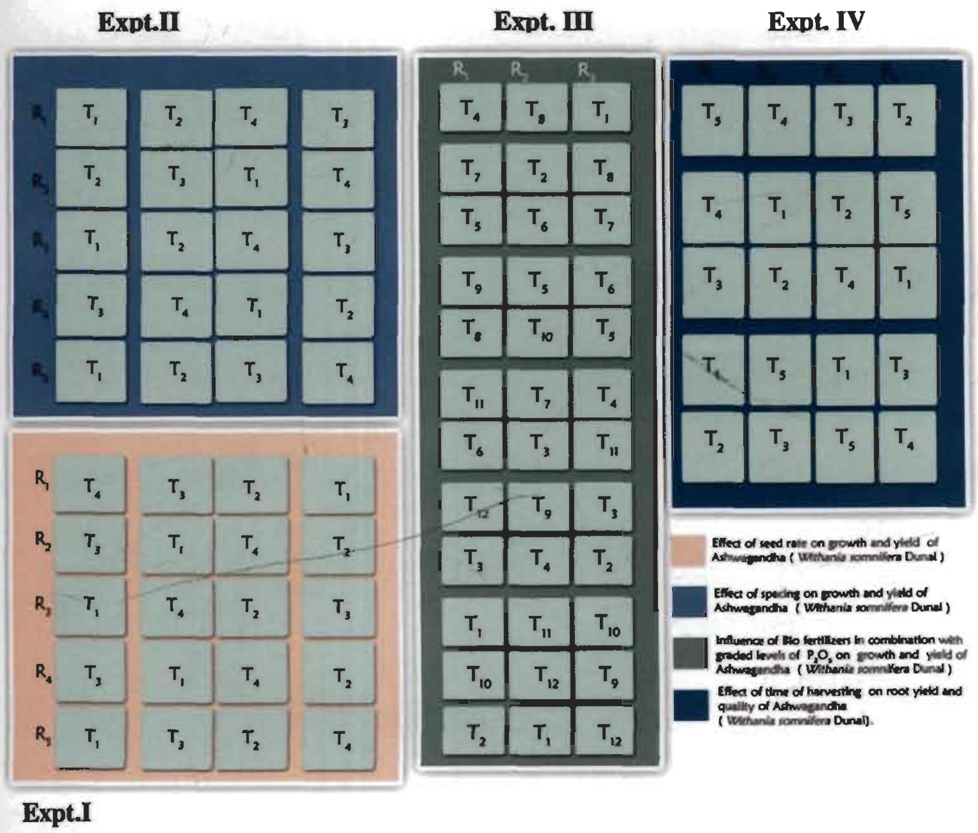
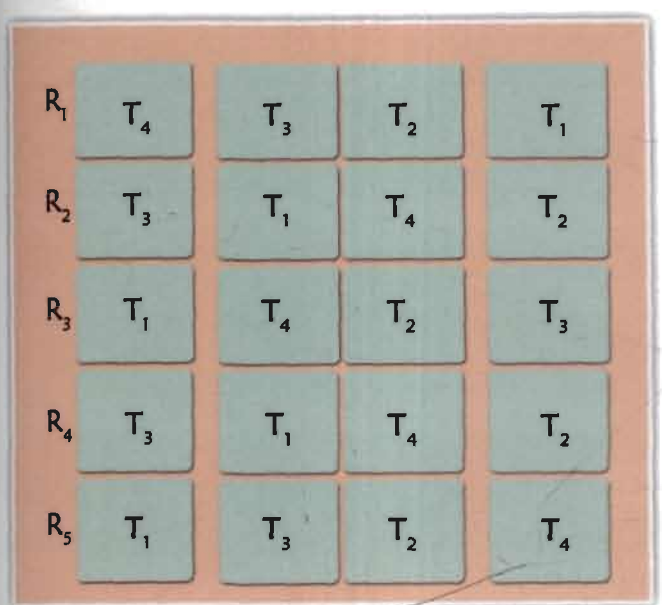


Plate 1: Overall view of Expt. on "Standardization of Agro techniques for ashwagandha *(Withania somnifera* Dunal*)* in coastal districts of Andhra Pradesh".

Fig.1b: Layout plan of Expt.I:

EFFECT OF SEED RATE ON GROWTH AND YIELD OF ASHWAGANDHA (*Withania somnifera* Dunal).



N

Design: RBD

Treatments: 4

T_1:6 kg ha^{-1}

T_2: 8 kg ha^{-1}

T_3: 10 kg ha^{-1}

T_4: 12 kg ha^{-1}

Replications: 5

Gross plot size : 4.0 x 3.0 m

Net plot size : 3.5 x 2.5 m

Plate 2: General view of Expt.I : Effect of Seed rate on growth and yield of ashwagandha (*Withania somnifera* Dunal).

Table 1: Physico - chemical properties of the experimental soil

Properties	Value	Method of analysis
A. Physical compositions		
Sand (%)	62	International pipette method (Piper, 1966)
Silt (%)	22	
Clay (%)	16	
Textural class	Sandy loam	
B. Chemical composition		
Soil PH (1:2.5 soil water suspension)	6.59	Digital pH meter (DI-707) (Jackson, 1973)
EC(dS m^{-1})	0.20	Conductivity Bridge (Jackson,1973)
Organic carbon (%)	0.44	Wet digestion procedure (Walkley and Black, 1934)
Available nitrogen (kg ha^{-1})	192	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available phosphorus (kg ha^{-1})	28.5	Olsen's extractant method (Olsen *et al.*, 1954)
Available potassium (kg ha^{-1})	255	Neutral normal ammonium acetate method (Jackson, 1973)

3.3 CLIMATIC CONDITIONS

Weather data recorded during the crop period (20-8-2009 to 16-2-2010 and 20-8-2010 to 16-2-2011) are presented in Appendix-1. The average weekly maximum temperature ranged from 27.66 ^{0}C to 34.71^{0}C during 2009-10 and 25.86 ^{0}C to 33 ^{0}C during 2010-11, while the minimum mean temperature varied between 18.57^{0}C to

26.76^{0}C and 18.43^{0}C to 26.29^{0}C during 2009-10 and 2010-11 respectively. Similarly, the weekly mean relative humidity ranged from 74.00 to 91.33 per cent at 7.16 hrs and 49.14 to 82.20 per cent at 14.00 hrs during 2009-10 and 83.29 to 92.43 per cent (7.16 hrs) and 50.15 to 83 per cent (14 hrs) during 2010-11. The total rainfall received during the crop period (2009-10) was 71.17 mm in 14 rainy days, while it was 94.48 mm in 14 rainy days during 2010-11.

3.4 Experimental details

The investigation was divided into five experiments.

3.4.1 Experiment No. 1:

EFFECT OF SEED RATE ON GROWTH AND YIELD OF ASHWAGANDHA *(Withania somnifera* Dunal.*)*

Design: RBD

Treatments: Broadcasting @

1) 6 kg of seed ha^{-1}

2) 8 kg of seed ha^{-1}

3) 10 kg of seed ha^{-1}

4) 12 kg of seed ha^{-1}

Replications: 5

3.4.2 Experiment No. 2:

EFFECT OF SPACING ON GROWTH AND YIELD OF ASHWAGANDHA *(Withania somnifera* Dunal. *)*

Design: RBD

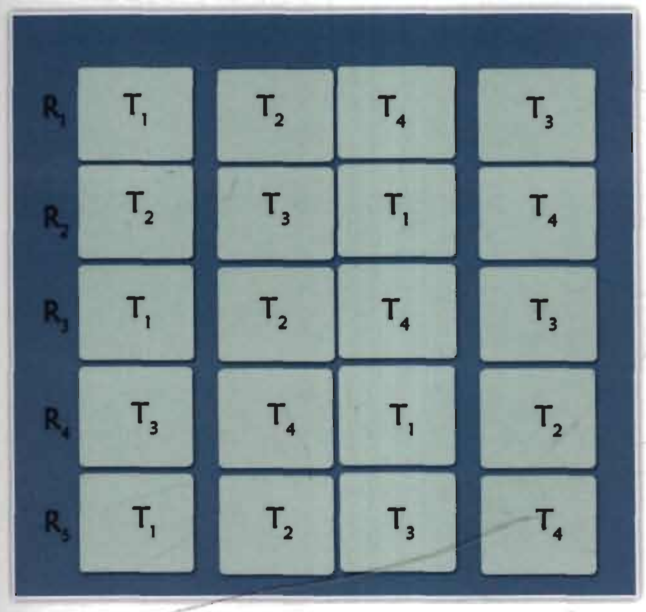
Treatments: Spacing:

1) 30x30 cm

2) 30x10 cm

Fig.1c: Layout plan of Expt.II:

EFFECT OF SPACING ON GROWTH AND YIELD OF ASHWAGANDHA (*Withania somnifera* Dunal).



Design: RBD

Treatments: 4

T_1:30 x 30 cm

T_2: 30 x 10 cm

T_3: 20 x 20 cm

T_4: 20 x 10 cm

Replications: 5

Gross plot size : 4.0 x 3.0 m

Net plot size : 3.5 x 2.5 m

Plate 3: General view of Expt.II Effect of spacing on growth and yield of ashwagandha (*Withania somnifera* Dunal).

ig.1d: Layout plan of Expt.III: INFLUENCE OF BIO-FERTILISERS IN OMBINATION WITH GRADED LEVELS OF P_2O_5 ON GROWTH ND YIELD OF ASHWAGANDHA (*Withania somnifera* Dunal).

N

Design: RBD

Treatments: 12

T_1: P_2O_5 @ 30 kgha^{-1}

T_2: P_2O_5 @ 40 kgha^{-1}

T_3: P_2O_5 @ 50 kgha^{-1}

T_4:Azotobacter + P_2O_5 @ 30 kgha^{-1}

T_5: Azotobacter + P_2O_5 @ 40 kgha^{-1}

T_6: Azotobacter + P_2O_5 @ 50 kgha^{-1}

T_7:Phosphobacteria+ P_2O_5 @ 30 kgha^{-1}

T_8: Phosphobacteria+ P_2O_5 @ 40 kgha^{-1}

T_9: Phosphobacteria+ P_2O_5 @ 50 kgha^{-1}

T_{10}: Azotobacter

T_{11}: Phosphobacteria

T_{12}:Control

Replications : 3

Gross plot size : 4.0 x 3.0 m

Net plot size : 3.5 x 2.5 m

late 4: General view of Expt.III: Influence of bio-fertilisers in combination with graded vels of P_2O_5 on growth and yield of ashwagandha (*Withania somnifera* Dunal).

3) 20x20 cm

4) 20x10 cm

Replications: 5

Observations recorded:

1) Plant height (cm)
2) No. of primary branches
3) Leaf area index
4) Days to 50 per cent flowering
5) Days to harvest
6) Seed yield ($kgha^{-1}$)
7) No. of secondary roots
8) Root length (cm)
9) Root girth (cm)
10) Root yield (Fresh and dry) (q ha^{-1})

3.4.3 Experiment No. 3:

INFLUENCE OF BIOFERTILIZERS IN COMBINATION WITH GRADED LEVELS OF P_2O_5 ON GROWTH AND YIELD OF ASHWAGANDHA (*Withania somnifera* Dunal).

Design: RBD

Replications: 3

Treatments: 12

1. P_2O_5 @ 30 kg ha^{-1}
2. P_2O_5 @ 40 kg ha^{-1}
3. P_2O_5 @ 50 kg ha^{-1}
4. Azatobactor + P_2O_5 @ 30 kg ha^{-1}

5. Azatobactor + P_2O_5 @ 40 kg ha^{-1}

6. Azatobactor + P_2O_5 @ 50 kg ha^{-1}

7. Phosphobacteria + P_2O_5 @ 30 kg ha^{-1}

8. Phosphobacteria + P_2O_5 @ 40 kg ha^{-1}a

9. Phosphobacteria + P_2O_5 @ 50 kg ha^{-1}

10. Azatobactor

11. Phosphobacteria

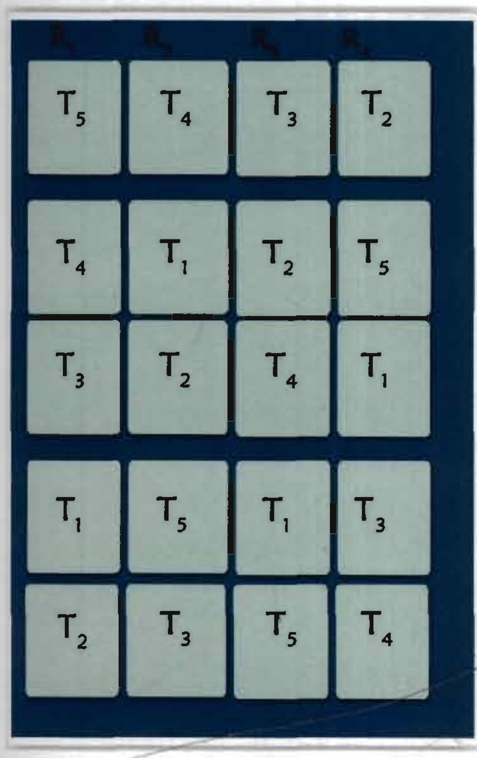
12. Control

All the treatments were applied with a common dose of 10 tonnes FYM, 40 kg N and 40 kg K_2O per ha^{-1}.Azotobactor and Phosphobacteria was applied @ 5 kg ha^{-1} and 200 g kg^{-1} seed each as soil application and seed inoculation, respectively.

Observations recorded:

1. Plant height (cm)
2. No. of primary branches
3. Leaf area index
4. Days to 50 per cent flowering
5. Days to harvest
6. Seed yield (kg ha^{-1})
7. No. of primary roots
8. Root length (cm)
10. Root girth (cm)
11. N, P, K content of leaves
12. N, P, K content of roots
13. Root yield (Fresh and dry) (q ha^{-1})

EFFECT OF TIME OF HARVESTING ON ROOT YIELD AND QUALITY OF ASHWAGANDHA (*Withania somnifera* Dunal).



Design: RBD

Treatments: 5

T_1:120 DAS

T_2: 135 DAS

T_3: 150 DAS

T_4: 165 DAS

T_5: 180 DAS

Replications: 4

Gross plot size : 4.0 x 3.0 m

Net plot size : 3.5 x 2.5 m

Spacing : 20 x 10 cm

Plate 5: General view of Expt.IV: Effect of time of harvesting on root yield and quality of ashwagandha (*Withania somnifera* Dunal).

3.4.4 Experiment No. 4:

EFFECT OF TIME OF HARVESTING ON ROOT YIELD AND QUALITY OF ASHWAGANDHA *(Withania somnifera* Dunal.*)*

Design: RBD

Treatments: 5

1) 120 days after sowing
2) 135 days after sowing
3) 150 days after sowing
4) 165 days after sowing
5) 180 days after sowing

Replications: 4

Observations recorded:

1. Tap root length (cm)
2. Tap root girth (cm)
3. No. of secondary roots
4. Alkaloid content at harvest
5. Grading quality

3.4.5 Experiment No. 5:

EFFECT OF TIME OF HARVESTING ON QUALITY OF ASHWAGANDHA (*Withania Somnifera* Dunal*)* ROOTS DURING STORAGE

Design: CRBD

Treatments: 5

1) 120 days after sowing
2) 135 days after sowing
3) 150 days after sowing

4) 165 days after sowing

5) 180 days after sowing

Replications: 4

Observations recorded:

1. Alkaloid content
2. Moisture content of the root
3. Girth of the root
4. Weight of the root

Sampling was done at 65, 90 and 135 days after harvest. The experiment I, II, III and IV were repeated in another adjacent field during 2010-11 in similar type of soil.

3.5 DESCRIPTION OF THE CULTIVAR

Ashwagandha cv. Poshita was developed by the Central Institute of Medicinal and Aromatic Crops (CIMAP), Lucknow. Poshita is medium tall in height; the leaves are semi-broad with medium dark green colour. The fruit (berry) colour is red at maturity; the root diameter and length are medium with high root yield. The variety has been recommended for late kharif to rabi season (Misra *et al.*, 2001). Ashwagandha cv. Poshita, seeds were obtained from Herbal garden,Rajendra nagar, Hyderabad for conducting experiment.

3.6 INOCULATION OF BIOFERTILIZERS

For this study, biofertilizers, *viz*., Azatobactor and Phosphobacteria were obtained from Agricultural Research Station (Acharya N. G. Ranga Agricultural University), Amaravathi, Andhra Pradesh. Commercial formulations of PSB with colony forming unit (CFU) of 1x 10^8 were used. Azatobactor and Phosphobacteria @ 5 kg ha^{-1} were inoculated (one week before application in the field) with the FYM and thoroughly incorporated in the soil before sowing of the crop. Seed inoculation of

Azatobacter and Phosphobacteria was also done @200 g kg^{-1} seed using gum arabica as adhesive for coating the seed with Azatobacter and Phosphobacteria.

3.7 CULTIVATION ASPECTS

3.7.1 Preparatory cultivation

The land was ploughed once with mould board plough and harrowed twice to bring the soil to fine tilth after receipt of monsoon rains. Stubbles and weeds were removed from the experimental site and the land was levelled.

3.7.2 Seed treatment

Ashwagandha seeds were treated with Dithane M-45 @ 3 g kg^{-1} seeds before sowing as a preventive measure against seed borne diseases.

3.7.3 Application of manures and fertilizers

The farm yard manure @ 10 t ha^{-1} was applied 15 days prior to sowing in all the experiments. A common fertilizer dose of 40 kg N, 40 kg K_2O and 30 kg P_2O_5 ha^{-1} was applied to all the plots at sowing in experiment I, II and IV. In case of experiment III, P_2O_5 was applied as per treatments. Nitrogen was applied in three equal splits as basal, at 30 DAS and 60 DAS. Entire phosphorous and potash were applied as basal along with 1/3 of nitrogen. Nitrogen, phosphorous and potassium nutrients were applied in the form of urea, single super phosphate and murate of potash respectively.

3.7.4 Sowing

The seed was soaked in water for 24 hours before sowing and the imbibed ones were selected for sowing. The seeds so selected were treated with Azatobacter and Phosphobacteria as per treatments in experiment III and were dibbled @ 2 - 3 seeds per hill at half way down the ridges with spacing of 20x10cm in experiment III. In experiment I, the seeds were broadcasted and in experiment II, the seeds were dibbled as per the spacing treatments. In experiment IV, the seeds were dibbled at a common spacing of 20x10cm and the field was irrigated immediately after sowing.

3.7.5 Gap filling

To maintain uniform population in all the treatments, gap filling with bagged seedlings of same age was done on the twelth day after sowing.

3.7.6 Thinning

Thinning of excess seedlings was done 30 days after sowing and only one healthy seedling per hill was retained in all the experiments except experiment II.

3.7.7 Irrigation

Immediately after sowing, irrigation was given and the second irrigation was on third day after sowing. Subsequent irrigations were given based on touch and feel method at the depth of 10 cm.

3.7.8 Weeding

The weed flora of the experimental area was predominated by the perennial weeds like *Cyperus rotundus* and *Cynodon dactylon* and broad-leaved weeds like *Croton sparsiflorus, Cleome viscose,* wild sesame which were hand weeded thrice *i.e.,* at 30 DAS, 60 DAS and 90 DAS.

3.7.9 Plant protection

The damping off disease was observed at early stages and effectively controlled by spraying and drenching of copper oxychloride @ 3 g l^{-1}. Insecticidal spray of neem oil @ 4 ml l^{-1} was given to control leaf eating caterpillars.

3.7.10 Harvesting

In each plot, five tagged plants were uprooted in the net plot area for recording growth and yield observations. The root yield of these plants was later added to the corresponding net plot root yields and total root yield of net plot area was recorded.

The plants from each net plot were uprooted manually at different periods of harvesting in experiment IV, at different maturity stages in experiment III and at 180 DAS in all other experiments. The field was irrigated day a before harvesting. The roots were separated and dried under sun. The dried roots were cleaned from adhering soil and weighed separately. The berries were also separated and dried. Later, the seeds are extracted from the dried berries, cleaned and weighed separately.

3.8 BIOMETRIC OBSERVATIONS RECORDED

3.8.1 Observations on growth parameters

Five plants were selected at random from each plot and labelled for data recording. The following biometric observations and their mean values were expressed.

3.8.1.1 Plant height (cm)

The plant height from the ground level to the growing tip of the plants was measured. The mean height of five plants was calculated and expressed in centimeters.

3.8.1.2 Number of primary branches

The number of primary branches per plant was recorded on five labelled plants at 45, 90, 135 and 180 DAS (at harvest) and the average per plant was calculated.

3.8.1.3 Leaf area (cm^2 $plant^{-1}$)

The Leaf area of fully opened leaves per plant was measured at 45days intervals (45, 90, 90, 135 and 180 DAS) by using leaf area meter with transparent belt conveyor utilizing an electronic digital display and expressed in cm^2 $plant^{-1}$.

3.8.1.4 Leaf area index

Leaf area index is defined as the ratio of leaf area occupied by a plant to the land area. It was worked out using the formula given by Watson (1958).

$$LAI = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Ground area occupied by the plant (cm}^2\text{)}}$$

3.8.2 Observations on yield parameters

3.8.2.1 Days to 50 per cent flowering

Number of days taken from sowing to flowering of 50 per cent of the plants in a plot in each treatment was recorded.

3.8.2.2 Root length (cm)

The length of roots in five labeled plants was measured from collar region to the tip of root and the average was calculated and expressed in centimeters.

3.8.2.3 Days to harvest:

Based on the leaf withering and drying symptoms and colour change of the berries into red or yellow, the plants in different treatments were harvested at that particular time in experiment III.

3.8.2.4 Primary roots per plant

The number of roots which arise from the tap roots was counted and the mean value of five plants was recorded.

3.8.2.5 Secondary roots per plant

The number of roots which arise from the primary roots was counted and the mean value of five plants was recorded.

3.8.2.6 Root girth (cm)

The diameter of roots at the thickest portion was measured using vernier calipers in five labeled plants. The average was calculated and expressed in centimeters.

3.8.2.7 Fresh root weight per plant

The roots from the uprooted plants were separated from the stem and weighed. The mean fresh root weight of five plants was recorded and expressed in gram per plant.

3.8.2.8 Dry root weight per plant

The roots after recording fresh weight were cut into pieces of 5 cm length and oven dried at 60°C to constant weight. The mean dry root weight of five plants was calculated and expressed in grams .

3.8.2.9 Dry root yield per hectare

After recording the fresh root yield the roots were sun dried and then oven dried at 60°C to constant weight. The root yield was recorded as kg per plot. The yield per hectare was computed and expressed as root yield in kg .

3.8.2.10 Berries per plant

The number of berries in the tagged plants was counted and mean was calculated.

3.8.2.11 Seed yield per plant (g)

The fully ripened berries from the tagged plants were harvested and sun-dried. The seeds were extracted by gently rubbing the berries against the cement flour and threshed by hand. The extracted seeds were cleaned by winnowing, weighed and expressed in gram per plant.

3.8.2.12 Seed yield per hectare (kg)

The seed yield from the net plots was recorded after cleaning and expressed in kg per plot. The seed yield per hectare was computed and expressed as seed yield in kg.

3.8.3 Quality parameters

3.8.3.1 Grading of roots:

The dried whole roots were cleaned, trimmed and main tap root was cut into transverse pieces, and the entire product was carefully hand-sorted into four grades, based on the thickness and uniformity of the pieces (Purohit and Vyas, 2010)

Grade	Size of root piece in length(cm)	Diameter (cm)	Type	Colour
Grade – A	7cm	1-1.5	Solid	Brittle and pure white on the inside
Grade – B	5cm	Less than 1	Solid	Brittle and pure white on the inside
Grade – C	3-4cm	1 cm or less	Side branches solid	Yellow to white
Lower grade	Small root pieces	Very thin	Semi solid	Yellowish

For studying storage quality of roots, these were cut into small pieces of 2-3 inches and stored in transparent polythene covers for different periods. As per the requirement, these samples were ground in grinding machine and the powdered samples obtained were analysed for quality.

3.8.3.2 Moisture content of the roots (%):

The moisture content of the stored roots were estimated initially and at different intervals during storage period and expressed in per cent.

3.8.3.3 Total alkaloid content (%)

The total alkaloid content of the dry roots was estimated using composite samples from each treatment. The dried roots were powdered and 0.5 g of root powder was taken in a stoppers test tube. To this, 5 ml of chloroform and 2-3 drops of ammonia were added and mixed well and kept overnight. This mixture was filtered through cotton wool in a small beaker and the residue was washed with 5 - 10 ml of chloroform thrice. The extract was dried on hot water bath and 10 ml of chloroform was added and mixed with clean glass rod. Evaporated liquid portion confirms the removal of ammonia. To this, 10 ml of standard acid (0.01 N H_2SO_4) was added. The content was slightly warmed and further cooled. It was titrated against alkaline with standard NaOH (0.01 N). The volume of alkaline used in titration was noted down. A blank was run to find out the exact volume of acid neutralized by alkaline.

The total alkaloid content in roots was calculated by using following formula and expressed in percentage on dry weight basis (Mishra, 1989).

$$\text{Total alkaloid content (\% w/w)} = \frac{\text{TV (blank)} - \text{TV (sample)}}{\text{TV (blank)}}$$

Where TV = Titer value

3.9 CHEMICAL ANALYSIS OF PLANT MATERIAL

The dried leaves and roots samples were ground to a fine powder and were analyzed for N, P and K content following standard analytical methods(AOAC, 1975).

3.9.1 Nutrient uptake

The nutrient uptake (kg ha^{-1}) was calculated based on the total dry matter production per hectare and the nutrient content (%) in plant tissue by using the formula given by Jackson, 1973.

$$\text{Nutrient uptake (Kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) X dry matter production (kg ha}^{-1}\text{)}}{100}$$

3.9.1.1 Nitrogen

Total nitrogen (%) was determined by Micro-Kjeldhal method as outlined by Piper (1966) and uptake was calculated and expressed as kg ha^{-1}. A plant sample of 0.5 gram was digested with digestion mixture ($CuSo_4$, K_2S0_4 and Se in 100: 20: 1 ratio) in a digestion chamber along with 10 ml of concentrated sulphuric acid. The digested mixture was then distilled and the ammonia released was trapped in 4 per cent boric acid with mixed indicator. This was titrated against standard sulphuric acid.

3.9.1.2 Phosphorus

Plant sample (0.5 g) was digested using diacid mixture (HNO_3+$HClO_4$ in 10:4 ratio) and volume made upto 50 ml. A known aliquot was taken for the total phosphorus content (%) by using Vanadomolybdate phosphoric acid yellow colour method (Jackson, 1973) and uptake was calculated as kg ha^{-1}.

3.9.1.3 Potassium

The total potassium content (%) in the plant was estimated by feeding the di-acid digested extractant to a flame photometer as outlined by (Muhr *et al.,* 1965).

3.10 ECONOMICS

3.10.1 Cost of cultivation

The prices of all the inputs and the labour cost that were prevailing at the time of their use were taken into consideration while working out the cost of cultivation and expressed as rupees per hectare.

3.10.2 Gross income

The gross income was worked out based on the prevailing market price for the ashwagandha dry root and expressed as rupees per hectare.

3.10.3 Net income

The net income per hectare was calculated by subtracting the cost of cultivation per hectare from the gross income per hectare and expressed as rupees per hectare.

3.10.4 Benefit to cost ratio

The benefit to cost ratio was worked out by using the following formula.

$$\text{Benefit: cost (B:C) ratio} = \frac{\text{Net income (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.11 STATISTICAL ANALYSIS

Statistical analysis for the data recorded in this experiment was done following the procedure outlined by Panse and Sukhatme (1983). Statistical significance was tested by applying F-test at 0.05 level of probability and critical differences were calculated for those parameters which turned significant to compare the effects of different treatments.

RESULTS

CHAPTER IV

RESULTS AND DISCUSSION

EXPT. I: EFFECT OF SEED RATE ON GROWTH AND YIELD OF ASHWANGANDHA (*Withania somnifera* Dunal.)

4.1 GROWTH PARAMETERS

4.1.1 Plant height (cm)

The plant height increased significantly with increased seed rate at different stages of crop growth (Table 2).

At 45 DAS, the plant height was significantly highest (14.40 cm) at a seed rate of 12 kgha^{-1} followed by 10 kg ha^{-1}. The lowest plant height (13.65 cm) was recorded at 6 kg ha^{-1}.

At 90 DAS, the plants sown with 12 kg ha^{-1} seed recorded maximum plant height (35.40 cm) which was on par with 10 kg ha^{-1}(34.55 cm). The lowest plant height (31.25 cm) was recorded with 6 kg ha^{-1} seed.

The maximum plant height at 135 DAS (53.00 cm) was noticed with a seed rate of 12 kg ha^{-1}, but it was on par with 10 kg ha^{-1} (52.00 cm). The plant height with lower seed rate of 6 kg ha^{-1} recorded the lowest (46.98 cm).

At harvest, maximum plant height (64.10 cm) was recorded with higher seed rate of 12 kg ha^{-1} and was on par with 10 kg ha^{-1}(63.00 cm). The minimum plant height (54.90 cm) was observed due to lower seed rate of 6 kg ha^{-1} which was significantly inferior to all other treatments.

4.1.2 Leaf area (cm^2)

The leaf area per plant increased with decreased seed rate at all the stages of crop growth (Table 3).

Table 2: Plant height of ashwagandha as influenced by seed rate

Plant height (cm)												
	45 DAS			90 DAS			135 DAS			at harvest		
Seed rate	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
T1: 6 kg ha^{-1}	13.81	13.49	13.65	30.76	31.74	31.25	47.28	46.68	46.98	55.16	54.64	54.90
T2: 8 kg ha^{-1}	13.80	13.60	13.70	32.32	32.78	32.55	48.35	47.61	47.98	62.47	63.33	62.90
T3: 10 kg ha^{-1}	13.98	14.02	14.00	34.33	34.77	34.55	51.39	52.61	52.00	62.79	63.21	63.00
T4: 12 kg ha^{-1}	14.42	14.38	14.40	35.38	35.42	35.40	52.65	53.36	53.00	63.81	64.39	64.10
Mean	**14.00**	**13.87**	**13.94**	**33.20**	**33.68**	**33.44**	**49.91**	**50.07**	**49.99**	**61.06**	**61.39**	**61.22**
S.Em±	0.15	0.21	0.14	0.36	0.39	0.29	0.50	0.70	0.43	0.88	0.82	0.60
C.D at 5%	0.46	0.63	0.40	1.12	1.21	0.86	1.55	2.17	1.26	2.70	2.53	1.73

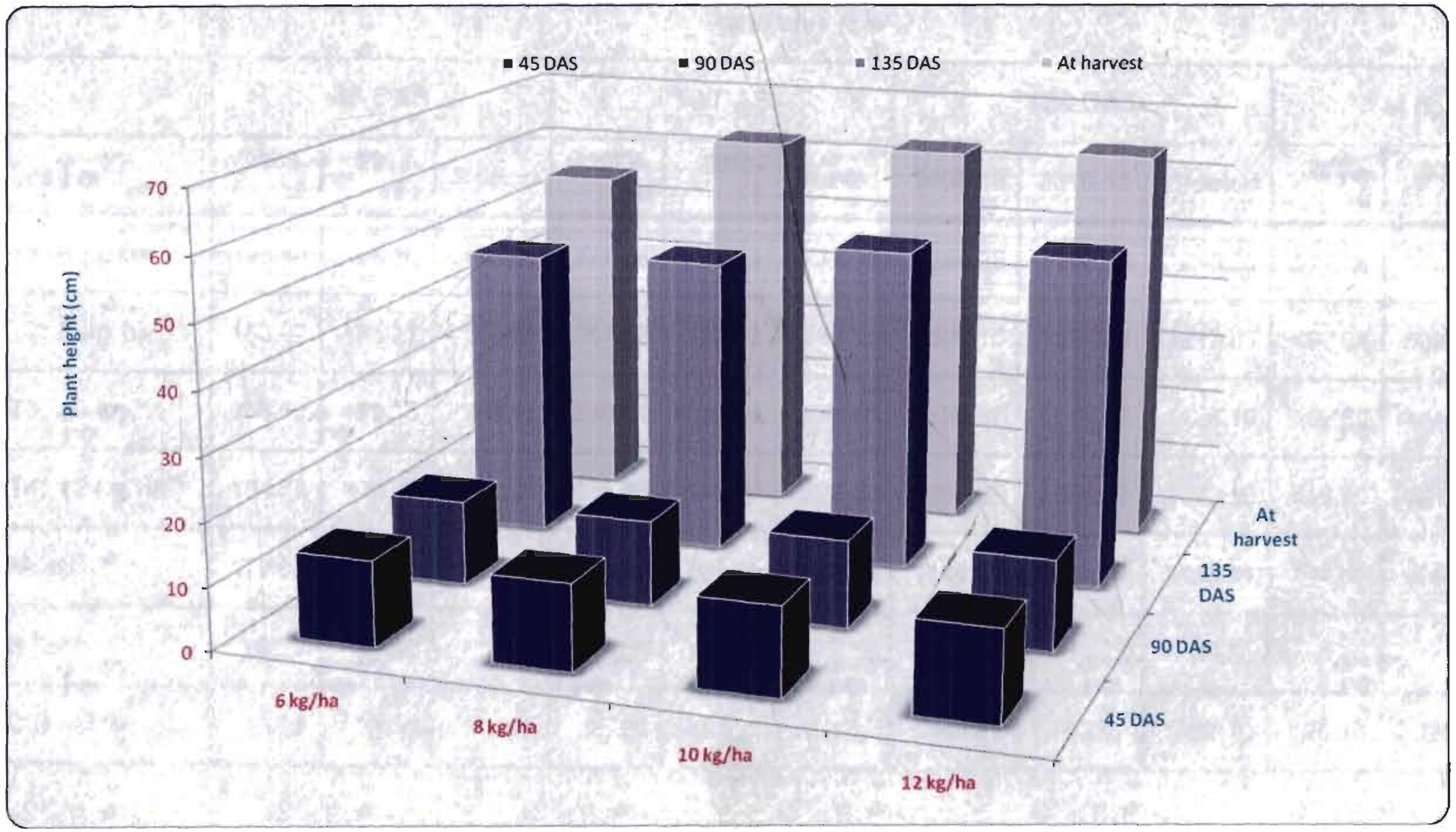


Fig.7 Plant height (cm) of ashwagandha as influenced by seed rate

Table 3: Leaf area of ashwagandha as influenced by seed rate

Leaf area (cm^2)												
	45 DAS			90 DAS			135 DAS			at harvest		
Seed rate	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	199.44	198.36	198.90	777.38	768.42	772.90	1244.23	1252.16	1248.20	517.56	510.84	514.20
T2: 8 kg ha^{-1}	183.92	185.27	184.60	751.67	752.62	752.15	1209.16	1226.53	1217.85	497.64	502.56	500.10
T3: 10 kg ha^{-1}	168.13	172.16	170.15	656.61	662.98	659.80	1138.37	1117.83	1128.10	462.59	454.71	458.65
T4: 12 kg ha^{-1}	164.74	160.76	162.75	639.60	618.39	629.00	1087.66	1058.53	1073.10	418.66	428.34	423.50
Mean	**179.06**	**179.14**	**179.10**	**706.32**	**700.60**	**703.46**	**1169.86**	**1163.77**	**1166.81**	**474.11**	**474.11**	**474.11**
S.Em±	5.20	4.50	4.80	8.60	8.070	7.10	14.74	14.27	10.36	6.70	7.50	4.84
C.D at 5%	15.60	13.50	14.40	25.80	24.865	21.30	45.41	43.97	31.10	20.10	23.12	14.50

At 45 DAS, the maximum leaf area (198.90 cm^2) was noticed with 6 $kgha^{-1}$seed, which was on par with 8 kg seed (184.60 cm^2). The lowest leaf area (162.75 cm^2) was recorded with higher seed rate, 12 kg ha^{-1} and was on par with 10 kg ha^{-1}seed.

The leaf area at 90 DAS was maximum (772.90 cm^2) with 6 kg ha^{-1} seed, however it was on par with 8 kg ha^{-1} seed (752.15 cm^2). The minimum leaf area (629.00 cm^2) was recorded with higher seed rate, 12 kg ha^{-1}.

At 135 DAS, significantly higher leaf area per plant (1248.20 cm^2) was recorded at lower seed rate i.e 6 $kgha^{-1}$, which was on par with 8 kg ha^{-1} seed (1217.85cm^2).

At harvest, the maximum leaf area (514.20 cm^2) was observed with 6 kg ha^{-1} seed, however it was on par with 8 kg ha^{-1} seed (500.10 $cm^{2)}$. The minimum leaf area (423.50 cm^2) was observed with 12 kg ha^{-1} seed.

4.1.3 Number of primary branches

The data on number of primary branches per plant (Table 4) revealed a significant influence of seed rate on.

At 45 DAS, the number of primary branches (1.75) was significantly more due to lower seed rate i.e., 6 kg ha^{-1}. Significantly lowest number of primary branches (1.50) was observed due to 12 kg seed rate.

At 90 DAS, primary branches were more (5.75) in plants raised with broadcasting of 6 kg ha^{-1}seed, which was on par with 8 kg seed. The lowest number of primary branches (5.10) was observed with 12 kg seed.

The number of primary branches per plant at 135 DAS, significantly influenced by 6 kg seed rate in getting maximum number of branches (7.46) and it was on par with 8 kg seed (6.90). The minimum number of primary branches (6.50) was recorded with 12 kg seed.

Table 4: Number of primary branches of ashwagandha as influenced by seed rate

Primary branches												
	45 DAS			90 DAS			135 DAS			at harvest		
Seed rate	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	1.76	1.74	1.75	5.72	5.78	5.75	7.52	7.40	7.46	7.84	7.66	7.75
T2: 8 kg ha^{-1}	1.64	1.66	1.65	5.34	5.46	5.40	6.96	6.84	6.90	7.38	7.42	7.40
T3: 10 kg ha^{-1}	1.58	1.62	1.60	5.25	5.17	5.21	6.95	6.75	6.85	7.09	7.21	7.15
T4: 12 kg ha^{-1}	1.52	1.48	1.50	5.05	5.15	5.10	6.39	6.61	6.50	6.71	6.69	6.70
Mean	**1.63**	**1.62**	**1.63**	**5.34**	**5.39**	**5.37**	**6.95**	**6.90**	**6.93**	**7.25**	**7.25**	**7.25**
S.Em±	0.02	0.02	0.01	0.07	0.05	0.13	0.09	0.07	0.19	0.08	0.10	0. 16
C.D at 5%	0.05	0.05	0.04	0.23	0.15	0.37	0.27	0.22	0.57	0.25	0.31	0.46

At harvest, the highest number of primary branches (7.75) was observed with 6 kg seed rate, which was on par with 8 kg seed. The lowest numbers of primary branches (6.70) was observed in plants where the seed was broadcasted at 12 kg ha^{-1}.

4.1.4 Days to 50% flowering

Different seed rates significantly influenced the initiation of flowering of ashwagandha (Table 5). The plants raised with broadcasting of 6 kg seed recorded the lowest number of days to complete 50 per cent flowering (75.70 days), while those raised by broadcasting of 12 kg seed recorded the highest number of days (78.20), which were on par with each other.

4.1.5 Days to harvest

Seed rate did not exhibit significant influence on days to harvest (Table 6).

4.1.6 ROOT YIELD AND ITS ATTRIBUTES

4.1.7 Root length (cm)

The root length was significantly increased with increased plant age upto harvest (Table 7).

At 45 DAS, the maximum root length (7.65 cm) was recorded with 12 kg seed and minimum root length (6.00 cm) was recorded at a seed rate of 6 kg ha^{-1}.

At 90 DAS, the crop sown with 12 kg seed ha^{-1} recorded maximum root length (15.15 cm) and minimum root length was observed at a seed rate of 6 kg ha^{-1}(13.10 cm).

The highest root length (19.15 cm) was noticed at 135 DAS with a seed rate of 12 kg ha^{-1} and was on par with 10 kg seed (18.20 cm) while the shortest roots were observed with a seed rate of 6 kg ha^{-1} (16.15 cm).

Table 5: Days to 50% flowering of ashwagandha as influenced by seed rate

Days to 50% flowering			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	76.03	77.37	75.70
T2: 8 kg ha^{-1}	76.50	77.30	75.90
T3: 10 kg ha^{-1}	77.61	78.39	78.00
T4: 12 kg ha^{-1}	76.59	79.81	78.20
Mean	**76.68**	**78.22**	**77.45**
S.Em±	1.12	0.79	0.65
C.D at 5%	3.45	2.45	1.90

Table 6: Number of days to harvest of ashwagandha as influenced by seed rate

Days to harvest			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	176.19	176.81	176.30
T2: 8 kg ha^{-1}	177.82	176.08	176.45
T3: 10 kg ha^{-1}	176.94	176.26	176.60
T4: 12 kg ha^{-1}	176.35	175.95	176.70
Mean	**176.83**	**176.20**	**176.51**
S.Em±	--	--	--
C.D at 5%	NS	NS	NS

At harvest, the maximum root length (24.00 cm) was observed in plants raised with 12 kg seed, however it was on par with a seed rate of 10 kg ha^{-1} (23.00 cm). The minimum root length (21.65 cm) was recorded at 6 kg ha^{-1}.

4.1.8 Root girth (cm)

The root girth was significantly influenced by different seed rates (Table 8). Significantly highest root girth (1.18 cm) was obtained in the plants raised with a seed rate of 6 kgha^{-1}, which was on par with 8 kg seed ha^{-1}(1.15 cm). The lowest root girth (0.85 cm) was recorded in the plants raised with 12 kg seed, however, it was on par with 10 kg seed (1.05 cm).

4.1.9 Number of primary roots

The number of primary roots per plant was significantly influenced by different seed rates (Table 9). The maximum number of primary roots (2.40) were produced in plants grown with a seed rate of 6 kg ha^{-1} , which was significantly superior to the rest. The minimum number of roots were produced with 12 kg seed (1.20) and was preceded by those produced at 10 kg ha^{-1} (1.40) .

4.1.10 Number of secondary roots

The data (Table 10) on number of secondary roots per plant revealed significant differences among different treatments. The maximum number of secondary roots (1.40) was produced in plants sown with lower seed rate of 6 kg ha^{-1} and was significantly superior to those produced at other seed rates. The lowest number of secondary roots (0.30) was produced in plants grown with 12 kg ha^{-1} seed.

4.1.11 Fresh root yield (q ha^{-1})

Fresh root weight (yield) recorded at final harvest showed the significant difference among treatments (Table 11). The maximum fresh weight (16.15 q ha^{-1}) of roots was observed in crop grown with a seed rate of 12 kg ha^{-1} which was on par with

Table 7: Root length of ashwagandha as influenced by seed rate

Root Length (cm)												
	45 DAS			90 DAS			135 DAS			at harvest		
Seed rate	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	6.08	5.93	6.00	13.23	12.97	13.10	16.13	16.17	16.15	21.92	21.38	21.65
T2: 8 kg ha^{-1}	6.99	6.91	6.95	13.26	13.94	13.60	17.59	17.81	17.70	23.25	22.55	22.90
T3: 10 kg ha^{-1}	7.13	7.17	7.15	13.86	14.14	14.00	18.66	17.74	18.20	23.18	22.82	23.00
T4: 12 kg ha^{-1}	7.54	7.76	7.65	15.18	15.12	15.15	19.17	19.13	19.15	24.02	23.98	24.00
Mean	**6.93**	**6.94**	**6.94**	**13.88**	**14.04**	**13.96**	**17.89**	**17.71**	**17.80**	**23.09**	**22.68**	**22.89**
S.Em±	0.10	0.09	0.07	0.20	0.16	0.12	0.16	0.18	0.32	0.19	0.31	0.37
C.D at 5%	0.31	0.27	0.19	0.61	0.50	0.35	0.50	0.55	0.96	0.58	0.96	1.10

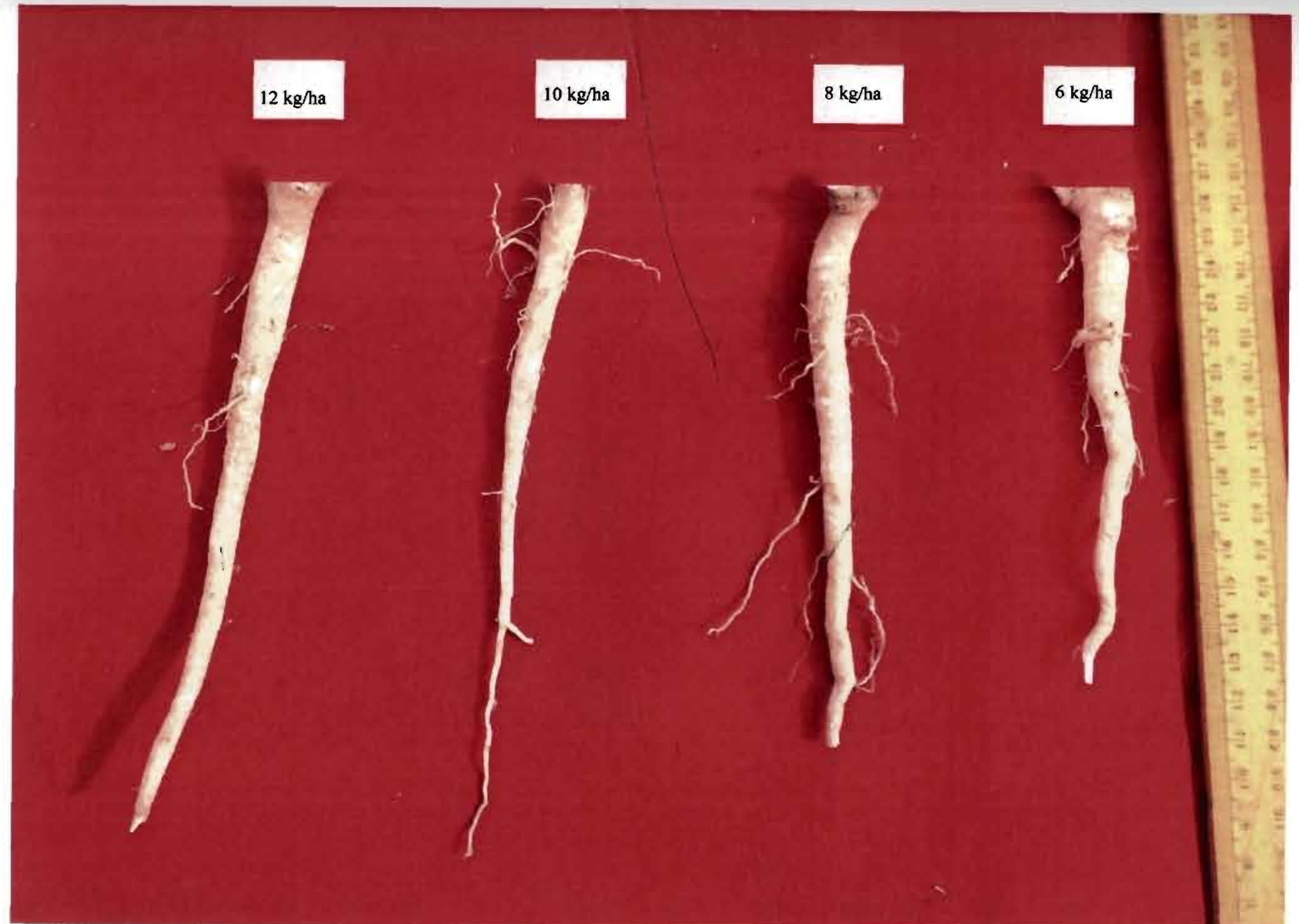


Plate. 6 Root growth of ashwagandha as influenced by different seed rates

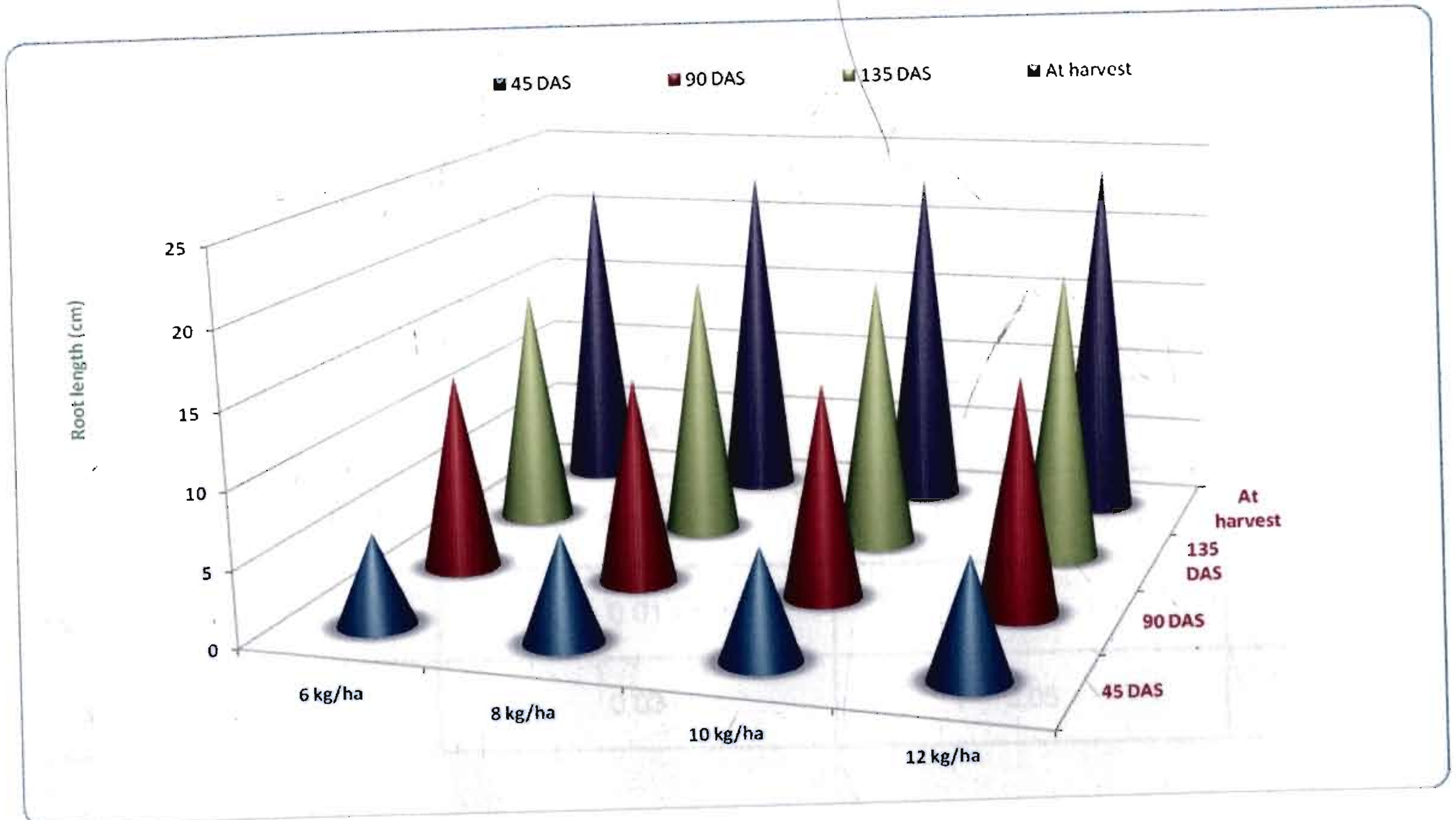


Fig. 8 Root length (cm) of ashwagandha as influenced by seed rate

Table 8: Root girth of ashwagandha as influenced by seed rate

Root girth (cm)			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	1.18	1.18	1.18
T2: 8 kg ha^{-1}	1.15	1.15	1.15
T3: 10 kg ha^{-1}	1.05	1.06	1.05
T4: 12 kg ha^{-1}	0.84	0.86	0.85
Mean	**1.055**	**1.062**	**1.057**
S.E m±	0.01	0.02	0.02
C.D at 5%	0.03	0.05	0.04

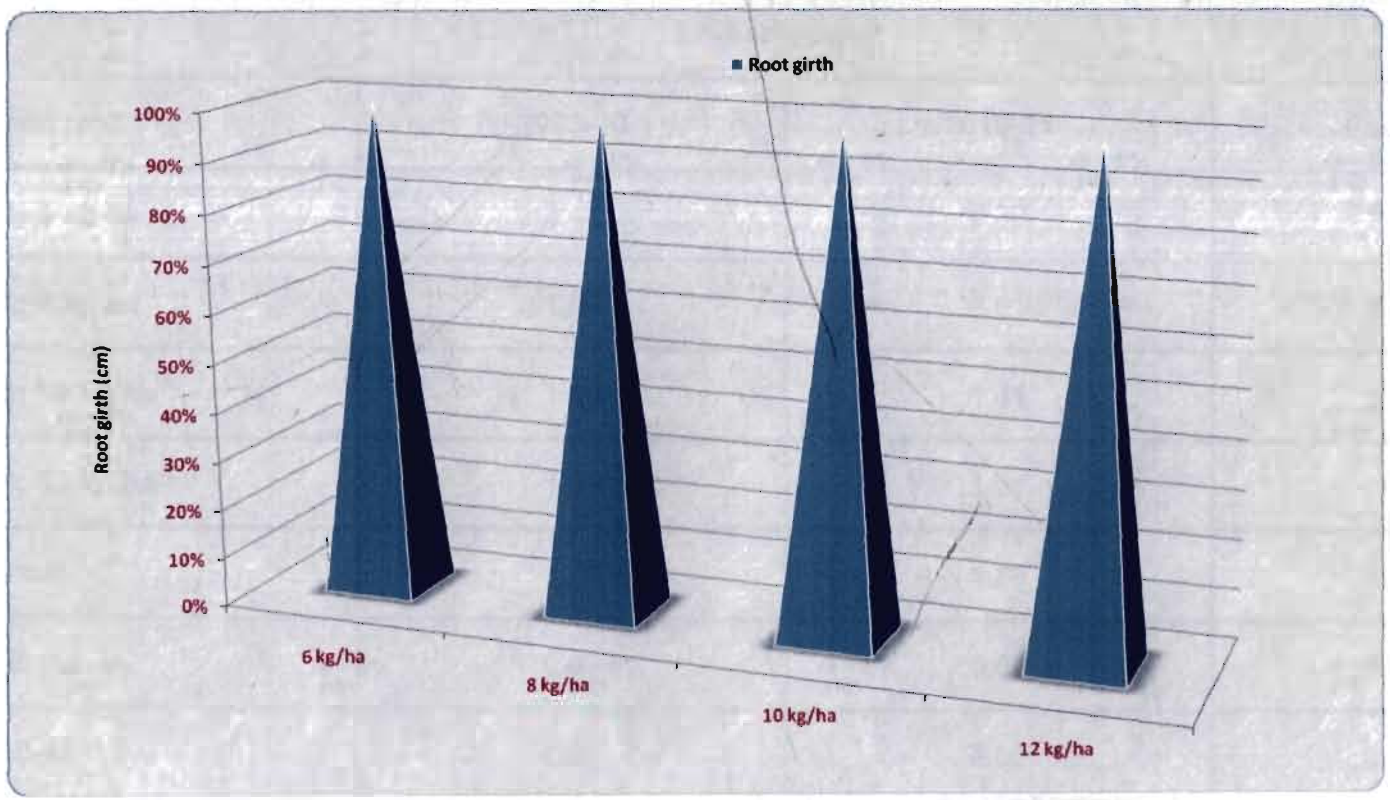


Fig. 9 Root girth (cm) of ashwagandha as influenced by seed rate

Table 9: Number of Primary roots of ashwagandha as influenced by seed rate

Primary roots			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	2.41	2.39	2.40
T2: 8 kg ha^{-1}	1.99	2.01	2.00
T3: 10 kg ha^{-1}	1.39	1.41	1.40
T4: 12 kg ha^{-1}	1.19	1.21	1.20
Mean	**1.75**	**1.76**	**1.75**
S.E m±	0.02	0.02	0.01
C.D at 5%	0.06	0.06	0.04

Table 10: Number of Secondary roots of ashwagandha as influenced by seed rate

Secondary roots			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	1.39	1.41	1.40
T2: 8 kg ha^{-1}	1.21	1.19	1.20
T3: 10 kg ha^{-1}	0.99	1.01	1.00
T4: 12 kg ha^{-1}	0.30	0.30	0.30
Mean	**0.98**	**0.98**	**0.98**
S.E m±	0.02	0.01	0.01
C.D at 5%	0.06	0.04	0.03

Table 11: Fresh root weight of ashwagandha as influenced by seed rate

Fresh root weight (q ha^{-1})			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	14.19	13.81	14.00
T2: 8 kg ha^{-1}	14.42	14.08	14.25
T3: 10 kg ha^{-1}	16.33	15.87	16.10
T4: 12 kg ha^{-1}	16.04	16.26	16.15
Mean	**15.24**	**15.01**	**15.13**
S.Em±	0.17	0.18	0.14
C.D at 5%	0.54	0.57	0.40

10 kg seed (16.10 q ha^{-1}). The minimum fresh root weight (14.00 q ha^{-1}) was recorded at 6 kg seed and it was on par with 8 kg seed.

4.1.12 Dry root yield (q ha^{-1})

Significantly highest dry root yield (weight) (7.00 q ha^{-1}) was observed in the crop sown with 12 kg seed (Table 12), but it was on par with 10 kg seed (6.85q ha^{-1}). The lowest dry root weight (5.00 q ha^{-1}) was recorded at a seed rate of 6 kg ha^{-1}.

4.1.13 Seed yield (kg ha^{-1})

The seed yield obtained from different treatments was significant (Table 13). The maximum seed yield (148.35 kg ha^{-1}) was collected from the crop grown with a seed rate of 12 kg ha^{-1}, which was on par with 10kg seed (146.92 kg ha^{-1}). The minimum seed yield (124.75 kg ha^{-1}) was recorded with 6 kg seed.

4.1.14 Cost of cultivation (Rs ha^{-1})

Maximum cost of cultivation of Rs. 29,408/- was recorded with seed rate @ 12 Kg ha^{-1} followed by seed rate @ 10 Kg ha^{-1} while a minimum of Rs. 28,928 was registered with seed rate @ 6 Kg ha^{-1}(Appx.- 6)

4.1.15 Gross income and Net income (Rs ha^{-1})

The gross incomes obtained with seed rate at 12 Kg ha^{-1} was the highest Rs. 88,868 followed by seed rate at 10 Kg ha^{-1} while they were lowest with seed rate at 6 Kg ha^{-1} (Rs. 64,980). Maximum net income was realized with seed rate at 12 Kg ha^{-1} Rs. 59,460 followed by seed rate at 10 Kg ha^{-1} while minimum was realized with seed rate at 6 Kg ha^{-1} (Rs. 36052) (Appx.- 6).

4.1.16 Benefit: cost ratio (BCR)

The treatment, seed rate @ 12 Kg ha^{-1} had recorded the maximum BCR of 2.02 followed by seed rate @ 10 Kg ha^{-1} while seed rate @ 6 Kg ha^{-1} recorded the minimum BCR of 1.24 (Appx.- 6).

Table 12: Dry root weight of ashwagandha as influenced by seed rate

Dry root weight (q ha^{-1})			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	5.00	5.00	5.00
T2: 8 $kgha^{-1}$	5.16	5.14	5.15
T3: 10 kg ha^{-1}	6.78	6.92	6.85
T4: 12 kg ha^{-1}	6.95	7.05	7.00
Mean	**5.97**	**6.03**	**6.00**
S.E m±	0.27	0.37	0.31
C.D at 5%	0.79	1.10	0.92

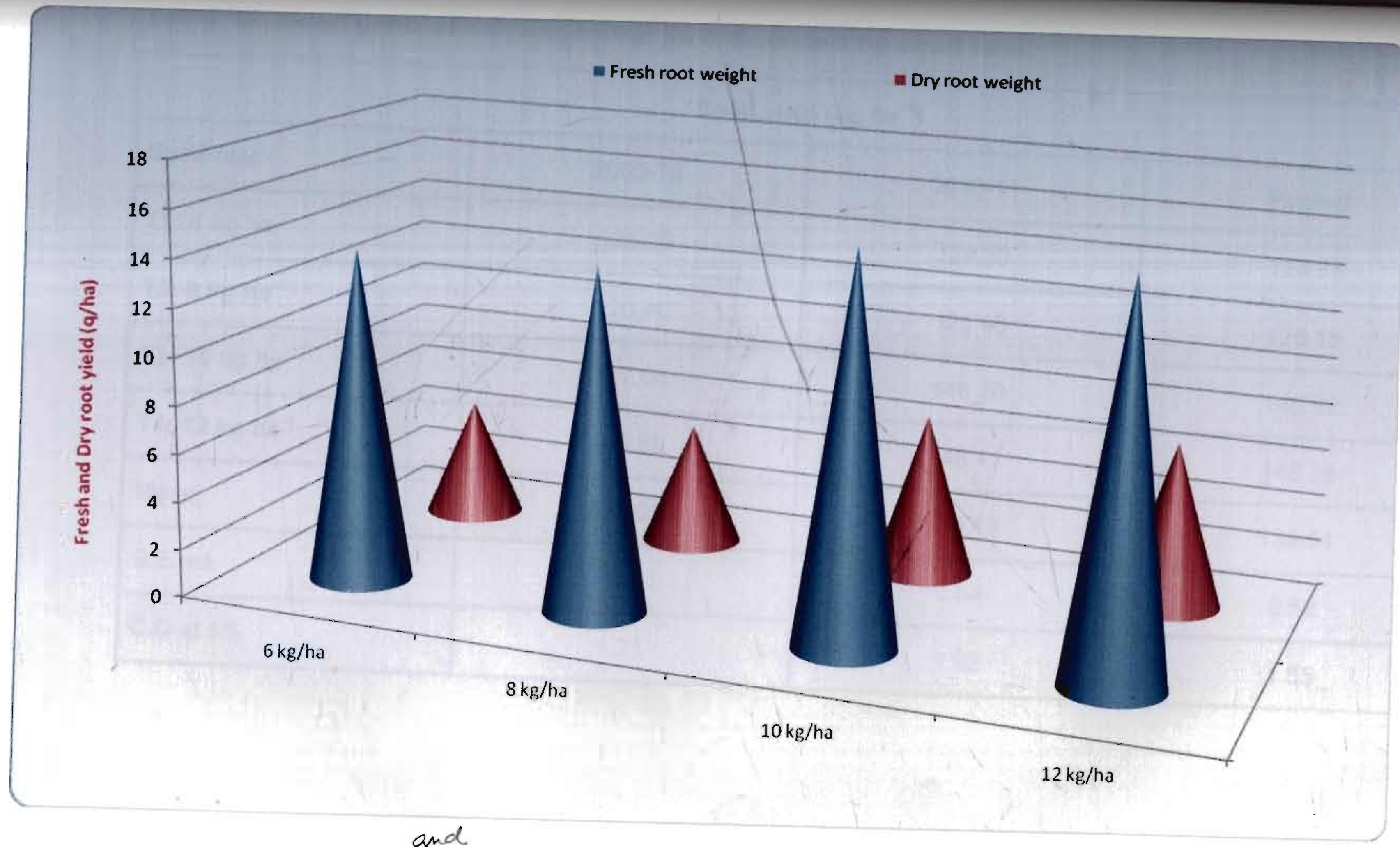


Fig.10 Fresh and Dry root weight (q/ha) of ashwagandha as influenced by seed rate

Table 13: Seed yield of ashwagandha as influenced by seed rate

Seed yield (kg ha^{-1})			
Seed rate	**2009-10**	**2010-11**	**Pooled**
T1: 6 kg ha^{-1}	125.20	124.30	124.75
T2: 8 kg ha^{-1}	126.40	125.90	126.15
T3: 10 kg ha^{-1}	147.64	146.20	146.92
T4: 12 kg ha^{-1}	148.59	148.11	148.35
Mean	**136.95**	**136.13**	**136.54**
S.E m±	0.41	0.64	0.52
C.D at 5%	1.21	1.92	1.55

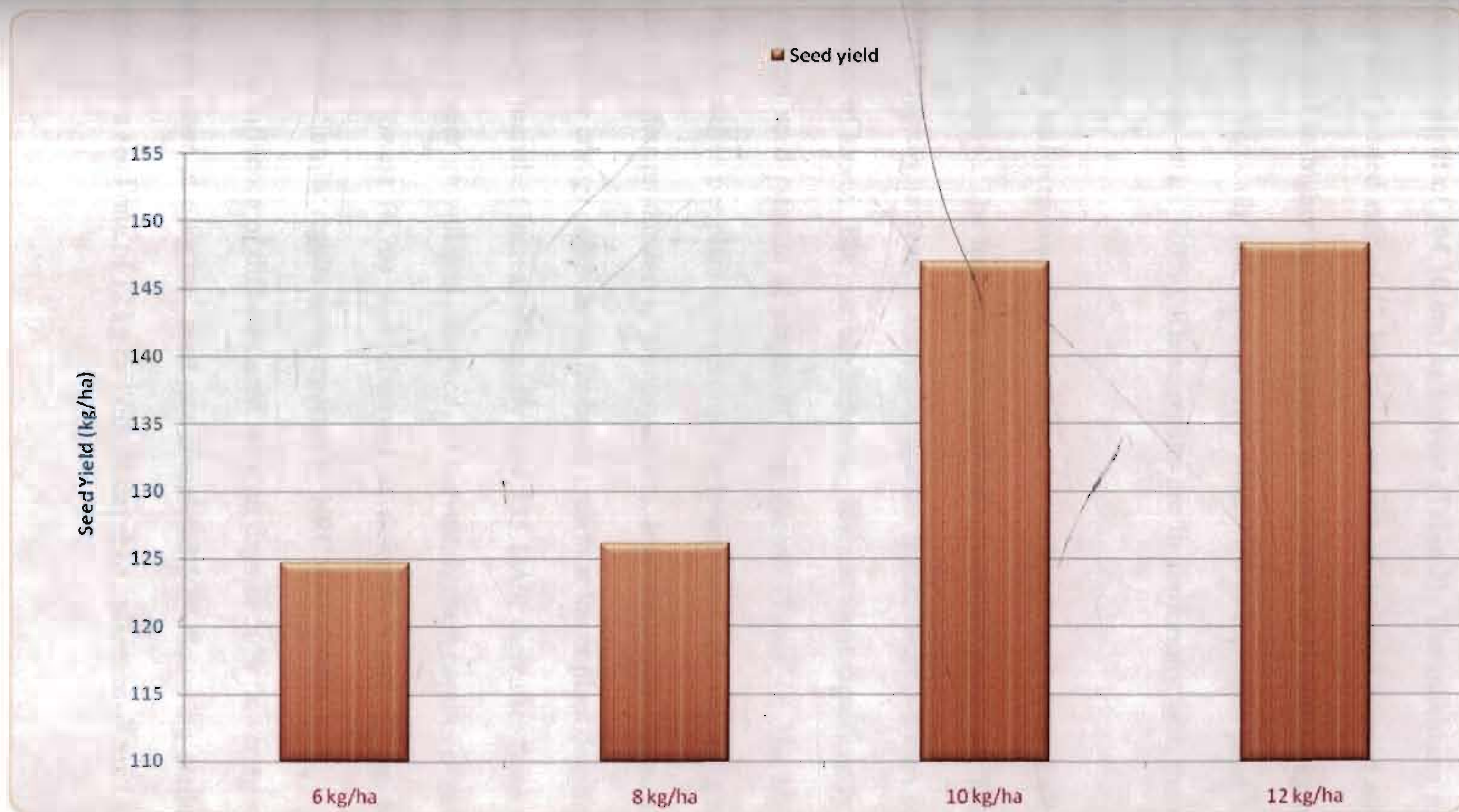


Fig. 11 Seed yield of Ashwagandha as influenced by seed rate

Different seed rates significantly influenced the plant growth and yield attributes of ashwangandha.

The plant height was significantly influenced by different seed rates at various stages of crop growth. Plant height increased rapidly till 135 DAS and reached a maximum height of (64.10 cm) at harvest (Table 2). The maximum plant height was recorded at a seed rate of 12 kg ha^{-1} over rest of the seed rates at all stages of crop growth. Due to higher number of plants per unit area at 10 and 12 kg ha^{-1} seed, plants have grown vertically and more linearly which led to increased plant height as opined by Wankhade *et al.* (2009). These results are in conformity with the results of NRC MAP (2005).

The leaf area was also influenced by different seed rates at all stages of crop growth (Table-4). The leaf area increased with increased plant age. The leaf area upto 135 DAS rapidly increased, thereafter sudden fall at harvest which could be due to senescence of leaves. The number of primary branches was significantly influenced due to different seed rates at al stages of crop growth (Table 4). The higher number of primary branches per plant was recorded at lowest seed rate *viz.*, 6 kg ha^{-1}. This might be due to higher production of photosynthates, less competition for nutrients and water which are the energy components for better growth at lower plant densities. The number of primary branches increased rapidly upto 135 DAS, thereafter from 135 DAS to at harvest, a linear growth was observed. At harvest, highest number of primary branches (7.75) and lowest (6.70) was observed at 6 kg ha^{-1} and 12 kg ha^{-1} seed rates respectively. Similar results were reported by NRCMAP (2008).

The influence of different seed rates on days to 50% flowering was significant. The plants sown at 6 kg ha^{-1} seed rate completed 50% flowering earlier (75.70 days) than those at a seed rate of 12 kg ha^{-1} (78.20 days) i.e., plants at all seed rates completed

50% flowering in a time lag of 1.5 days (Table 5). The number of days taken to harvest was also followed the same trend as that of 50% flowering (Table 6). Early maturity was observed at 6 kg ha^{-1}(176.30 days) while at 12 kg ha^{-1}, the crop recorded longest duration (176.70 days) and the trends observed are in accordance with those reported earlier (NRCMAP,2006a).

The root yield parameters like root length, root girth, number of primary and secondary branches, fresh and dry root yield was significantly influenced by different seed rates.

The increased trend in root length was observed with increased age of plant. The maximum root length was observed at 12 kg ha^{-1} seed rate throughout the crop growth stage. At harvest, the longest roots (24.00 cm) and shortest roots (21.65 cm) was observed at 12 kg ha^{-1} and 6 kg ha^{-1} seed rates respectively. The roots growth was very rapid up to 135 DAS and after which the growth rate was slow (NRC MAP, 2008a).

The girth of root is one of the important characters in grading the roots. The root girth was also influenced significantly by different seed rates at all stages of crop growth. At harvest, the maximum root girth (1.18 cm) and minimum root girth (0. 85 cm) was recorded at 6 kg ha^{-1} and 12 kg ha^{-1} seed rates respectively. The root girth at 6 kg ha^{-1} seed rate was 2.54, 11.02 and 28.00 per cent higher than 8 kg ha^{-1}, 10 kg ha^{-1} and 12 kg ha^{-1} seed rates. (Table 8). The lower plant density per unit area at 6 kg ha^{-1} seed rate might have facilitated the availability of more space, nutrients and moisture and led to decreased competition between plants for resources and thus recorded maximum root girth (Wankhade *et al.*, 2009).

The effect of seed rates on production of primary and secondary roots was significant. The maximum number of primary and secondary roots were recorded at lower seed rate viz., 6 kg ha^{-1} (Table 9 and 10). At harvest, the highest number of primary and secondary roots at lower seed rate, 6 kg ha^{-1} was 2.40 and 1.40 respectively. These findings are in consonance with results reported by Kothari *et al.* (2003) who observed increased number of roots with reduced seed rates.

The fresh and dry root yield was significantly influenced due to different seed rates. The fresh and dry root yield increased with increased seed rates. At higher seed rate (12 kg ha^{-1}), the fresh root yield was 16.15 q ha^{-1}. The dry root yield at 12 kg ha^{-1} seed was 2.14, 26.43 and 28.57 per cent higher than yield at 10 q ha^{-1}, 8 q ha^{-1} and 6 q ha^{-1} seed rate respectively.

The seed yield was also significantly influenced by different seed rates. The highest seed yield was recorded with higher seed rate i.e., 12 kg ha^{-1} (Table 13). The seed yield decreased at lower seed rates. The per cent increase of seed yield at 12 kg ha^{-1} was 15.90 over 6 kg ha^{-1} seed.

Though the per plant seed yield was decreased at higher seed rates, the increase in seed yield with increased seed rates might be due to increased plant population per unit area.

The increased plant height, root length at higher seed rate was due to more linear growth of plant as a result of higher plant densities, plants grown vertically for search of light and water (Ramachandran and Muthuswami, 1982 and Mastiholi *et al.*,2007).

The sufficient availability of resources like light, space, moisture and nutrients to individual plants and lesser competition for resources at lower seed rate led to increased growth attributes like number of primary branches, leaf area per plant and there by increased root yield per plant. But, the increase in yield per unit area with increased seed rate could be due to increased plant density per unit area, although the yield per plant decreased. Higher yield per plant obtained at low seed rate did not compensate the decrease in plant density. These results are in agreement with those reported by Nigam *et al.*,(1984), NRCMAP (2005), Panday and Shukal (2007), NRCMAP (2008b), and Wankhade *et al.*,(2009).

Higher gross income were obtained with the treatments, seed rate @ 12 Kg ha^{-1} compared to seed rate @ 10 Kg ha^{-1}owing to higher yield recorded with the treatments. Further the treatment seed rate @ 6 Kg ha^{-1} were observed with lower dry root yield resulting in lower net income and BCR. The treatment, seed rate @ 12 Kg ha^{-1} had recorded the maximum BCR followed by seed rate @ 10 Kg ha^{-1} .

4.2 EXPT.II: EFFECT OF SPACING ON GROWTH AND YIELD OF ASHWAGANDHA *(Withania somnifera* Dunal.)

4.2.1 GROWTH PARAMETERS

4.2.1.1 Plant height (cm)

The data on plant height as influenced by spacing presented in table 14 revealed that the plant height increased throughout the crop growth period.

At 45 DAS, the crop sown at 30 x 30 cm spacing recorded significantly highest plant height (14.50 cm) followed by 20x20 cm (14.10 cm). The lowest plant height (13.80 cm) was observed at 20 x 10 cm which was on par 20x20 cm and 30x10 cm spacing.

At 90 DAS, plant height recorded was significantly maximum (35.61cm) with 20x10 cm spacing compared to rest of the spacings. The minimum plant height (31.55 cm) was recorded at 30x30 cm spacing.

At 135 DAS, significantly highest plant height (53.10 cm) was recorded at 20x10 cm spacing while the lowest plant height (47.35cm) was observed at 30x30 cm.

At harvest, significantly maximum plant height (64.25cm) was observed with 20x10 cm and was on par with 30x10 cm (63.20 cm) and 20x20cm (63.00 cm) spacings. The minimum plant height (55.06 cm) was observed at 30x30 cm spacing.

4.2.1.2 Leaf area (cm^2)

At 45 DAS, the crop sown at 30x30 cm spacing recorded significantly highest leaf area (200.50 cm^2) compared to other spacings (table 15). The lowest leaf area (163.20 cm^2) was recorded at 20x10 cm spacing. Leaf area at 90 DAS recorded maximum (776.40 cm^2) at 30x30 cm spacing. The minimum leaf area (630.1 cm^2) was recorded with 20x10 cm spacing.

Table 14: Plant height of Ashwagandha as influenced by spacing

Plant height (cm)												
	45 DAS			90 DAS			135 DAS			At harvest		
Spacing	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	14.52	14.48	14.50	31.05	32.05	31.55	47.65	47.05	47.35	55.32	54.80	55.06
T_2: 30 x 10 cm	14.07	13.73	13.90	34.58	35.02	34.80	51.49	52.71	52.10	62.77	63.63	63.20
T_3: 20 x 20 cm	14.08	14.12	14.10	32.47	32.93	32.70	48.72	47.98	48.35	62.80	63.21	63.00
T_4: 20 x10 cm	13.90	13.70	13.80	35.59	35.63	35.61	52.74	53.46	53.10	63.97	64.54	64.25
Mean	**14.14**	**14.01**	**14.08**	**33.42**	**33.90**	**33.67**	**50.15**	**50.30**	**50.23**	**61.21**	**61.55**	**61.38**
S.Em±	0.15	0.21	0.14	0.37	0.40	0.27	0.51	0.71	0.44	0.88	0.82	0.60
C.D at 5%	0.46	0.64	0.41	1.13	1.22	0.77	1.56	2.18	1.26	2.71	2.539	1.73

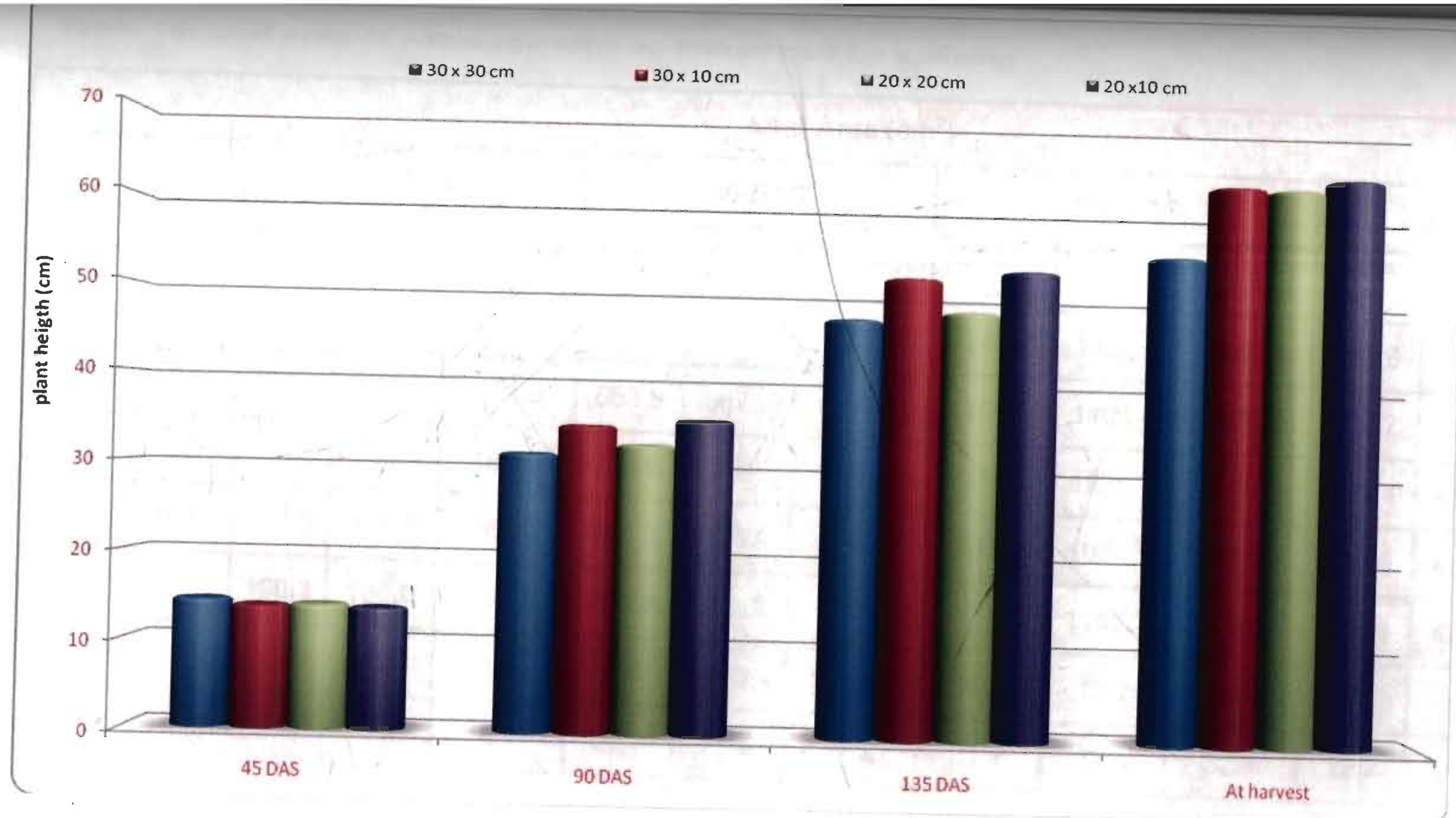


Fig. 2 Plant height (cm) of ashwagandha as influenced by spacing

Table 15: Leaf area of Ashwagandha as influenced by spacing

Leaf Area (cm^2)												
	45 DAS			**90 DAS**			**135 DAS**			**At harvest**		
Spacing	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	203.0	198.0	200.5	784.3	768.5	776.4	1249.5	1252.1	1250.8	523.9	510.8	517.4
T_2: 30 x 10 cm	170.9	172.0	171.5	653.9	667.5	660.7	1159.1	1101.4	1130.3	463.7	456.6	460.1
T_3: 20 x 20 cm	186.5	184.4	185.5	734.6	771.8	753.2	1211.3	1226.7	1219.0	509.4	494.1	501.8
T_4: 20 x10 cm	160.9	165.6	163.2	631.3	628.9	630.1	1077.1	1074.5	1075.8	425.6	424.7	425.2
Mean	**180.3**	**180.0**	**180.2**	**701.0**	**709.2**	**705.1**	**1174.3**	**1163.7**	**1169.0**	**480.6**	**471.6**	**476.1**
S.Em±	2.5	2.1	1.6	9.6	8.3	5.9	10.3	12.2	10.9	4.0	6.7	5.2
C.D at 5%	7.8	6.4	4.7	29.7	25.6	17.2	31.7	37.5	32.1	12.2	20.7	15.7

At 135 DAS, significantly maximum leaf area (1250.80 cm^2) was noticed with 30x30 cm spacing which was on par with 20x20 cm spacing (1219cm^2). The minimum leaf area (1075.80 cm^2) was observed with 20x10 cm spacing.

The maximum leaf area (517.40 cm^2) was recorded at harvest with 30x30 cm spacing followed by 20x20 cm spacing (501.8 cm^2) while the minimum leaf area (425.20 cm^2) was recorded with 20x10 cm spacing.

4.2.1.3 Leaf Area Index (LAI)

The leaf area index was significantly influenced by different spacings at all stages of crop growth (table 16).

At 45 DAS, LAI was highest (0.82) at closer spacing, 20x10 cm. The lowest LAI (0.22) was recorded at 30x30 cm spacing.

At 90 DAS, the crop sown at 20x10 cm recorded significantly highest LAI (3.15) compared to other spacings. The lowest LAI (0.86) was recorded at wider spacing of 30x30 cm.

At 135 DAS, 20x10 cm spacing had significantly recorded highest LAI (5.38) compared to other spacing. The lowest LAI (1.39) was recorded at 30x30 cm spacing, with which it was on par.

At harvest, the LAI recorded significantly maximum (2.13) with 20x10 cm compared to others except 30x10 cm spacing (1.53) which was on par with each other. The minimum LAI (0.57) was recorded at 30x30 cm spacing.

4.2.1.4 Number of primary branches

The number of primary branches was significantly influenced by different spacings at all stages of crop growth (Table 17).

Table 16: Leaf area index of Ashwagandha as influenced by spacing

Leaf Area Index												
	45 DAS			90 DAS			135 DAS			At harvest		
Spacing	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
T_1: 30 x 30 cm	0.23	0.22	0.22	0.86	0.86	0.86	1.39	1.39	1.39	0.57	0.58	0.57
T_2: 30 x 10 cm	0.58	0.56	0.57	2.22	2.18	2.20	3.75	3.79	3.77	1.52	1.54	1.53
T_3: 20 x 20 cm	0.47	0.46	0.46	1.89	1.88	1.88	3.04	3.05	3.05	1.25	1.26	1.25
T_4: 20 x10 cm	0.81	0.82	0.82	3.13	3.17	3.15	5.33	5.43	5.38	2.10	2.15	2.13
Mean	**0.52**	**0.52**	**0.52**	**2.03**	**2.02**	**2.02**	**3.38**	**3.41**	**3.40**	**1.36**	**1.38**	**1.37**
S.Em±	0.01	0.01	0.01	0.03	0.03	0.02	0.18	0.55	0.58	0.01	0.02	0.20
C.D at 5%	0.021	0.027	0.026	0.08	0.09	0.06	1.59	1.65	1.70	0.04	0.06	0.61

Table 17 : Primary branches of Ashwagandha as influenced by spacing

Primary branches												
	45 DAS			90 DAS			135 DAS			At harvest		
Spacing	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	1.82	1.79	1.80	5.77	5.83	5.80	7.56	7.44	7.50	7.89	7.71	7.80
T_2: 30 x 10 cm	1.58	1.62	1.60	5.50	5.40	5.45	7.00	6.80	6.90	7.19	7.31	7.25
T_3: 20 x 20 cm	1.74	1.76	1.75	5.44	5.56	5.50	7.06	6.94	7.00	7.48	7.52	7.50
T_4: 20 x10 cm	1.52	1.48	1.50	5.25	5.35	5.30	6.39	6.61	6.50	6.82	6.80	6.81
Mean	**1.66**	**1.66**	**1.66**	**5.49**	**5.54**	**5.51**	**7.00**	**6.95**	**6.98**	**7.35**	**7.33**	**7.34**
S.Em±	0.01	0.02	0.01	0.08	0.05	0.05	0.09	0.07	0.19	0.08	0.10	0.23
C.D at 5%	0.03	0.05	0.04	0.23	0.16	0.13	0.27	0.22	0.54	0.26	0.31	0.60

At all the stages of crop growth, plants at 30x30 cm spacing registered highest number of primary branches per plant.

At 45 DAS, the plant spaced at 30x30 cm recorded maximum number of primary branches per plant (1.80), while minimum numbers of primary branches (1.50) was recorded at 20x10 cm spacing.

At 90 DAS, the maximum primary branches, (5.80) were produced at 30x30 cm spacing and minimum numbers of primary branches (5.30) were observed at 20x10 cm.

At 135 DAS, the maximum numbers of primary branches (7.50) was produced at wider spacing *i.e.,* 30x30 cm, which was on par with 20x20 cm (7.00). The minimum number of primary branches (6.81) were produced at closer spacing of 20x10 cm.

The highest number of primary branches (7.80) at harvest was recorded with 30x30 cm spacing which was on par with 20x20 cm spacing. The minimum number of primary branches (6.81) was recorded with 20x10 cm spacing.

4.2.1.5 Days to 50% flowering

The differences observed in number of days taken for 50 percent flowering as influenced by different spacings was significant (Table 18).

The plants sown at 20x10 cm recorded the highest number of days (77.80) to 50 percent flowering which was on par with 30x10 cm (77.60), while the plants grown at 30x30 cm spacing recorded the lowest number of days (76.20).

4.2.1.6 Days to harvest (Table 19).

The plants sown at 30x30 cm spacing harvested earlier (177.20 days) followed by plants at 20x20 cm spacing (177.30 days) which were on par with each other. The plants spaced at 20x10 cm took maximum number of days (178.6 days) for harvesting.

Table 18: Days to 50% flowering of Ashwagandha as influenced by spacing

days to 50% flowering			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	75.54	76.87	76.20
T_2: 30 x 10 cm	77.20	77.98	77.60
T_3: 20 x 20 cm	74.73	77.87	76.30
T_4: 20 x10 cm	77.41	78.19	77.80
Mean	**76.22**	**77.73**	**76.98**
S.Em±	0.30	0.37	0.33
C.D at 5%	0.89	1.10	1.01

Table 19: Days to harvest of Ashwagandha as influenced by spacing

Days to harvest			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	177.50	176.90	177.20
T_2: 30 x 10 cm	178.65	178.25	178.45
T_3: 20 x 20 cm	177.65	176.95	177.30
T_4: 20 x10 cm	178.85	178.35	178.60
Mean	**178.16**	**177.61**	**177.89**
S.Em±	0.08	0.05	0.06
C.D at 5%	0.22	0.15	0.17

4.2.2 ROOT YIELD AND ITS ATTRIBUTES

4.2.2.1 Root length (cm)

Among different spacings, closer spacing, 20x10 cm recorded maximum root length at all stages of crop growth (Table 20).

At 45 DAS, the crop sown at 20x10 cm spacing recorded significantly highest root length (7.74 cm) and was on par with 30x10 cm spacing (7.710 cm).

At 90 DAS, the crop spaced at 20x10 cm spacing recorded significantly highest root length (15.10 cm) compared to other spacings and was on par with 30x10 cm spacing (14.20 cm). The minimum root length (13.15cm) was observed at 30x30 cm spacing.

The root length at 135 DAS, was significantly superior (19.25cm) at 20 x 10 cm spacing over all other spacings and was on par with 30x10 cm (18.50 cm)

At harvest, a spacing of 20x10 cm recorded significantly maximum root length (24.11cm) compared to rest of the spacings but on par with 30x10 cm spacing. The minimum root length (21.85cm) was observed with 30x30 cm spacing.

4.2.2.2 Root girth (cm)

The girth of the root increased from closer spacing, 20x10 cm to wider spacing 30x30 cm (Table 21). The maximum root girth (1.30 cm) was recorded with 30x30 cm spacing which was on par with 20x20 cm. The minimum root girth (0.95cm) was recorded at 20x10 cm spacing.

4.2.2.3 Number of primary roots

It was evident from the data (Table 22), spacing significantly influenced the number of primary roots per plant. Plants spaced at wider spacing of 30x30 cm recorded the highest number of primary roots (2.60), closely followed by those spaced

Table 20 : Root length of Ashwagandha as influenced by spacing

Root length (cm)												
	45 DAS			90 DAS			135 DAS			At harvest		
Spacing	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	6.27	6.23	6.25	13.23	13.07	13.15	16.45	16.55	16.50	21.99	21.71	21.85
T_2: 30 x 10 cm	7.62	7.80	7.71	14.13	14.27	14.20	18.67	18.33	18.50	23.40	23.00	23.20
T_3: 20 x 20 cm	6.97	7.03	7.00	13.74	13.76	13.75	17.67	17.93	17.80	22.89	23.11	23.00
T_4 : 20 x10 cm	7.83	7.65	7.74	15.35	14.85	15.10	19.51	18.99	19.25	23.83	24.39	24.11
Mean	**7.17**	**7.18**	**7.17**	**14.11**	**13.99**	**14.05**	**18.08**	**17.95**	**18.01**	**23.03**	**23.05**	**23.04**
S.Em±	0.07	0.10	0.06	0.11	0.15	0.32	0.22	0.23	0.26	0.25	0.36	0.31
C.D at 5%	0.21	0.31	0.17	0.34	0.47	0.95	0.69	0.70	0.76	0.77	1.12	0.92

Plate.7 Root growth of ashwagandha as influenced by different spacings

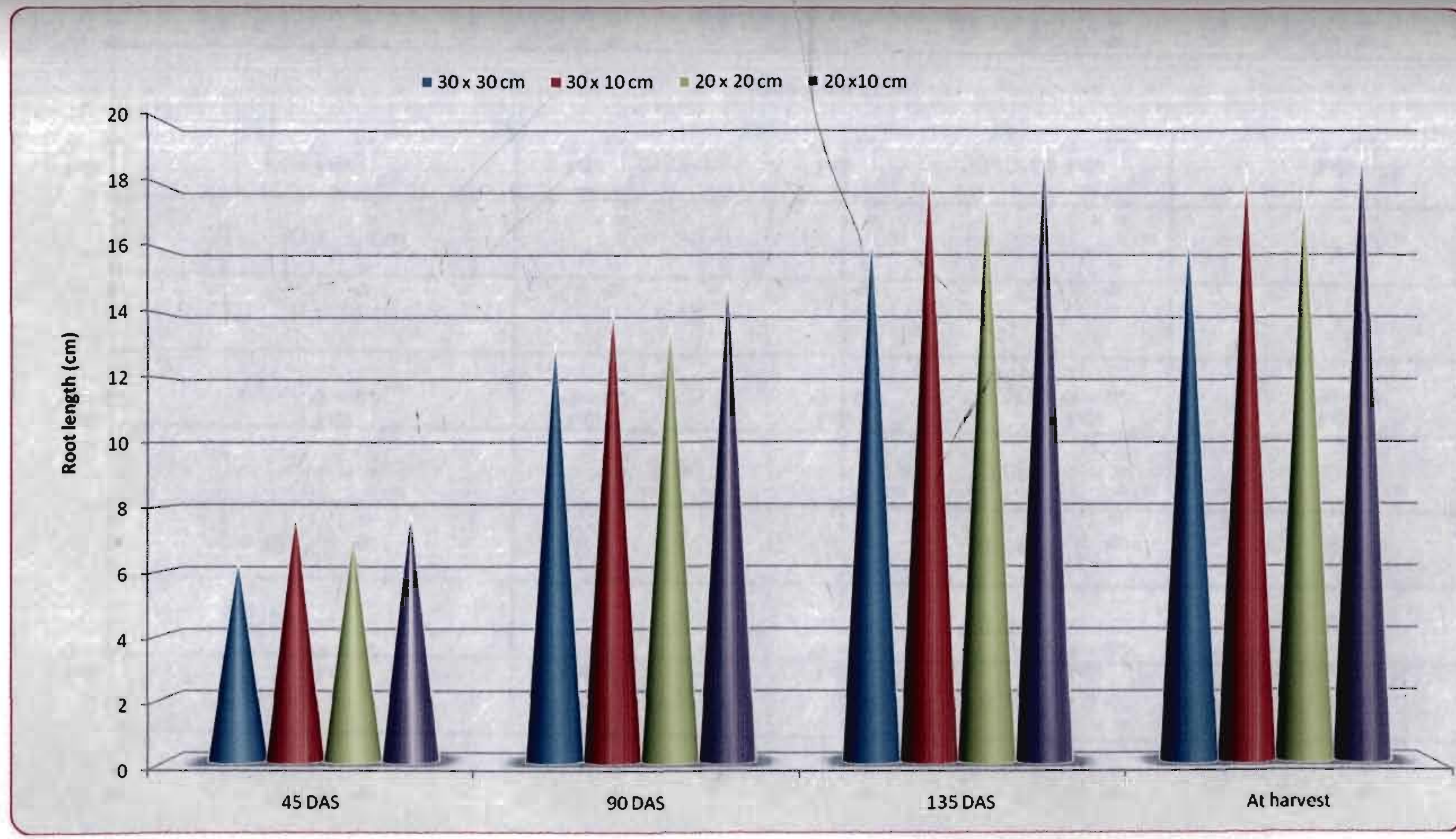


Fig. 3 Root length (cm) of ashwagandha as influenced by spacing

Table 21: Root girth (cm) of ashwagandha as influenced by spacing

Root girth(cm)			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	1.30	1.30	1.30
T_2: 30 x 10 cm	1.13	1.11	1.12
T_3: 20 x 20 cm	1.20	1.20	1.20
T_4: 20 x10 cm	0.94	0.96	0.95
Mean	**1.14**	**1.14**	**1.14**
S.Em±	0.04	0.04	0.06
C.D at 5%	0.10	0.12	0.16

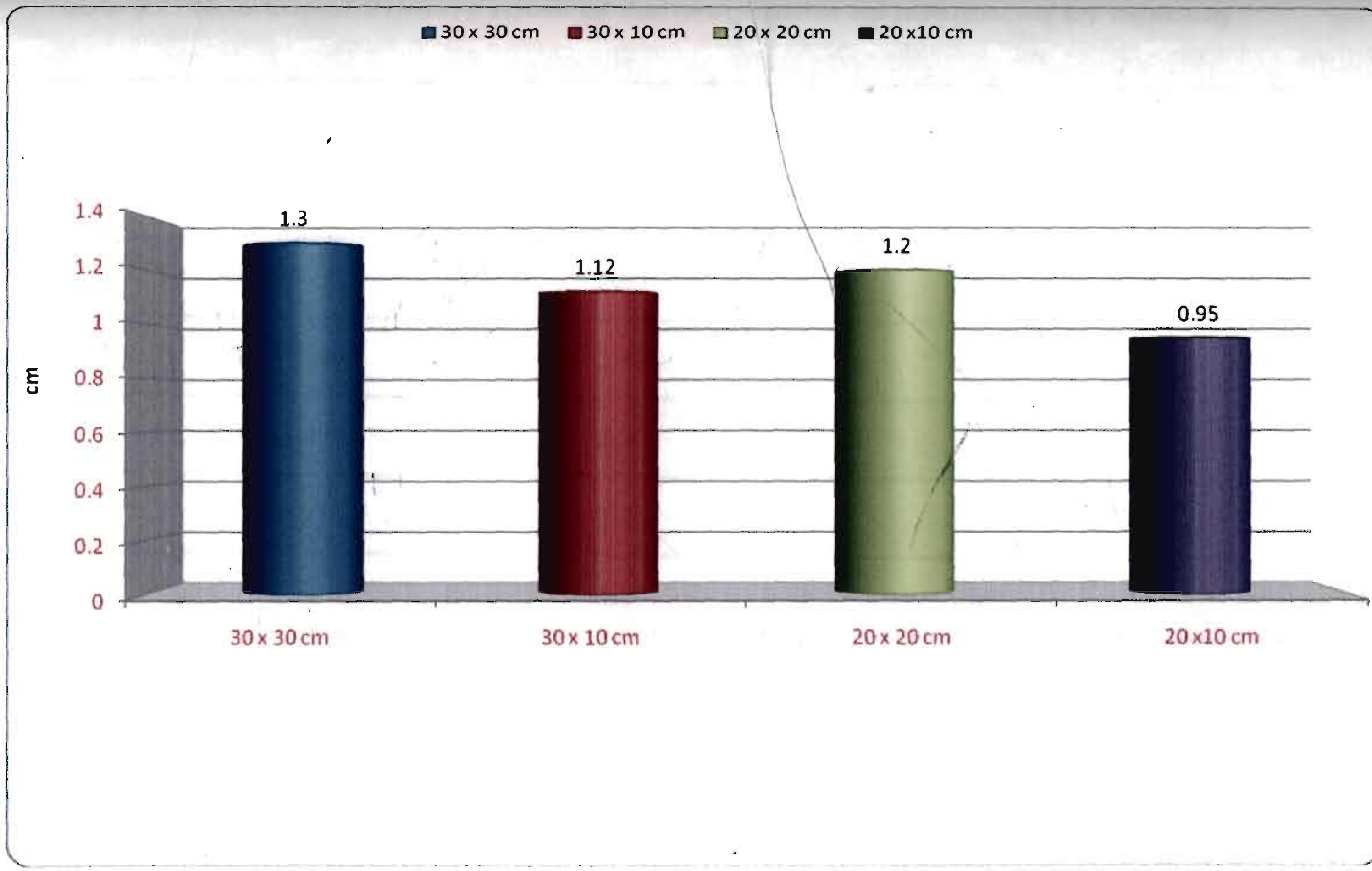


Fig. 4 Tap root girth (cm) of ashwagandha as influenced by spacing

Table 22: Number of Primary roots of Ashwagandha as influenced by spacing

Primary roots			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	2.61	2.59	2.60
T_2: 30 x 10 cm	1.49	1.52	1.50
T_3: 20 x 20 cm	2.39	2.41	2.40
T_4: 20 x10 cm	1.39	1.41	1.40
Mean	**1.97**	**1.98**	**1.98**
S.Em±	0.02	0.02	0.02
C.D at 5%	0.07	0.07	0.05

at 20x20 cm (2.40). The lowest number of primary roots (1.40) was recorded in plants spaced at 20x10 cm.

4.2.2.4 Number of secondary roots

The data (Table 23) revealed significant increase in number of secondary roots from closer spacing to wider spacing. Significantly highest numbers of secondary roots (1.50) were observed with wider spacing of 30x30 cm followed by 20x20 cm (1.30). The lowest numbers of secondary roots were recorded with 20x10 cm spacing (0.30).

4.2.2.5 Fresh root yield (q ha^{-1})

Among all spacings, the closest spacing of 20x10 cm, recorded significantly higher fresh root yield (16.95 q ha^{-1}) which was on par with 30x10 cm spacing (16.18 q ha^{-1}) (Table 24). The lowest fresh root yield (14.31q ha^{-1}) was recorded at wider spacing of 30x30 cm.

4.2.2.6 Dry root yield (q ha^{-1})

The data presented in table 25 revealed that the highest dry root yield (7.15q ha^{-1}) was obtained from closer spacing of 20x10 cm which was on par with 30x10 cm (6.80 q ha^{-1}). The lowest dry root yield (5.20 q ha^{-1}) was obtained from 30x30 cm spacing.

4.2.2.7 Seed yield (kg ha^{-1})

The seed yield recorded from different spacing treatments was significant (Table 26).The maximum seed yield (152.12 kgha^{-1}) was obtained from the crop grown at a spacing of 20x10 cm which was on par with 30x10 cm spacing (148.85 kgha^{-1}). The minimum seed yield (118.75 kg ha^{-1}) was recorded at wider spacing 30x30 cm.

Table 23: Number of Secondary roots of Ashwagandha as influenced by spacing

Secondary roots			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	1.49	1.51	1.50
T_2: 30 x 10 cm	1.09	1.11	1.10
T_3: 20 x 20 cm	1.32	1.29	1.30
T_4 : 20 x10 cm	0.30	0.30	0.30
Mean	**1.05**	**1.05**	**1.05**
S.Em±	0.02	0.01	0.01
C.D at 5%	0.06	0.04	0.03

Table 24: Fresh root weight of Ashwagandha as influenced by spacing

Fresh root weight (qha^{-1})			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	14.48	14.14	14.31
T_2: 30 x 10 cm	16.18	16.18	16.18
T_3: 20 x 20 cm	14.37	14.63	14.50
T_4 : 20 x10 cm	17.06	16.84	16.95
Mean	**15.52**	**15.45**	**15.49**
S.Em±	0.29	0.23	0.26
C.D at 5%	0.89	0.67	0.78

Table 25: Dry root weight of Ashwagandha as influenced by spacing

Dry root weight(qha^{-1})			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	5.25	5.15	5.20
T_2: 30 x 10 cm	6.74	6.86	6.80
T_3: 20 x 20 cm	5.72	5.73	5.72
T_4 : 20 x10 cm	7.15	7.15	7.15
Mean	**6.21**	**6.22**	**6.22**
S.Em±	0.09	0.09	0.13
C.D at 5%	0.29	0.29	0.37

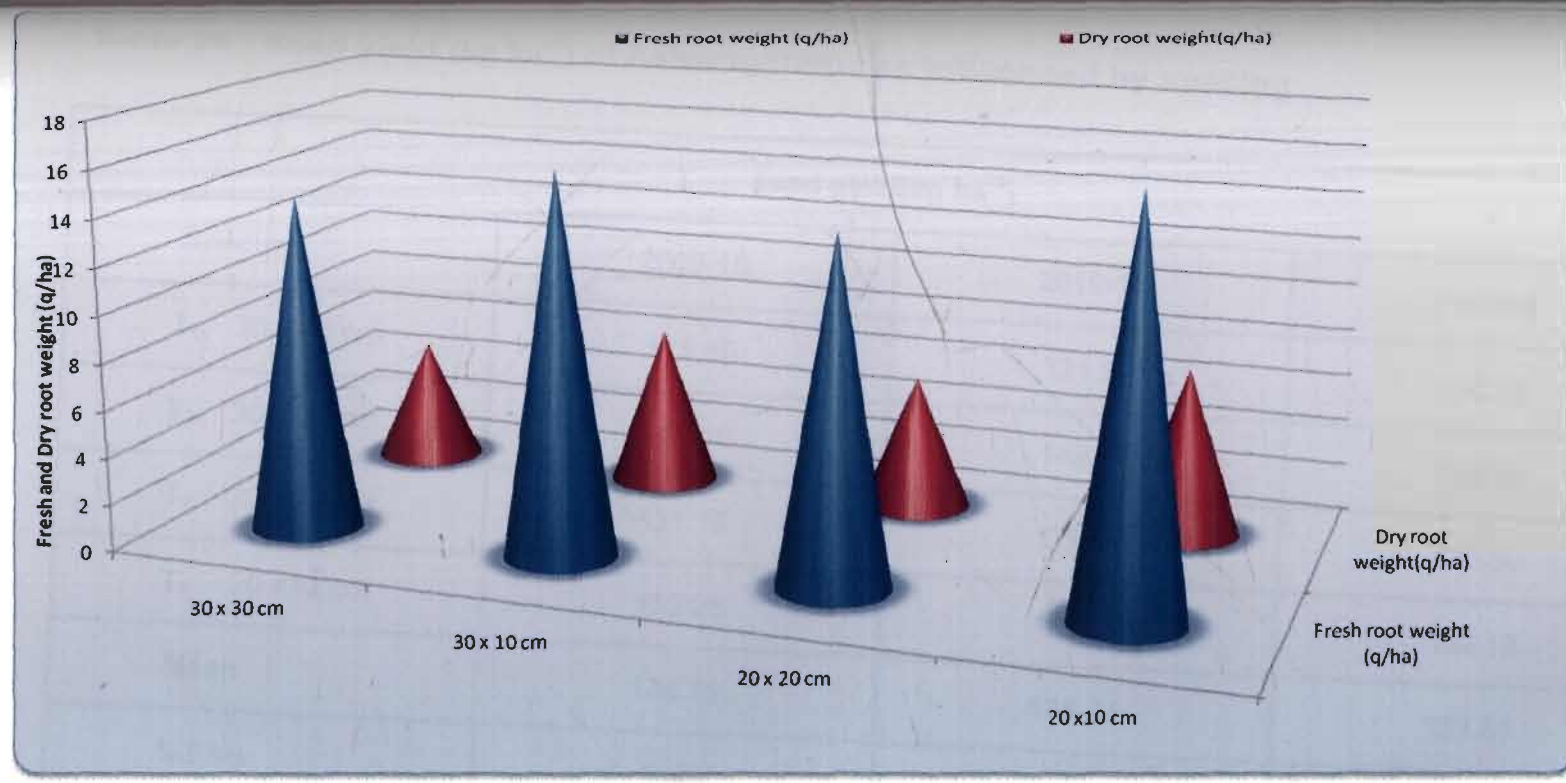


Fig. 5 Fresh and Dry root weight / yield (q / ha) of ashwagandha as influenced by spacing

Table 26 : Seed yield (kg ha^{-1}) of Ashwagandha as influenced by spacing

seed yield(kg ha^{-1})			
Spacing	**2009-10**	**2010-11**	**Pooled**
T_1: 30 x 30 cm	115.60	121.90	118.75
T_2: 30 x 10 cm	148.10	149.60	148.85
T_3: 20 x 20 cm	131.15	129.45	130.30
T_4 : 20 x10 cm	152.25	152.00	152.12
Mean	**136.78**	**138.24**	**137.51**
S.Em±	1.40	0.85	1.18
C.D at 5%	4.20	2.55	3.52

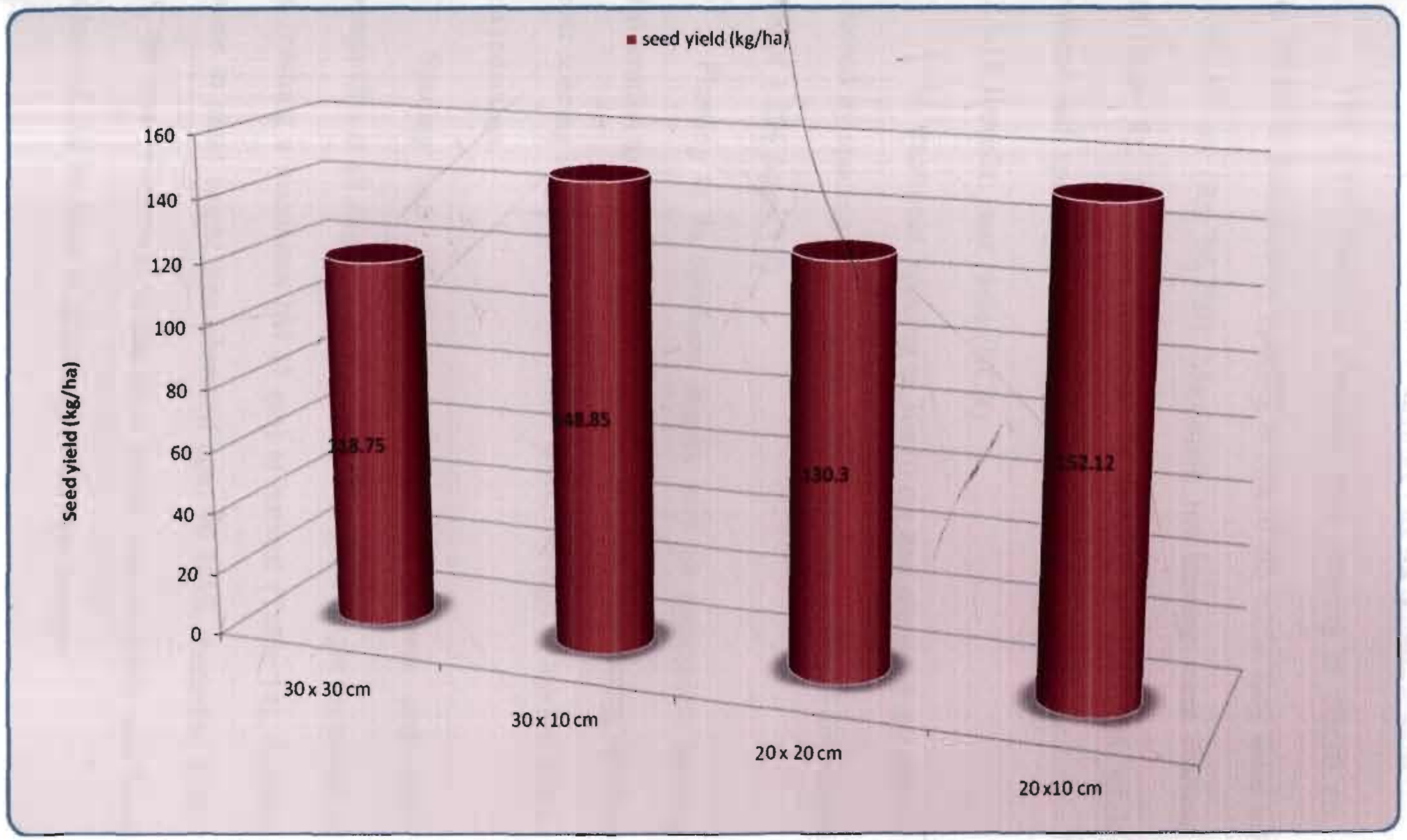


Fig.6 Seed yield (kg/ha) of ashwagandha as influenced by spacing

4.2.2.8 Cost of cultivation (Rs ha^{-1})

Maximum cost of cultivation of Rs. 33,448 was recorded with spacing at 20x10 cm followed by spacing at 20x20 cm while a minimum of Rs. 29,948 were registered with spacing at 30x30 cm (Appx.- 3).

4.2.2.9 Gross income and Net income (Rs ha^{-1})

The gross incomes obtained with spacing at 20x10 cm were the highest Rs. 90,819.6 followed by spacing at 30x10 cm while they were lowest with spacing at 30x10 cm (Rs. 66,700). Maximum net income were realized with spacing at 20x10cm Rs. 57,371.6 followed by spacing at 30x10cm while minimum were realized with spacing at 30x10 cm (Rs. 36,752) (Appx.- 7)

4.2.2.10 Benefit: cost ratio (BCR)

The treatment, spacing at 30x10 cm had recorded the maximum BCR of 1.80 followed by spacing at 20x10 cm while spacing at 30x30 cm recorded the minimum BCR of 1.22(Appx.- 7)

Planting to an optimum density with an appropriate spacing is an important consideration to improve the productivity of crop. Maintaining optimum plant density at proper spacing is of prime importance since, too high or too low plant density results in yield reduction.

Spacing had significant influence on growth and yield parameters of ashwagandha at all stages of crop growth. The plant height increased with the age of the crop reaching a maximum (64.25 cm) at harvest (Table 14). Further, a rapid rate of increase in plant height was observed upto 90 DAS, thereafter from 90 DAS to 135 DAS, the rate of increase in the plant height was moderate and beyond 135 DAS to final harvest, the increase in plant height was very meagre.

Closer plant spacing (20x10 cm) resulted in higher plant height than wider spacing of 30x30 cm and 20x20 cm (Table 14). At harvest, closer spacing of 20x10 cm, recorded maximum plant height (64.25 cm).

Leaf Area Index (LAI) was also influenced by different spacings at different stages of crop growth. LAI increased with advancement of age of the crop (Table 16). The LAI increased rapidly up to 135 DAS at all spacings, thereafter, decline in LAI was observed from 135 DAS to harvest. At all stages of crop growth, maximum LAI was recorded at closer spacing of 30x10 cm while minimum at wider spacing of 30x30 cm. Highest LAI (5.33) was noticed at 135 DAS with 20x10 cm spacing. The crop duration also has influenced the LAI significantly. Significantly greater LAI was recorded at 135 DAS than at 90 DAS and at harvest. This might be due to leaf senescence occurred at harvest stage and led to less LAI.

Unlike plant height and LAI, significantly highest number of primary branches per plant was registered at wider spacing of 30x30 cm, than at closer spacing of 20x10 cm (Table 17) At all stages of crop growth, significant differences were observed in number of primary branches due to different spacings. Number of primary branches per plant increased with increase in duration of the crop at wider spacing (30x10 cm).

At harvest, 30x30 cm spacing recorded highest number of primary branches (7.80) and lowest (6.81) at 20x10 cm spacing. Number of primary branches increased rapidly upto 90DAS, thereafter form 135 DAS to harvest, slow and static trend was observed.

The number of days taken to 50% flowering was significant due to different spacing treatments. The plants sown at wider spacing (30x30 cm) completed 50% flowering earlier (76.20 days) than spacing at 20x10 cm (77.80 days). The difference between the wider spacing of 30x30 cm and closer spacing of 20x10 cm was only 1.6

days (Table 18). The same trend was observed in number of days taken to harvest at different spacings (Table 19). Early harvest was done (177.20 days) at 30x30 cm, closely followed by 20x20 cm spacing (177.30 days) (NRC MAP, 2006b).

The root yield and its attributes like root length, root girth, number of primary and secondary roots, fresh and dry root yield and seed yield were significantly influenced due to different spacings.

The root length increased with increased age of the plant at all spacing treatments. The longest root (24.11 cm) was noticed at closer spacing of 20x10 cm. The root growth was almost doubled in length at 90 DAS (15.10 cm) over 40 DAS (7.74 cm) and thereafter, a little difference in growth of root was observed. Similar results were observed by Manish Agarwal *et al*.(2004). The root length was 9.37, 4.60 and 3.78 per cent higher in 20x10 cm than 30x30 cm, 20x20 cm and 30x10 cm spacings respectively (Table 20). Kothari *et al.* (2003), Saudan Singh *et al.* (2003) and Nigam *et al.* (1984) reported similar findings in ashwagandha. The results of the present investigation were also in accordance with those reported by Jayalakshmi (2003) and Chandrasekhar *et al.* (2007) in coleus.

The root girth at all stages of crop growth significantly influenced by different spacings. The maximum root diameter (1.30 cm) was observed at wider spacing of 30x30 cm. At this spacing (30x30 cm), the root girth was 13.85, 7.70 and 26.92 per cent higher than 30x10 cm, 20x20 cm and 20x10 cm spacing respectively (Table 21).

Similarly the number of primary and secondary roots was also significantly influenced due to different spacings. The highest number of primary and secondary roots were observed at wider spacing compared to closer spacing. (Table 22 & 23). The highest number of primary and secondary roots at wider spacing (30x30 cm) was 2.60

and 1.50 respectively. These results are in conformity with the findings of Kothari *et al.* (2003).

The fresh root yield (q ha^{-1}) was significantly higher at closer spacing of 20x10cm. The fresh root yield increased with increased spacing. At closer spacing, 20x10 cm, the fresh root yield was 4.54, 14.45 and 15.60 per cent higher than 30x10 cm (16.18 q ha^{-1}), 20x20 cm (14.50 q ha^{-1}) and 30x30 cm (14.31 q ha^{-1}) respectively (Table 24). Similarly the dry root yield (q ha^{-1}) was also significantly increased with increased spacing (Table 25).The highest dry root yield (7.15 q ha^{-1}) was recorded at closer spacing of 20x10 cm. The dry root yield at closer spacing of 20x10 cm was 4.90, 20.00 and 27.27 per cent higher than at 30x10 cm (6.80 q ha^{-1}), 20x20 cm (5.72 q ha^{-1}) and 30x30 cm (5.20 q ha^{-1}) spacing respectively. The results were in conformity with the findings of Kahar *et al*.(1991), Mohd. Abbas *et al*.(1994), Mishra (1998), Manish Agarwal *et al*.(2004) , Kothari *et al.* (2003) and Wankhade *et al.* (2009), Patel *et al.* (2003), in ashwagandha. Similar findings were reported by Mastiholi *et al.* (2007) and Mastiholi and Hiremath (2009) in coleus.

Similar trend was observed with seed yield (kg ha^{-1}). The seed yield was significantly highest at closer spacing of 20x10 cm. The seed yield (kg ha^{-1}) decreased with increased spacing. The maximum seed yield at closer spacing was 2.15, 14.34 and 21.94 per cent higher than at 30x10 cm (148.85 kgha^{-1}), 20x20 cm (130.3 kg ha^{-1}) and 30x30 cm (118.75 kg ha^{-1})spacing respectively.

The plant growth and yield attributes like plant height, leaf area index, fresh root yield, dry root yield and seed yield were increased with closer spacing (more plant density). Increase in plant height at closer spacing than at wider spacing might be due to more linear growth of plants as a result of higher density of plants (Mastiholi *et al.*, 2007 and Ramachandran and Muthuswami, 1982). The plants at closer spacing get less sunlight and air and hence grow more vertically leading to higher plant height (Mastiholi and Hiremath, 2009).

The wider spacing produced significantly higher yield and growth parameters per plant, which might be due to better availability of resources like space, nutrients and moisture etc. to individual plants and reduced inter plant competition in the plant community as opined by Man Singh *et al.,* 2002.

Availability of sufficient space, moisture, nutrients and light to individual plant and lesser competition for growth resources at wider spacing might have led to enhanced growth attributes like leaf area, number of branches (Table 15&17) and plant growth which in turn increase root yield per plant.

Although individual plant performance was better at wider spacing, the yield per unit area was substantially lower. On the contrary, the increase in yield per unit area with decrease in spacing could be due to the increased plant population, although, the yield per plant decreased. Higher yield per plant obtained at wider spacing did not compensate the decrease in plant density. These results are in line with the findings of Nigam(1985), Saxena and Dutta (1985), Farooqui and Sreenivas (2001), Pakkiyanadhan *et al.* (2004), Karad *et al.*(2009), Kubsad *et al.* (2009) and Shamaraj Chandranath *et al.* (2010) in ashwangandha. Similar findings were observed by Hegde(1985) in periwinkle and Chandrasekhar *et al.* (2007) in coleus.

Higher gross income were obtained with the treatments, spacing at 20x10 cm compared to spacing at 30x10 cm owing to higher yield recorded with the treatments. Further the treatment spacing at 30x30 cm were observed with lower dry root yield resulting in lower net income and BCR. The treatment, spacing at 30x10 cm had recorded the maximum BCR followed by spacing at 20x10 cm.

4.3 EXPT. III: INFLUENCE OF BIOFERTTILIZERS IN COMBINATION WITH GRADED LEVELS OF P_2O_5 ON GROWTH AND YIELD OF ASHWAGANDHA (*Withania somnifera* Dunal.)

Different levels of P_2O_5 along with biofertilizers (Azotobacter and Phosphobacteria significantly influenced on the plant growth and yield of ashwagandha (*Withania somnifera* Dunal.).

4.3.1 GROWTH PARAMETERS

4.3.1.1 Plant height (cm)

The influence of different levels of P_2O_5 and biofertilizers (Azotobacter and Phosphobacteria) on plant height was significant at different stages of crop growth (Table 27)

At 45 DAS, the treatment, AZB+P_{50} recorded significantly maximum plant height (14.20 cm), which was on par with AZB+P_{40} (13.71 cm). The minimum plant height (7.69 cm) was observed in control.

At 90 DAS, significantly highest plant height (34.21cm) was observed with AZB+P_{50}, but it was on par with AZB+P_{40} (33.68 cm), while the lowest plant height (24.53 cm) was recorded in control at harvest.

At 135 DAS, significantly superior plant height (52.96 cm) was recorded with AZB+P_{50} and was on par with AZB+P_{40} (52.24 cm). The lowest plant height (41.35 cm) was noticed in control.

At harvest, the maximum plant height (62.42 cm) was achieved with AZB+P_{50}, but it was on par with AZB+P_{40} (61.53 cm). The minimum pant height (48.81 cm) was noticed in control.

Table 27: Plant Height of Ashwagandha as influenced by biofertilizers and P_2O_5

Plant Height (cm)												
	45 DAS			90 DAS			135 DAS			at harvest		
Biofertilizers + P_2O_5	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: P30	9.53	9.43	9.48	26.72	26.54	26.63	44.48	43.88	44.18	52.69	51.67	52.18
T_2: P40	11.39	11.28	11.34	29.46	29.70	29.58	47.79	47.25	47.52	57.05	55.07	56.06
T_3: P50	11.70	11.68	11.69	30.31	29.95	30.13	47.97	48.45	48.21	57.30	56.54	56.92
T_4: AZB+P30	10.30	10.46	10.38	28.43	28.35	28.39	45.97	46.07	46.02	53.96	54.75	54.35
T_5: AZB+P40	13.58	13.84	13.71	33.99	33.37	33.68	52.64	51.84	52.24	61.42	61.64	61.53
T_6: AZB+P50	14.27	14.13	14.20	34.12	34.30	34.21	53.23	52.69	52.96	63.34	61.49	62.42
T_7: PSB+P30	10.18	10.34	10.26	28.08	27.96	28.02	45.79	45.44	45.62	53.77	53.93	53.85
T_8: PSB+P40	12.34	12.90	12.62	31.56	31.14	31.35	49.21	50.63	49.92	58.76	58.82	58.79
T_9: PSB+P50	12.98	13.22	13.10	32.04	31.88	31.96	50.74	50.74	50.74	59.95	59.31	59.63
T_{10}: AZB	8.61	8.63	8.62	26.17	26.55	26.36	43.87	44.12	44.00	51.40	52.10	51.75
T_{11}: PSB	8.46	8.58	8.52	26.10	26.20	26.15	42.84	43.88	43.36	51.24	51.09	51.17
T_{12}: CONTROL	7.52	7.86	7.69	24.53	24.52	24.53	40.68	42.02	41.35	48.62	49.00	48.81
Mean	**10.90**	**11.03**	**10.97**	**29.29**	**29.21**	**29.25**	**47.10**	**47.25**	**47.18**	**55.79**	**55.45**	**55.62**
S.Em±	0.24	0.20	0.25	0.47	0.51	0.34	0.66	0.62	0.55	0.86	0.70	0.64
C.D at 5%	0.67	0.58	0.70	1.37	1.49	0.98	1.95	1.73	1.58	2.53	1.98	1.82

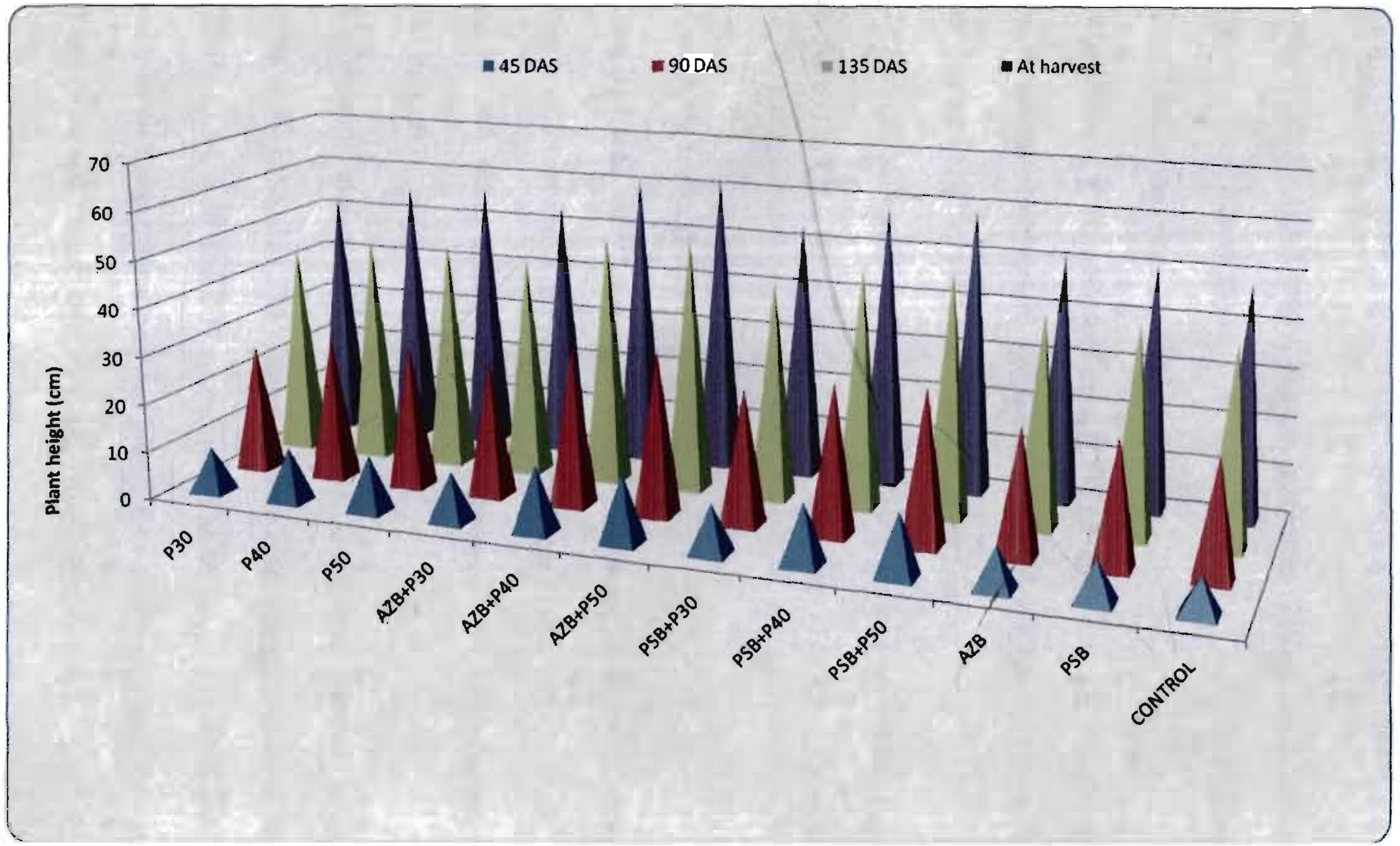


Fig.12 Plant height (cm) of ashwagandha as influenced by biofertilizers and P_2O_5

4.3.1.2 Leaf area (cm^2)

Leaf area was significantly influenced by different levels of P_2O_5 and biofertilizers at different stages of crop growth (Table 28).

At 45 DAS, significantly maximum leaf area (203.64 cm^2) was recorded withAZB+P_{50} and was par with AZB+P_{40} (199.41 cm^2). The minimum leaf area (140.20 cm^2) was observed in control.

At 90 DAS, significantly highest leaf area (780.08 cm^2) was recorded at AZB+P_{50}. However, it was on par with AZB+P_{40} (767.65 cm^2). The lowest leaf area (582.97 cm^2) was observed in control.

Significantly maximum leaf area (1274.62 cm^2) was recorded at 135 DAS in AZB+P_{50} treatment combination, which was on par with AZB+P_{40} (1259.16 cm^2). The minimum leaf area (100.89 cm^2) was observed in control.

At harvest, highest leaf area (526.22 $cm^{2)}$ was noticed with AZB+P_{50} and was on par with AZB+P_{40} (513.11 cm^2). The lowest leaf area (393.84 cm^2) was noticed in control.

4.3.1.3 Leaf Area Index (LAI)

The leaf area index was significantly influenced at different stages of crop growth due to different levels of P_2O_5 and biofertilizers (Table 29).

At 45 DAS, maximum LAI (1.02) was observed with AZB+P_{50} and was on par with AZB+P_{40} (1.00).

Significantly highest LAI (3.90, 6.37 and 2.63) was observed with AZB+P_{50} combination at 90 DAS, 135 DAS and at harvest respectively and these were on par with AZB+P_{40} (3.84, 6.30 and 2.57 respectively) at 90 DAS, 135 DAS and at harvest respectively. In all the combinations, the lowest LAI (2.90, 5.04 and 1.97 at 90 DAS, 135 DAS and at harvest respectively) was recorded with control.

Table 28: Leaf Area of Ashwagandha as influenced by biofertilizers and P_2O_5

Leaf Area (cm^2)												
	45 DAS			90 DAS			135 DAS			at harvest		
Biofertilizers + P_2O_5	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
T_1: P30	156.41	153.43	154.92	638.67	626.67	632.67	1071.92	1095.92	1083.92	437.55	442.45	440.00
T_2: P40	176.08	172.97	174.53	683.31	700.85	692.08	1128.29	1153.44	1140.87	481.78	476.83	479.31
T_3: P50	178.94	180.16	179.55	693.16	715.98	704.57	1146.15	1170.66	1158.41	496.92	480.16	488.54
T_4: AZB+P30	168.47	166.71	167.59	666.78	674.97	670.87	1117.95	1146.75	1132.35	465.43	471.58	468.50
T_5: AZB+P40	200.91	197.91	199.41	761.12	774.18	767.65	1253.83	1264.49	1259.16	514.68	511.54	513.11
T_6: AZB+P50	204.64	202.64	203.64	780.05	780.11	780.08	1269.60	1279.64	1274.62	526.44	526.00	526.22
T_7: PSB+P30	164.85	163.61	164.23	656.21	650.85	653.53	1109.00	1126.08	1117.54	450.08	467.68	458.88
T_8: PSB+P40	186.16	183.65	184.91	718.13	737.59	727.86	1192.18	1219.04	1205.61	499.88	496.23	498.05
T_9: PSB+P50	189.88	191.56	190.72	746.64	741.31	743.98	1206.64	1244.00	1225.32	502.07	503.24	502.65
T_{10}: AZB	153.56	155.29	154.42	627.47	621.35	624.41	1073.50	1087.79	1080.65	422.09	439.41	430.75
T_{11}: PSB	150.43	148.15	149.29	618.83	615.53	617.18	1062.98	1066.30	1064.64	417.21	436.95	427.08
T_{12}: CONTROL	141.81	138.59	140.20	579.80	586.14	582.97	1004.76	1015.02	1009.89	381.25	406.42	393.84
Mean	**172.68**	**171.22**	**171.95**	**680.85**	**685.46**	**683.15**	**1136.40**	**1155.76**	**1146.08**	**466.28**	**471.54**	**468.91**
S.Em±	2.14	2.81	2.01	11.17	9.16	7.23	18.45	15.36	12.00	8.76	7.42	4.69
C.D at 5%	6.28	8.23	5.98	32.77	26.86	20.57	54.10	45.06	34.15	25.69	21.76	14.05

Table 29: Leaf Area Index of Ashwagandha as influenced by biofertilizers and P_2O_5

Leaf Area Index												
	45 DAS			90 DAS			135 DAS			at harvest		
Biofertilizers + P_2O_5	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
T_1: P30	0.78	0.77	0.77	3.19	3.13	3.16	5.36	5.48	5.42	2.19	2.21	2.20
T_2: P40	0.88	0.86	0.87	3.42	3.50	3.46	5.64	5.77	5.70	2.41	2.38	2.40
T_3: P50	0.89	0.90	0.90	3.47	3.58	3.52	5.73	5.85	5.79	2.48	2.40	2.44
T_4: AZB+P30	0.84	0.83	0.84	3.33	3.37	3.35	5.59	5.73	5.66	2.33	2.36	2.34
T_5: AZB+P40	1.00	0.99	1.00	3.81	3.87	3.84	6.27	6.32	6.30	2.57	2.56	2.57
T_6: AZB+P50	1.02	1.01	1.02	3.90	3.90	3.90	6.35	6.40	6.37	2.63	2.63	2.63
T_7: PSB+P30	0.82	0.82	0.82	3.28	3.25	3.27	5.54	5.63	5.59	2.25	2.34	2.29
T_8: PSB+P40	0.93	0.92	0.92	3.59	3.69	3.64	5.96	6.10	6.03	2.50	2.48	2.49
T_9: PSB+P50	0.95	0.96	0.95	3.72	3.71	3.71	6.03	6.22	6.13	2.51	2.52	2.51
T_{10}: AZB	0.77	0.78	0.77	3.14	3.11	3.12	5.37	5.44	5.40	2.11	2.20	2.15
T_{11}: PSB	0.75	0.74	0.75	3.09	3.08	3.09	5.31	5.33	5.32	2.10	2.18	2.14
T_{12}: CONTROL	0.71	0.69	0.70	2.90	2.91	2.90	5.01	5.08	5.04	1.91	2.03	1.97
Mean	**0.86**	**0.86**	**0.86**	**3.40**	**3.43**	**3.41**	**5.68**	**5.78**	**5.73**	**2.33**	**2.36**	**2.34**
S.Em±	0.01	0.02	0.01	0.06	0.05	0.04	0.10	0.06	0.07	0.03	0.03	0.02
C.D at 5%	0.04	0.05	0.03	0.16	0.16	0.11	0.30	0.17	0.19	0.10	0.09	0.07

4.3.2 ROOT YIELD AND ITS ATTRIBUTES

4.3.2.1 Root length (cm)

At all stages of crop growth, root length was significantly influenced due to different levels of P_2O_5 and biofertilizers (Table 30).

At 45 DAS, significantly maximum root length (7.08 cm) was recorded with AZB+P_{50} and followed by AZB+P_{40} (6.92 cm) which were on par. The minimum root length (3.09 cm) was observed in control.

The longest root (15.19 cm) at 90 DAS was recorded with AZB+P_{50}, which was on par with AZB+P_{40} (14.88 cm). The shortest root length (10.13 cm) was recorded in control.

At 135 DAS, maximum root length (19.59 cm) was noticed with AZB+P_{50} and it was on par with AZB+P_{40} (19.26 cm). The minimum root length (13.96 cm) was observed in control.

Significantly superior root length (24.68 cm) was recorded at AZB+P_{50} treatment, however it was on par with AZB+P_{40} (24.14 cm). The lowest root length (16.39 cm) was observed in control.

4.3.2.2 Root girth (cm)

The maximum root girth was recorded with AZB+P_{50} (1.49 cm) and it was on par with AZB+P_{40} (1.46 cm). The minimum root girth (0.70 cm) was observed in control (Table 31).

4.3.2.3 Number of primary branches

The number of primary branches per plant was significantly influenced due to different levels of P_2O_5 and biofertilizers (Table 32).

Table 30: Root Length of Ashwagandha as influenced by biofertilizers and P_2O_5

Root Length (cm)												
	45 DAS			90 DAS			135 DAS			at harvest		
Biofertilizers + P_2O_5	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
T_1: P30	3.92	3.92	3.92	11.22	11.42	11.32	15.16	15.42	15.29	18.62	17.91	18.26
T_2: P40	5.37	5.38	5.38	13.01	13.10	13.06	17.20	17.34	17.27	21.00	21.36	21.18
T_3: P50	5.62	5.48	5.55	13.14	13.15	13.14	17.38	17.38	17.38	21.51	21.13	21.32
T_4: AZB+P30	4.70	4.66	4.68	12.29	12.28	12.29	16.11	16.53	16.32	19.93	19.67	19.80
T_5: AZB+P40	6.87	6.97	6.92	15.04	14.72	14.88	18.90	19.62	19.26	24.42	23.86	24.14
T_6: AZB+P50	7.12	7.04	7.08	15.37	15.01	15.19	19.56	19.62	19.59	24.49	24.87	24.68
T_7: PSB+P30	4.58	4.52	4.55	12.14	12.07	12.10	15.83	16.51	16.17	19.89	19.31	19.60
T_8: PSB+P40	6.17	6.19	6.18	13.94	13.78	13.86	18.19	18.37	18.28	22.87	23.29	23.08
T_9: P SB+P50	6.20	6.22	6.21	14.06	14.24	14.15	18.32	18.46	18.39	23.41	23.02	23.22
T_{10}: AZB	3.76	3.89	3.83	11.34	10.90	11.12	15.29	15.24	15.26	18.33	17.69	18.01
T_{11}: PSB	3.75	3.87	3.81	11.04	10.98	11.01	14.75	15.15	14.95	17.52	17.94	17.73
T_{12}: CONTROL	3.13	3.05	3.09	10.17	10.09	10.13	13.82	14.10	13.96	16.20	16.58	16.39
Mean	**5.10**	**5.10**	**5.10**	**12.73**	**12.65**	**12.69**	**16.71**	**16.98**	**16.84**	**20.68**	**20.55**	**20.62**
S.Em±	0.09	0.08	0.06	0.15	0.20	0.12	0.29	0.30	0.21	0.36	0.34	0.25
C.D at 5%	0.26	0.24	0.18	0.45	0.57	0.35	0.85	0.88	0.58	1.07	1.01	0.70

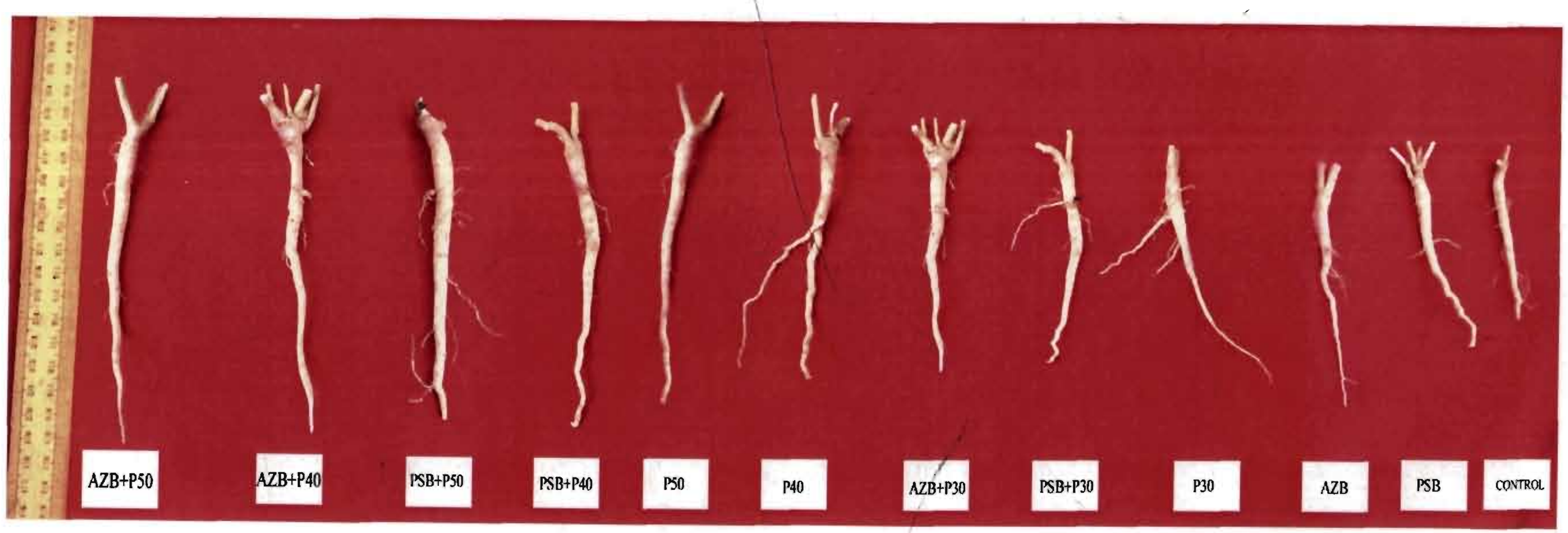


Plate. 8 Root growth of ashwagandha as influenced by biofertilizers and P_2O_5

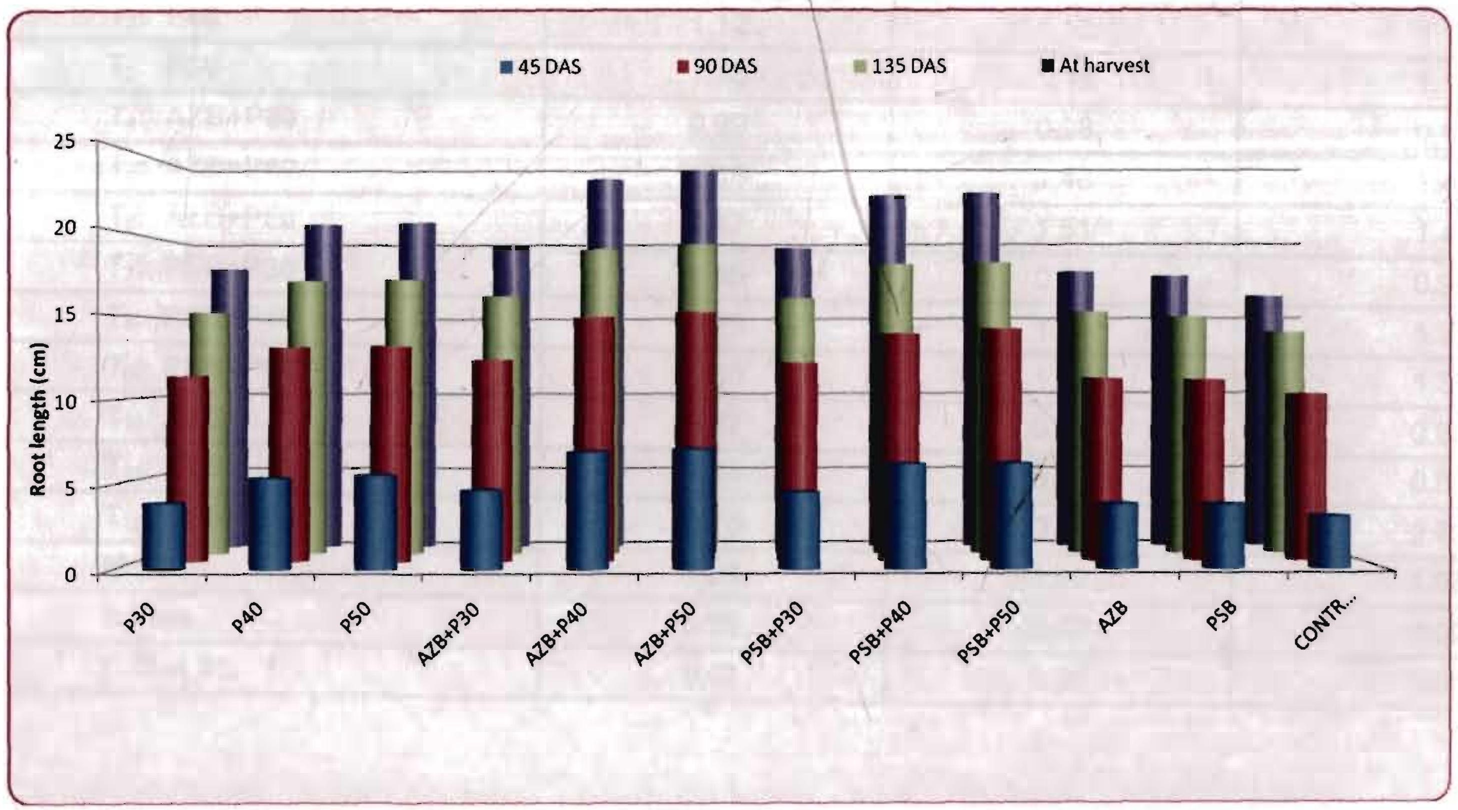


Fig. 13 Root length (cm) of ashwagandha as influenced by biofertilizers and P_2O_5

Table 31: Root girth of Ashwagandha as influenced by biofertilizers and P_2O_5

Root girth (cm)			
Biofertilizers + P_2O_5	**2009-10**	**2010-11**	**Pooled**
T_1: P30	0.90	0.88	0.89
T_2: P40	1.12	1.12	1.12
T_3: P50	1.13	1.15	1.14
T_4: AZB+P30	0.99	0.98	0.98
T_5: AZB+P40	1.44	1.48	1.46
T_6: AZB+P50	1.47	1.51	1.49
T_7: PSB+P30	0.95	0.95	0.95
T_8: PSB+P40	1.29	1.26	1.27
T_9: PSB+P50	1.30	1.33	1.31
T_{10}: AZB	0.87	0.85	0.86
T_{11}: PSB	0.84	0.83	0.83
T_{12}: CONTROL	0.70	0.70	0.70
Mean	**1.08**	**1.09**	**1.08**
S.Em±	0.02	0.02	0.02
C.D at 5%	0.07	0.06	0.04

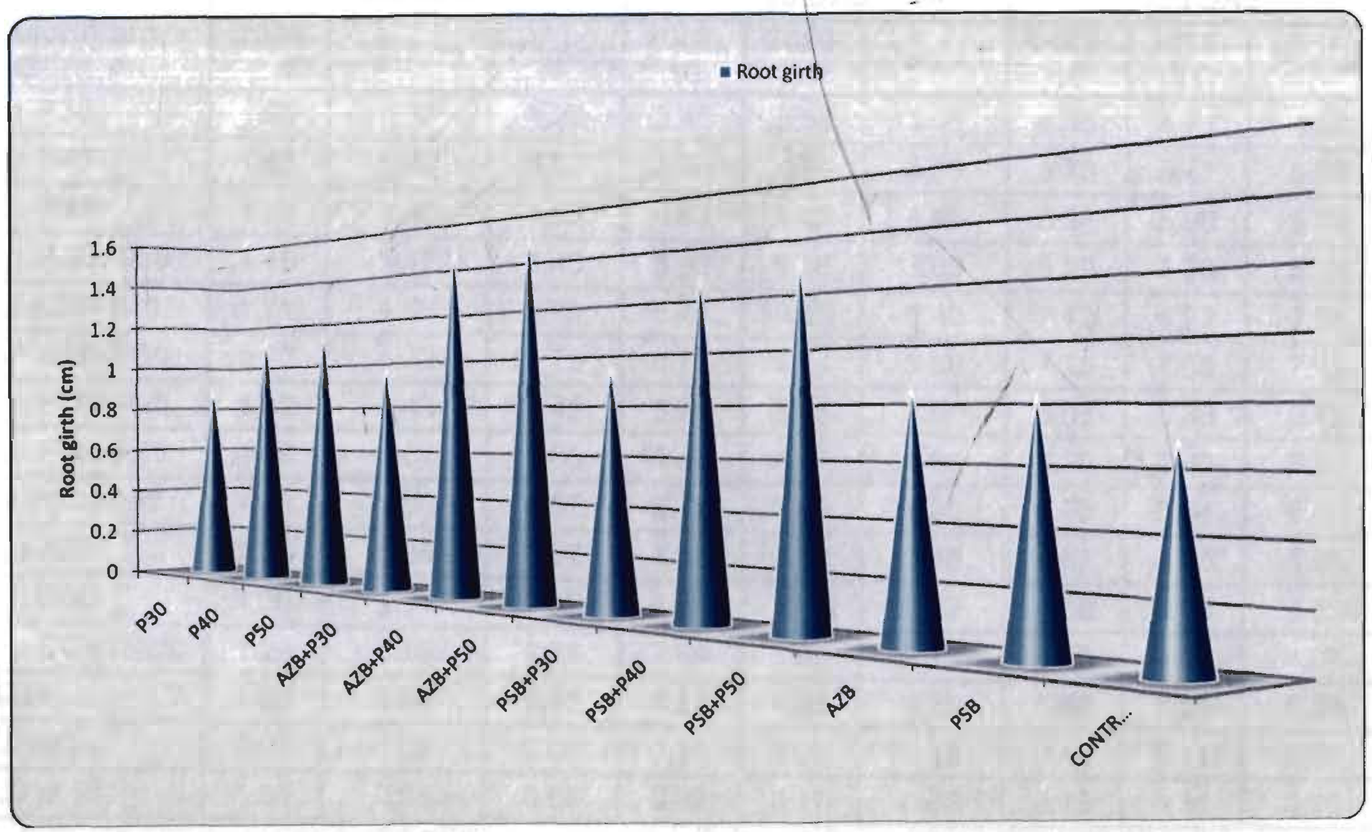


Fig. 14 Root girth (cm) of ashwagandha as influenced by biofertilizers and P_2O_5

Table 32: Primary Branches of Ashwagandha as influenced by biofertilizers and P_2O_5

Primary Branches												
	45 DAS			90 DAS			135 DAS			at harvest		
Biofertilizers + P_2O_5	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
T_1: P30	1.39	1.37	1.38	3.45	3.58	3.51	4.66	4.71	4.68	4.84	4.97	4.91
T_2: P40	1.53	1.49	1.51	4.34	4.39	4.36	5.73	5.71	5.72	6.30	6.22	6.26
T_3: P50	1.55	1.49	1.53	4.55	4.43	4.49	5.94	5.90	5.92	6.38	6.38	6.38
T_4: AZB+P30	1.43	1.47	1.45	3.92	3.86	3.89	5.22	5.30	5.26	5.51	5.71	5.61
T_5: AZB+P40	1.71	1.68	1.70	5.41	5.43	5.42	7.12	6.92	7.02	7.80	7.58	7.69
T_6: AZB+P50	1.78	1.72	1.75	5.72	5.64	5.68	7.18	7.06	7.12	7.89	7.71	7.80
T_7: PSB+P30	1.42	1.43	1.43	3.76	3.86	3.81	5.08	5.30	5.19	5.53	5.55	5.54
T_8: PSB+P40	1.66	1.64	1.65	4.85	4.87	4.86	6.25	6.40	6.32	7.03	6.99	7.01
T_9: PSB+P50	1.68	1.66	1.67	5.13	5.03	5.08	6.46	6.54	6.50	7.12	7.02	7.07
T_{10}: AZB	1.38	1.35	1.37	3.38	3.50	3.44	4.61	4.60	4.60	4.79	4.89	4.84
T_{11}: PSB	1.38	1.34	1.36	3.21	3.42	3.32	4.60	4.58	4.59	4.65	4.80	4.74
T_{12}: CONTROL	1.23	1.19	1.21	2.84	3.02	2.93	4.10	4.04	4.07	4.25	4.27	4.26
Mean	**1.51**	**1.49**	**1.50**	**4.21**	**4.25**	**4.23**	**5.58**	**5.59**	**5.58**	**6.01**	**6.01**	**6.01**
S.Em±	0.03	0.02	0.02	0.11	0.06	0.12	0.10	0.11	0.07	0.10	0.08	0.06
C.D at 5%	0.08	0.05	0.06	0.32	0.17	0.36	0.29	0.31	0.20	0.30	0.23	0.18

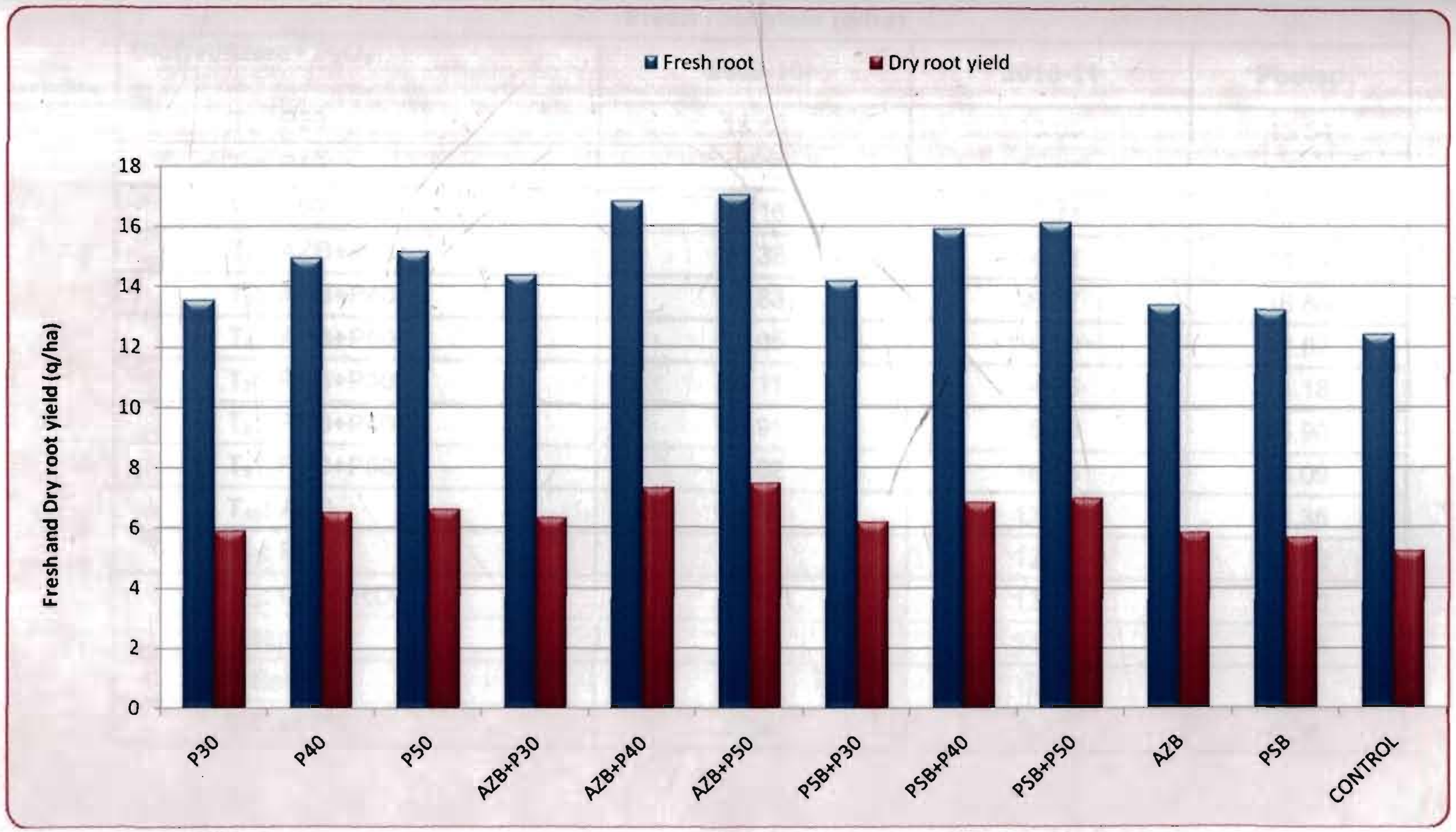


Fig.15 Fresh and Dry root weight (q/ha) of ashwagandha as influenced by biofertilizers and P_2O_5

Table 33: Fresh root weight of Ashwagandha as influenced biofertilizers and P_2O_5

Fresh root yield (q/ha)			
Biofertilizers+ P_2O_5	**2009-10**	**2010-11**	**Pooled**
T_1: P30	13.43	13.65	13.54
T_2: P40	15.05	14.77	14.91
T_3: P50	15.16	15.11	15.14
T_4: AZB+P30	14.38	14.31	14.34
T_5: AZB+P40	16.83	16.77	16.80
T_6: AZB+P50	17.05	16.99	17.02
T_7: PSB+P30	14.11	14.26	14.18
T_8: PSB+P40	15.91	15.90	15.90
T_9: PSB+P50	16.02	16.16	16.09
T_{10}: AZB	13.38	13.32	13.35
T_{11}: PSB	13.24	13.20	13.22
T_{12}: CONTROL	12.36	12.43	12.40
Mean	**14.74**	**14.74**	**14.74**
S.Em±	0.29	0.25	0.19
C.D at 5%	0.84	0.72	0.54

At 45 DAS, the maximum number of primary branches per plant (1.75) was observed with AZB+P_{50} and it was on par with AZB+P_{40} (1.70). The minimum number of branches per plant (1.21) was recorded in control.

At 90 DAS, the highest number of primary branches (5.68) was noticed with AZB+P_{50}, which was on par with AZB+P_{40} (5.42). The minimum number of primary branches per plant (2.93) was recorded in control.

The maximum number (7.12) of primary branches at 135 DAS was observed with AZB+P_{50}**,** however it was on par with AZB+P_{40} (7.02). The minimum numbers of primary branches (4.07) was recorded in control.

At harvest, the highest number of primary branches (7.80) was recorded at AZB+P_{50}**,** which was on par with AZB+P_{40} (7.69). The lowest number of primary branches (4.26) was recorded in control.

4.3.2.4 Fresh root yield (q ha^{-1})

Among all the treatments, AZB+P_{50} recorded significantly highest fresh root yield (17.02 q ha^{-1}) which was on par with AZB+P_{40} (16.80 q ha^{-1}). The lowest fresh root yield (12.40 q ha^{-1}) was recorded in control (Table 33)

4.3.2.5 Dry root yield (q ha^{-1})

The data presented in table 34 revealed that the maximum dry root yield (7.46q ha^{-1}) was obtained from AZB+P_{50} and it was on par with AZB+P_{40} (7.30 q ha^{-1}). This was followed by AZB+P_{50} the higher dry root yield was recorded with PSB+P_{50} (6.95 q ha^{-1}). The minimum dry root yield (5.21 q ha^{-1}) was noticed in control.

4.3.2.6 Seed yield (kg ha^{-1})

The seed yield was significantly influenced by different treatments (Table 35). The highest seed yield (164.34 kg ha^{-1}) was recorded from the treatment AZB+P_{50}.

Table 34: Dry root yield of Ashwagandha as influenced Biofertilizers and P_2O_5

Dry root yield (Q/ha)			
Biofertilizers+ P_2O_5	**2009-10**	**2010-11**	**Pooled**
T_1: P30	5.83	5.92	5.88
T_2: P40	6.53	6.48	6.50
T_3: P50	6.54	6.63	6.59
T_4: AZB+P30	6.33	6.33	6.33
T_5: AZB+P40	7.13	7.47	7.30
T_6: AZB+P50	7.38	7.53	7.46
T_7: PSB+P30	6.08	6.25	6.17
T_8: PSB+P40	6.82	6.83	6.82
T_9: PSB+P50	6.98	6.92	6.95
T_{10}: AZB	5.74	5.86	5.80
T_{11}: PSB	5.68	5.70	5.69
T_{12}: CONTROL	5.17	5.25	5.21
Mean	**6.35**	**6.43**	**6.39**
S.Em±	0.12	0.10	0.08
C.D at 5%	0.36	0.29	0.22

Table 35: Seed yield of Ashwagandha as influenced Biofertilizers and P_2O_5

Seed yield (kg/ha)			
Biofertilizers+ P_2O_5	**2009-10**	**2010-11**	**Pooled**
T_1: P30	132.19	135.15	133.67
T_2: P40	146.81	144.17	145.49
T_3: P50	147.84	146.59	147.21
T_4: AZB+P30	141.81	142.43	142.12
T_5: AZB+P40	162.51	160.73	161.62
T_6: AZB+P50	164.09	164.59	164.34
T_7: PSB+P30	140.42	138.26	139.34
T_8: PSB+P40	152.55	154.19	153.37
T_9: PSB+P50	155.47	156.31	155.89
T_{10}: AZB	130.42	133.61	132.02
T_{11}: PSB	129.78	132.63	131.21
T_{12}: CONTROL	121.42	124.21	122.82
Mean	**143.78**	**144.41**	**144.09**
S.Em±	2.35	2.46	1.67
C.D at 5%	6.88	7.23	4.74

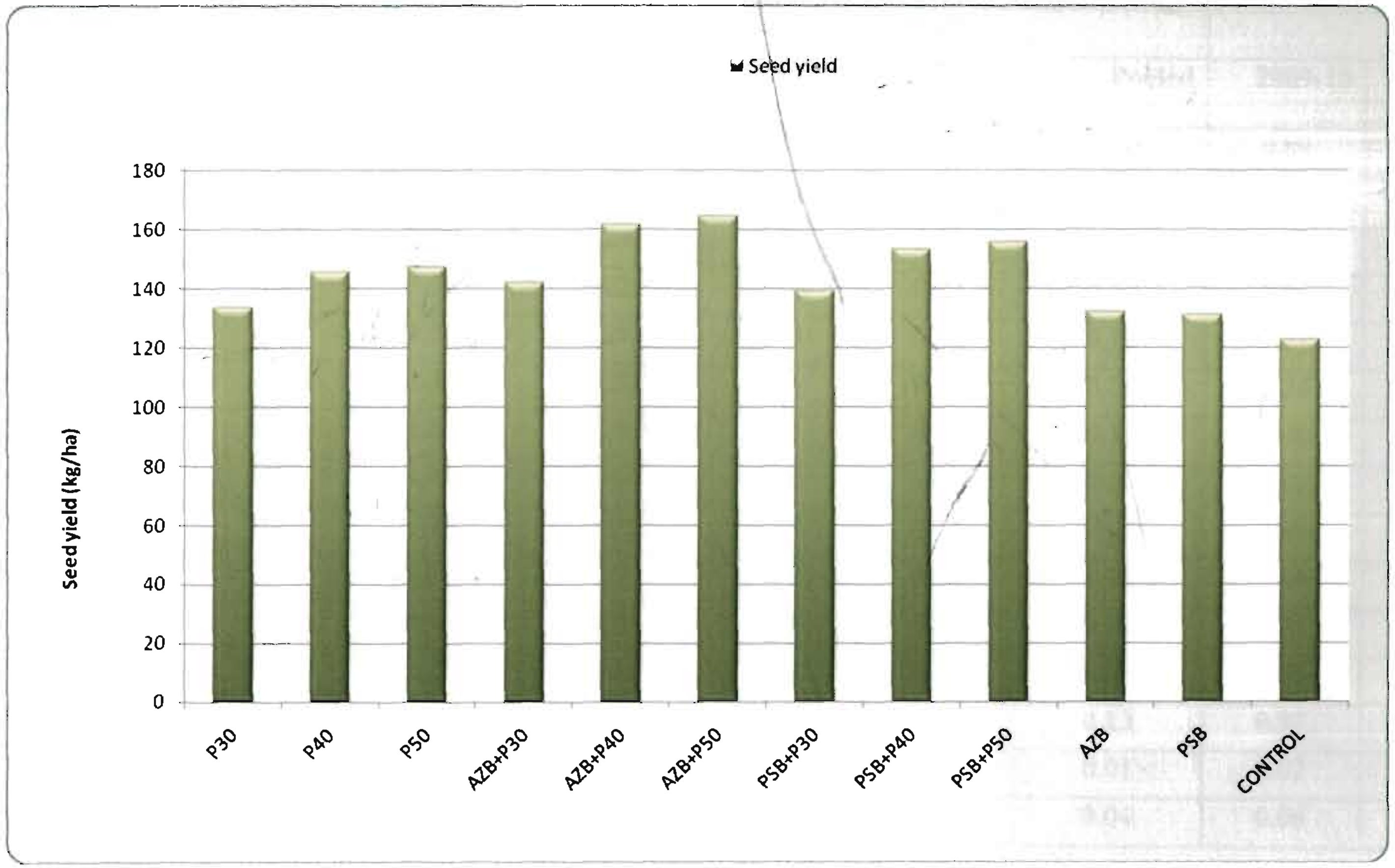


Fig.16 Seed yield (kg/ha) of ashwagandha as influenced by biofertilizers and P_2O_5

Table 36: Effect of biofertilizers and P_2O_5 on N, P and K content(%) of leaves at harvest

Leaves at Harvest									
	N%			P%			K%		
Biofertilizers+ P_2O_5	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
P30	1.20	1.19	1.20	0.10	0.10	0.10	0.89	0.87	0.88
P40	1.26	1.21	1.23	0.13	0.13	0.13	0.94	0.94	0.94
P50	1.22	1.26	1.24	0.14	0.14	0.14	0.98	0.96	0.97
AZB+P30	1.22	1.22	1.22	0.12	0.12	0.12	0.92	0.92	0.92
AZB+P40	1.27	1.28	1.28	0.18	0.18	0.18	1.21	1.19	1.20
AZB+P50	1.27	1.30	1.28	0.19	0.19	0.19	1.24	1.26	1.25
PSB+P30	1.20	1.23	1.21	0.11	0.11	0.11	0.90	0.90	0.90
PSB+P40	1.23	1.28	1.26	0.16	0.16	0.16	1.10	1.10	1.10
PSB+P50	1.27	1.25	1.26	0.17	0.16	0.17	0.99	1.01	1.00
AZB	1.16	1.22	1.19	0.10	0.10	0.10	0.84	0.86	0.85
PSB	1.18	1.19	1.19	0.10	0.10	0.10	0.83	0.85	0.84
CONTROL	1.09	1.09	1.09	0.09	0.09	0.09	0.78	0.80	0.79
Mean	**1.21**	**1.23**	**1.22**	**0.13**	**0.13**	**0.13**	**0.97**	**0.97**	**0.97**
S.Em±	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01
C.D at 5%	0.06	0.05	0.04	0.06	0.05	0.04	0.06	0.05	0.04

Table 37: Effect of biofertilizers and P_2O_5 on N, P and K content (%) of Roots at harvest

Roots at Harvest									
	N%			P%			K%		
Biofertilizers+ P_2O_5	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
P30	1.28	1.23	1.25	0.10	0.11	0.11	0.79	0.81	0.80
P40	1.33	1.32	1.33	0.11	0.11	0.11	0.96	0.94	0.95
P50	1.32	1.36	1.34	0.11	0.11	0.11	1.02	0.98	1.00
AZB+P30	1.28	1.31	1.30	0.11	0.11	0.11	0.91	0.89	0.90
AZB+P40	1.43	1.38	1.41	0.13	0.13	0.13	1.09	1.11	1.10
AZB+P50	1.41	1.43	1.42	0.14	0.14	0.14	1.09	1.15	1.12
PSB+P30	1.28	1.28	1.28	0.11	0.11	0.11	0.84	0.86	0.85
PSB+P40	1.37	1.37	1.37	0.11	0.12	0.12	1.02	1.06	1.04
PSB+P50	1.39	1.37	1.38	0.13	0.13	0.13	1.10	1.08	1.09
AZB	1.21	1.25	1.23	0.10	0.11	0.11	0.75	0.75	0.75
PSB	1.21	1.23	1.22	0.10	0.10	0.10	0.72	0.76	0.74
CONTROL	1.17	1.19	1.18	0.10	0.10	0.10	0.70	0.70	0.70
Mean	**1.31**	**1.31**	**1.31**	**0.11**	**0.11**	**0.11**	**0.92**	**0.92**	**0.92**
S.Em±	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.02	0.01
C.D at 5%	0.06	0.06	0.04	0.00	0.01	0.00	0.04	0.05	0.03

But it was on par with AZB+P_{40} (161.62 kg ha^{-1}). The lowest seed yield (122.82 kg ha^{-1}) was recorded in control.

4.3.2.7 Effect of biofertilizers and phosphorus on N, P and K content (%) of leaves of ashwagandha at harvest

The N, P and K content (%) of leaves of ashwagandha at harvest was significantly influenced by different treatments (Table 36), Significantly the highest content of N (1.28 %), P (0.19) and K (1.25 %) was recorded with the treatment AZB+P_{50}. Whereas, control recorded the lowest content of N (1.09 %), P (0.09) and K (0.79 %) in leaves.

4.3.2.7 Effect of biofertilizers and phosphorus on N, P and K content (%) of roots of ashwagandha at harvest

The N, P and K content (%) of roots of ashwagandha at harvest (Table 37) followed the same trend as that of N, P and K content (%) of leaves.

4.3.3 ECONOMICS

The cost of cultivation, gross and net returns in addition to benefit: cost ratio was worked out for different levels of phosphorus in combination with biofertilizers in ashwagandha are presented in Appx. 4&5.

4.3.3.1 Cost of cultivation (Rs ha^{-1})

Maximum cost of cultivation of Rs.30,628 was recorded with AZB + P_{50} followed by T_9 while a minimum of Rs. 30128 were registered with control (T_{12}).

4.3.3.2 Gross income and Net income (Rs ha^{-1})

The gross incomes obtained with AZB + P_{50} were the highest Rs.95,207.2 followed by AZB + P_{40} while they were lowest with control (Rs.67,135.6).

Maximum net income was realized with AZB + P_{50} Rs.64579.2 followed by T_5 while minimum was realized with T_{12} (Rs. 37007.6)

4.3.3.3 Benefit: cost ratio (BCR)

The treatment, AZB + P_{50} had recorded the maximum BCR of 2.10 followed by AZB + P_{40} while control recorded the minimum BCR of 1.22.

Primary branches and leaf area per plant increased as the age of the plant advanced in all treatments. The increase in P_2O_5 level in combination with biofertilizers increased the no. of primary branches and leaf area. At harvest the highest number of primary branches (7.80) was recorded at AZB + P_{50} followed by AZB+ P_{40} (7.69) and PSB + P_{50} (7.07). The same trend was observed with leaf area also. The leaf area per plant increased rapidly up to 135 DAS in all the treatments. At harvest, the leaf area per plant declined, might be due to senescence of leaves at harvest stage.

The increase in plant height , no. of branches, leaf area might be due to enhanced vegetative growth, because of increased cell division and meristamatic cell elongation in the auxilary buds in turn trigged the various activities and increases the supply of photosynthates and there by increase in vegetative growth. Cytokinins produced by biofertilizers might be responsible for increased lateral branches.

The root yield attributes were also significantly influenced by different levels of P_2O_5 and biofertilizers. The root length, girth, fresh and dry root yields increased with increased levels of P_2O_5 in combination with AZB and PSB. The maximum root length was recorded with AZB + P_{50} followed by PSB + P_{50}. At harvest, the highest root length (24.68cm) were recorded with AZB + P_{50} followed by AZB + P_{40} and PSB + P_{50}

The root girth was also maximum at AZB + P_{50} and AZB + P_{40} closely following PSB + P_{50} and PSB + P_{40}. Due to increased root length and girth at AZB + P_{50} and AZB + P_{40} the resulting yield per hectare was also highest. The dry root yield increased with

AZB + P_{50} (7.46 q/ha). The seed yield was also increased with AZB + P_{50} followed by AZB + P_{40}.

Addition of biofertilizers might have played an important role in making the unavailable forms resulting in the better uptake of nutrients subsequently increasing the yield (Sanjay Singh *et al.*, 2002). The increased levels of P_2O_5 in combination with biofertilizers increased the root yield which might be due to release of energy rich organic compounds which increased growth and activity of microbial saprophytes and phosphatase activity. Similar results were reported by Mohandas (1987).

Higher gross income were obtained with the treatments, AZB+P_{50} compared to AZB+P_{40} owing to higher yield recorded with the treatments. Further the treatment control were observed with lower dry root yield resulting in lower net income and BCR. The treatment, AZB + P_{50} had recorded the maximum BCR followed by AZB + P_{40}.

4.4 EXPT.IV: EFFECT OF TIME OF HARVESTING ON ROOT YIELD AND QUALITY OF ASHWAGANDHA (*Withania somnifera* Dunal.)

4.4.1 Tap root length (cm)

The length of the tap root was significantly influenced by different stages of crop growth (Table 38). The root length increased with increased age of the plant. The longest root (24.14 cm) was observed when the plants were harvested at 180 DAS, while the shortest root (17.91 cm) was noticed when harvested at 120 DAS.

4.4.2 Tap root girth (cm)

The diameter of the root was influenced significantly due to different stages of harvest. The thicker roots (1.09 cm) were observed, where the crop was harvested at 180 DAS compared to rest of the harvesting stages (Table 39).

4.4.3 Number of primary roots per plant

The number of primary roots per plant was effected significantly at different stages of harvest. The higher number of primary roots (1.40) was observed when harvested at 180 DAS stage of harvest, while the lowest number of primary branches (0.98) was noticed at harvest stage of 120 DAS (Table 40).

4.4.4 Number of secondary roots per plant

The data (Table 41) on number of secondary roots per plant revealed a significant influence due to different stages of harvest. The crop harvested at 180 DAS recorded the maximum (0.30) number of secondary roots. However it was on par with harvesting stage at 160 DAS. The minimum number (0.25) of secondary roots was observed at the harvesting stage of 120 DAS. The data on secondary roots, harvested at 120 DAS and 150DAS and was on par with each other.

4.4.5 Grading quality of roots

The grading quality of roots was also influenced by different harvesting stages of ashwagandha (Table 42) The roots harvested at 120 DAS, produced 60.13 per cent 'B' grade, 30.13 per cent 'C' grade, and 10.0 per cent 'low' grade.

The crop harvested at 135 DAS produced 60% 'B' grade, 29% 'C' grade and 11% 'low' grade roots.

The crop harvested at 150 DAS, recorded 72.9 per cent 'B' grade, 15.00 per cent 'C' grade and 12.00 per cent 'low' grade roots.

The roots harvested at 165 DAS, yielded 76.14 per cent 'A' grade, 3.0 per cent 'B' grade, 10.88 per cent 'C' grade and 10.00 per cent roots of 'low' grade.

The crop harvested at 180 DAS recorded 76.13 per cent 'A' grade, 4.0 per cent 'B' grade, 12.00 per cent 'C' grade and 7.88 per cent 'low' grade roots.

The ‘A’ grades obtained by harvesting of the roots at 165 DAS and 180 DAS were on par. The ‘B’ grade roots were obtained from the crop harvest at 165 and 180 DAS and 120 as well as at 135 DAS were on par with each other.

4.4.6 Dry root yield (q ha^{-1})

The crop harvested at 180 DAS recorded significantly highest dry root yield (7.22 q ha^{-1}) compared to other harvesting stages. However, it was on par with crop harvested at 165 DAS (7.10 q ha^{-1}). The lowest dry root yield (5.34 q ha^{-1}) was recorded at harvesting stage of 120 DAS (Table 43). The dry root weight per plant (g) (Table 44) followed the same trend as that of dry root yield per ha

The dry root yield of ashwagandha increased with extended period of harvesting. The crop harvested at 180 DAS recorded significantly higher dry root yield(7.22 q ha^{-1}) closely following the results at 165 DAS harvest stage. This was 26.04 per cent higher over 120 DAS harvest. These results clearly indicated that the optimum stage of harvesting for ashwagandha would be 180 DAS. Patel *et al.* (2003) reported a significant increase in the yield of both thin and thick roots (92.0 to 171.0 kg ha^{-1} and 25.9 to 43.6 kg ha^{-1} respectively) with the increase in days of harvesting of ashwagandha from 120 to 180 DAS.

4.4.6 Alkaloid content (%)

The alkaloid content increased with the advancement of harvesting stage (Table 45). The lowest alkaloid content (0.25 %) was recorded at 120 DAS. The highest content of alkaloid (0.38 %) was observed at 180 DAS, however it was on par with 165 DAS

Table No 38: Tap root length of ashwagandha as influenced by stages of harvest

Tap root length (cm)			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	17.76	18.06	17.91
135 DAS	19.18	19.16	19.17
150 DAS	19.87	20.01	19.94
165 DAS	21.90	22.18	22.04
180 DAS	24.02	24.26	24.14
Mean	**20.55**	**20.73**	**20.64**
S.Em±	0.35	0.40	0.26
C.D at 5%	1.09	1.24	0.76

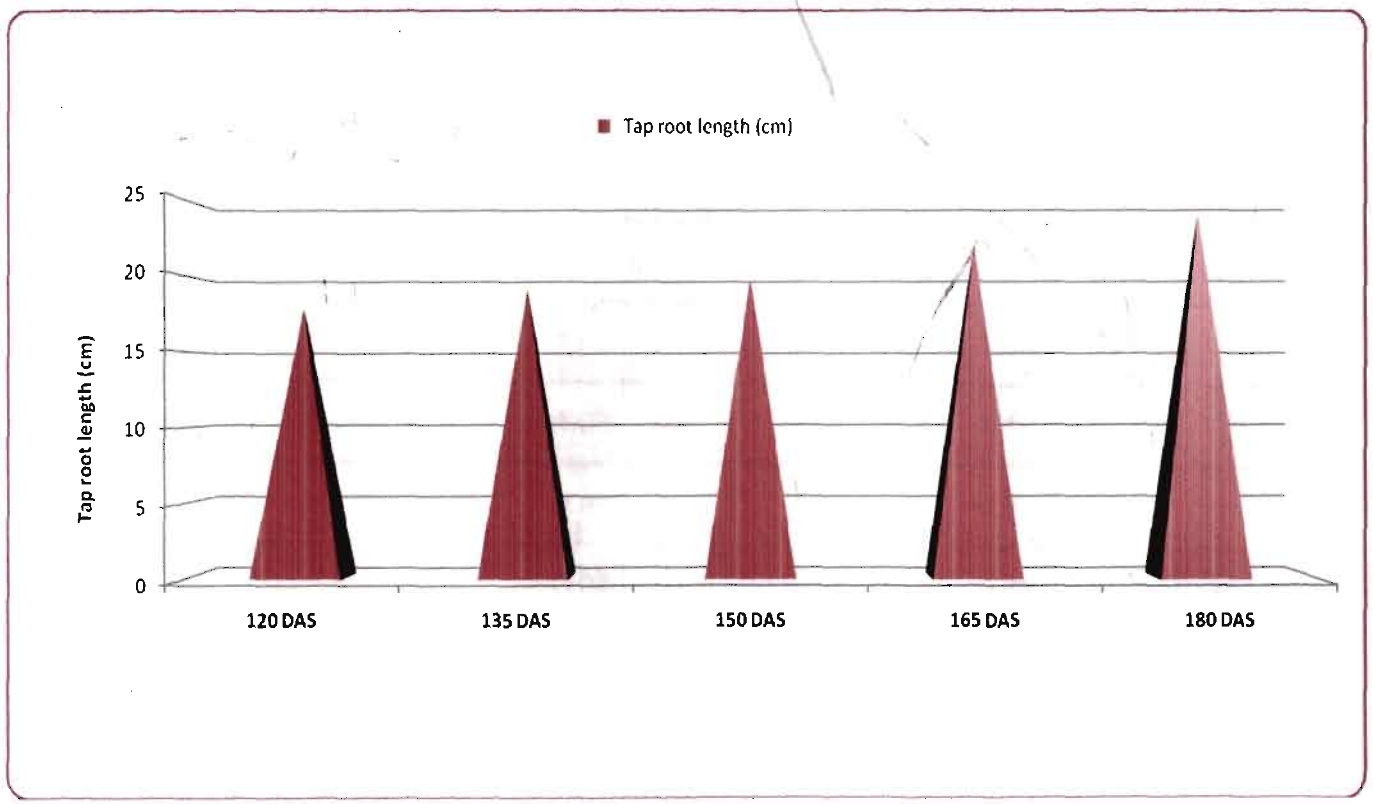


Fig. 17 Tap root length (cm) of ashwagandha as influenced by harvesting stage

Table 39: Tap root girth of ashwagandha as influenced by stages of harvest

Tap root girth (cm)			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	0.73	0.75	0.74
135 DAS	0.82	0.84	0.83
150 DAS	0.92	0.92	0.92
165 DAS	1.02	1.00	1.01
180 DAS	1.08	1.10	1.09
Mean	**0.91**	**0.92**	**0.92**
S.Em±	0.02	0.02	0.01
C.D at 5%	0.05	0.06	0.04

Plate. 9 Root growth of ashwagandha as influenced by different harvesting stages

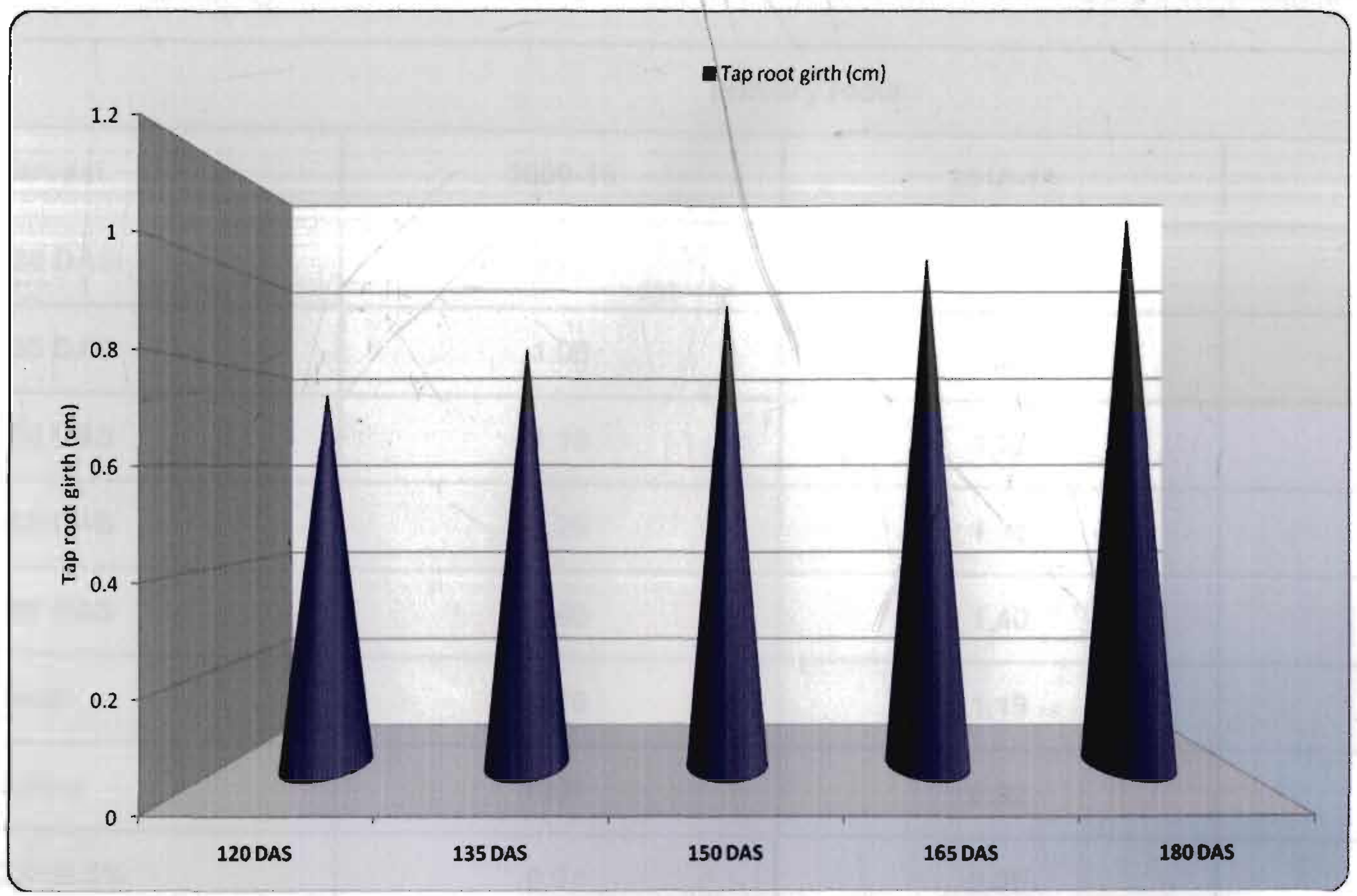


Fig. 18 Tap root girth (cm) of ashwagandha as influenced by harvesting stage

Table 40: Primary roots of ashwagandha as influenced by stages of harvest

primary roots			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	0.98	0.98	0.98
135 DAS	1.08	1.08	1.08
150 DAS	1.18	1.20	1.19
165 DAS	1.29	1.31	1.30
180 DAS	1.40	1.40	1.40
Mean	**1.19**	**1.19**	**1.19**
S.Em±	0.01	0.02	0.01
C.D at 5%	0.04	0.05	0.03

Table 41: Secondary roots of ashwagandha as influenced by stages of harvest

secondary roots			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	0.26	0.24	0.25
135 DAS	0.25	0.27	0.26
150 DAS	0.25	0.29	0.27
165 DAS	0.29	0.31	0.30
180 DAS	0.31	0.29	0.30
Mean	**0.27**	**0.28**	**0.28**
S.Em±	0.01	0.01	0.01
C.D at 5%	0.03	0.03	0.03

Table 42: **Root grade of ashwagandha influenced by stages of harvest**

Root grade(%)												
Harvest Stage	**Grade A**			**Grade B**			**Grade C**			**Grade Low**		
	2009-10	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
120 DAS	0.00	0.00	0.00	60.25	60.00	60.13	30.50	29.75	30.13	9.75	10.25	10.00
135 DAS	0.00	0.00	0.00	59.25	60.75	60.00	29.75	28.25	29.00	11.00	11.00	11.00
150 DAS	0.00	0.00	0.00	72.75	73.00	72.88	14.75	15.25	15.00	12.25	11.75	12.00
165 DAS	74.50	77.75	76.10	3.00	3.00	3.00	10.50	11.25	10.88	9.75	10.25	10.00
180 DAS	75.75	76.50	76.14	4.00	4.00	4.00	12.00	12.00	12.00	8.00	7.75	7.88
Mean	**30.05**	**30.85**	**30.45**	**39.85**	**40.15**	**40.00**	**19.50**	**19.30**	**19.24**	**10.15**	**10.20**	**10.18**
S.Em±	1.06	1.28	0.83	0.71	1.20	0.70	0.35	0.53	0.32	0.19	0.29	0.17
C.D at 5%	3.20	3.85	2.40	2.14	3.62	2.02	1.07	1.60	0.92	0.58	0.87	0.50

Table 43: Dry root yield of ashwagandha influenced by stages of harvest

Dry root yield (q ha^{-1})			
Spacing	**2009-10**	**2010-11**	**Pooled**
120 DAS	5.57	5.11	5.34
135 DAS	5.95	5.89	5.92
150 DAS	6.40	6.30	6.35
165 DAS	7.20	7.00	7.10
180 DAS	7.27	7.17	7.22
Mean	**6.50**	**6.30**	**6.40**
S.Em±	0.03	0.11	0.12
C.D at 5%	0.11	0.32	0.38

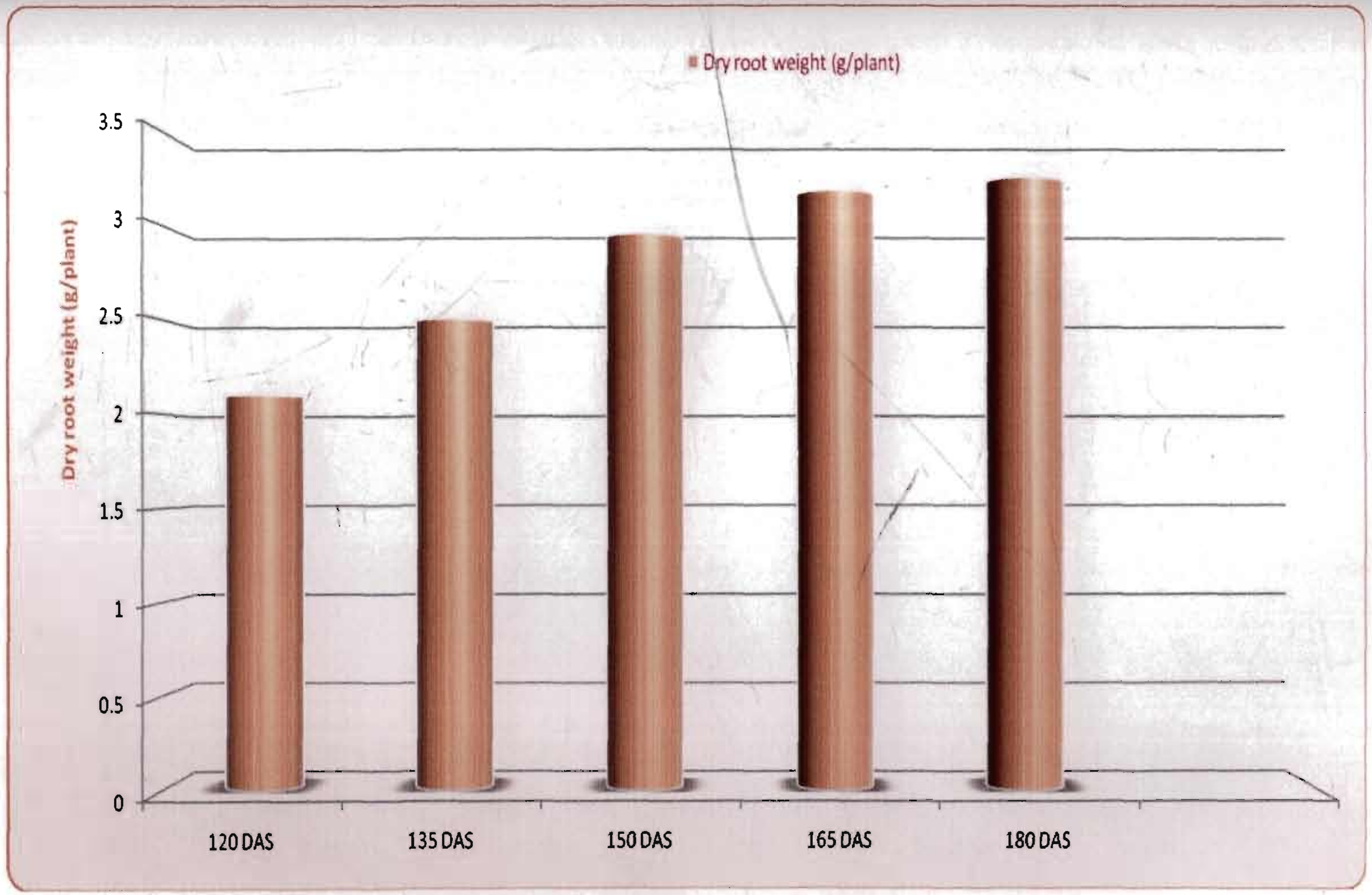


Fig.19 Dry root weight (g/plant) of ashwagandha as influenced by harvesting stage

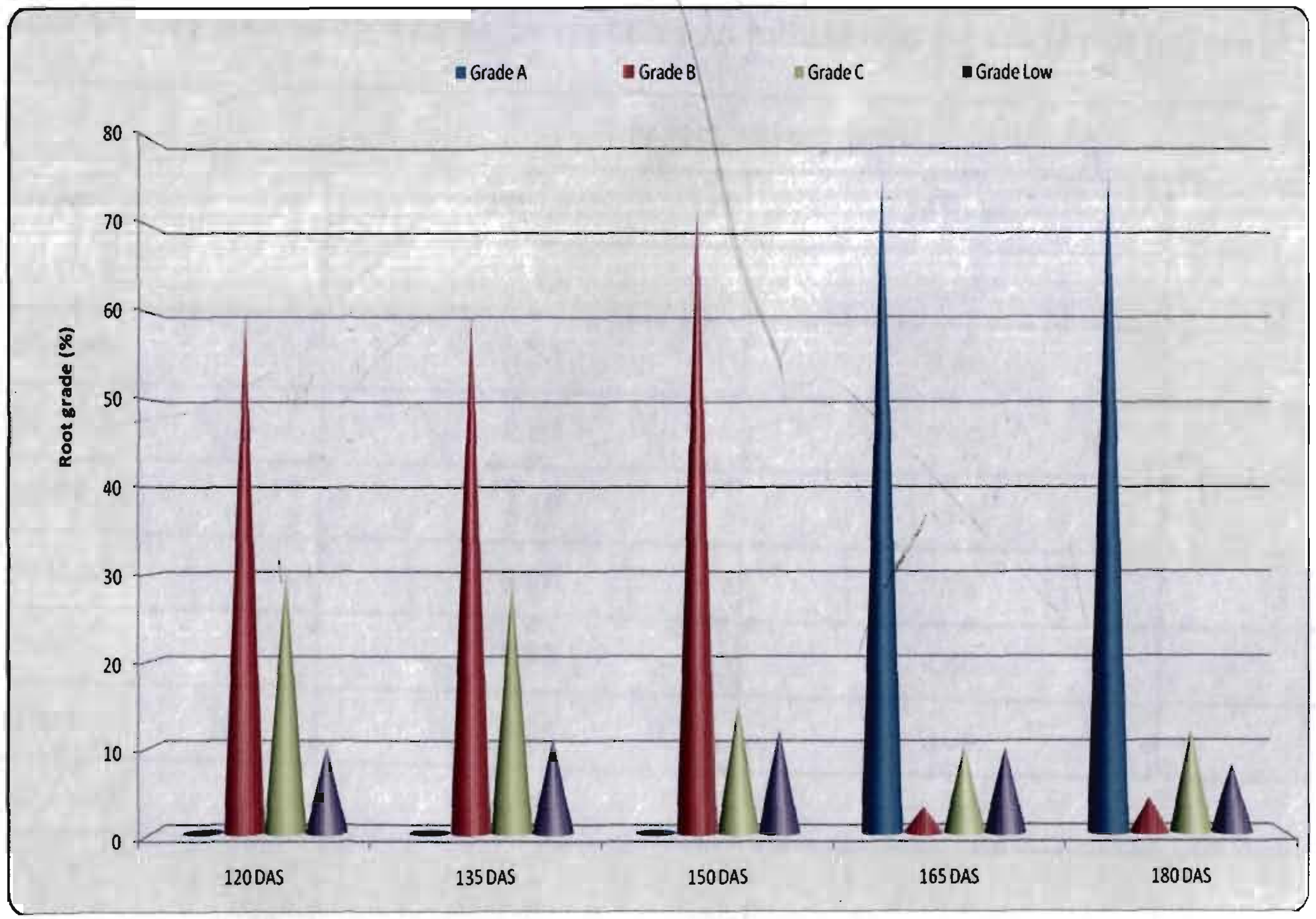


Fig.22 Root grade (%) of ashwagandha as influenced by harvesting stages

Table 44: Dry root weight of ashwagandha as influenced by stages of harvest

Dry root weight (gm/pl)			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	2.12	2.08	2.10
135 DAS	2.54	2.46	2.50
150 DAS	2.91	2.99	2.95
165 DAS	3.15	3.21	3.18
180 DAS	3.26	3.24	3.25
Mean	**2.80**	**2.80**	**2.80**
S.Em±	0.04	0.04	0.03
C.D at 5%	0.11	0.14	0.08

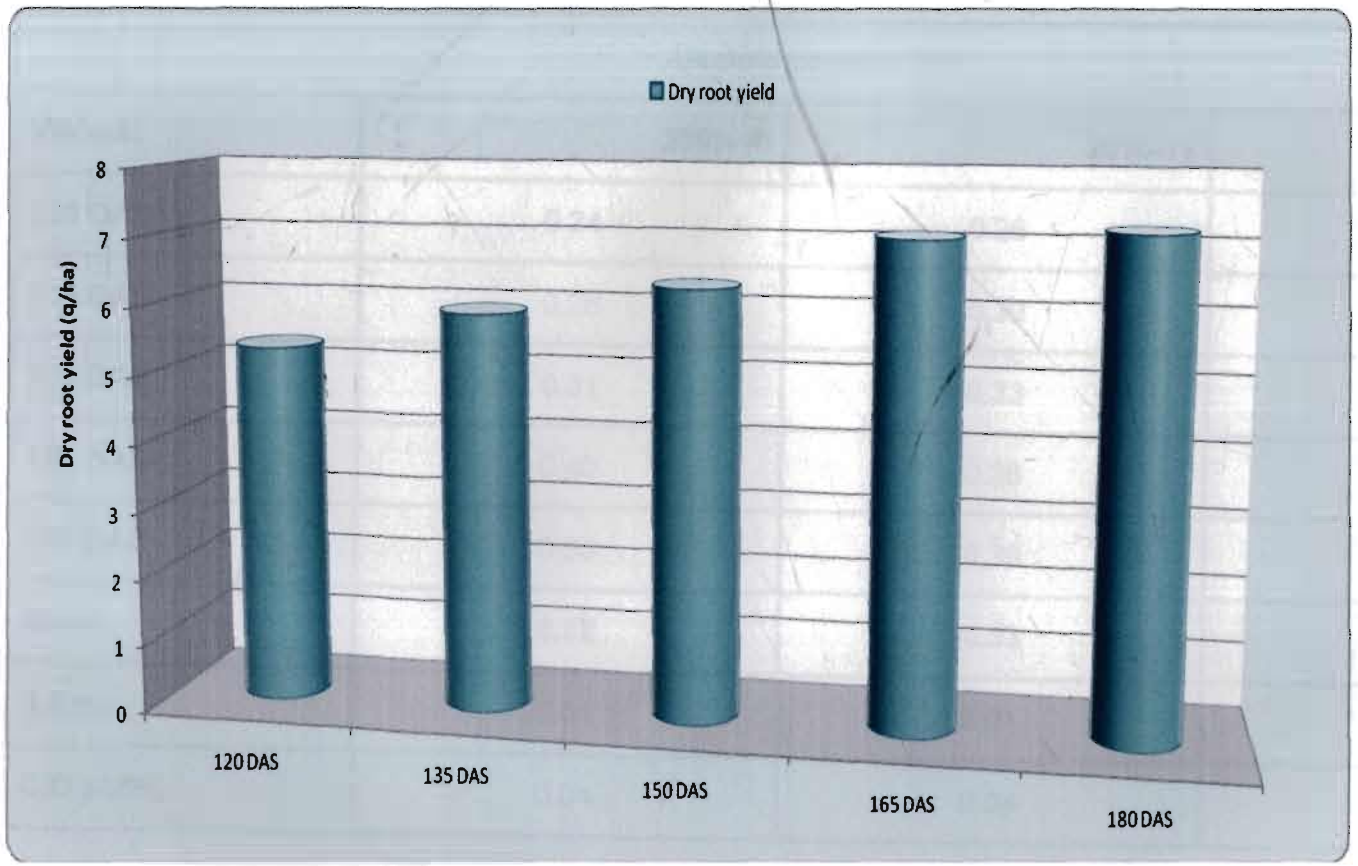


Fig.20 Dry root yield (q/ha) of ashwagandha as influenced by harvesting stage

Table 45: Alkaloid content of ashwagandha as influenced by stages of harvest

Alkaloid content (%)			
Harvest	**2009-10**	**2010-11**	**Pooled**
120 DAS	0.24	0.26	0.25
135 DAS	0.28	0.20	0.29
150 DAS	0.31	0.33	0.32
165 DAS	0.40	0.36	0.38
180 DAS	0.38	0.39	0.38
Mean	**0.32**	**0.33**	**0.32**
S.Em±	0.01	0.01	0.01
C.D at 5%	0.04	0.04	0.04

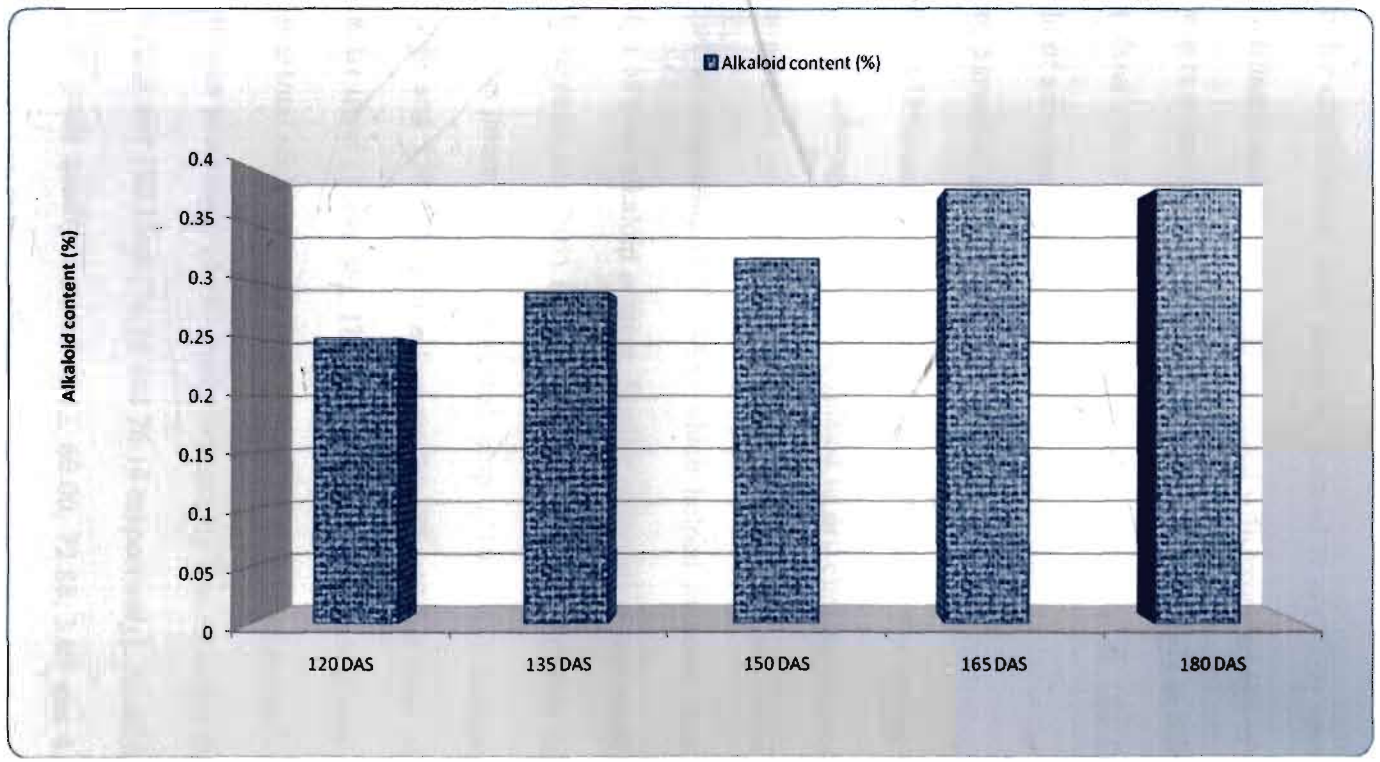


Fig.21 Alkaloid content (%) of ashwagandha as influenced by harvesting stage

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The higher root yield of ashwagandha crop harvested at 180 DAS can be attributed to higher values of yield parameters at harvest. The root length (24.14 cm cm), root girth (1.09 cm) and dry root weight (3.25 g/pl) were significantly higher at 180 DAS. Similar observations were made by Kubsad *et al*.(2009) who reported that the root yield attributes and dry root yield increased with extended age of crop upto 180 DAS. These results corroborate the findings of Jayalakshmi (2003) in coleus. Parthiban and Kiruthika Devi (2003) reported that harvesting the crop at 180 DAS recorded maximum yield of ashwagandha.

The crop harvested at 180 DAS had significantly higher alkaloid content in roots of ashwagandha (0.38%) compared to other stages of harvest. The higher total alkaloid contents in roots of ashwagandha could be related to dry climate coupled with winter low winter temperature prevailed during December and January months at grand growth period of ashwagandha (120 DAS) which helped in better root growth and higher production of total alkaloid content. Similar observation was made by Kahar *et al*.(1991) and Baraiya *et al*.(2005) in ashwagandha. Patel *et al*.(2003) found that the alkaloid content was more in late harvested crop (210 DAS) compared to early harvested crop (90 and 150 DAS) in ashwagandha. The higher total alkaloid yield followed the similar trend (Table 45). The higher total alkaloid yield was attributed to significantly higher total alkaloid content and higher dry root yield per ha^{-1}.

The maximum percentage of ‘A’ grade root quality was recorded from the crop harvested at 165 DAS and 180 DAS (76.10 and 76.14 respectively). At all the durations of crop harvest, ‘B’ grade quality roots of 60.13, 60.00, 72.88, 3.00 and 4.00 per cent were found at 120 DAS, 135 DAS, 150 DAS, 165 DAS and 180 DAS respectively. ‘C’ grade roots of 30.13, 29.00, 15.00, 10.09 and 12.00 per cent were noticed at 120, 135, 150, 165 and 180 DAS harvest stage respectively.

The 'low' grade roots of 10.00, 11.00, 12.00, 10.00 and 7.88 per cent was recorded at 120, 135, 150, 165 and 180 DAS harvest stage respectively.

The roots obtained at maturity stage, *i.e.*180 DAS yielded higher (76.14) per cent of 'A' grade roots, which was on par with roots harvested at 165 DAS. This could be attributed to maximum development of roots in length and girth by utilizing the maximum resources and increased translocation of photosynthates to roots led to better root development and thereby formation of best quality roots i.e. 'A' and 'B' grade.

4.5 EXPT.V: EFFECT OF TIME OF HARVESTING ON QUALITY OF ASHWAGANDHA ((*Withania somnifera* Dunal.) ROOTS DURING STORAGE

Harvesting of ashwagandha roots at different durations significantly influenced the root quality parameters like girth, weight, moisture and total alkaloid content at different storage periods.

4.5.1 Root girth(cm)

The root girth decreased gradually from first day of harvest to 135 DAH (Days after harvest). The initial as well as final girth of roots at different stages of harvest was presented in table 46

The roots harvested at 120 DAS have recorded a reduction of 0.04 cm (0.74 cm to 0.70 cm) from day one to 135 DAH. Similarly, the roots harvested at 135 DAS (initial girth is 0.83 cm) had lost its girth upto 0.03 cm at 135 DAH. Roots harvested at 150,165 and 180 DAS, has resulted in minimum girth reduction of 0.03 cm at 135 DAH.

4.5.2 Dry root weight (g plant^{-1})

The dry weight of root was also influenced by different harvesting stages and storage periods (Table 44 & 47). The dry weight of root was reduced during storage from day one to 135DAH. The roots harvested at 120 DAS, lost its weight from 2.10 to 1.80 g plant^{-1} during 135 days of storage. The roots harvested at 135 DAS lost its weight from 2.5 to 2.11 g plant^{-1}, while weight loss of roots harvested at 150 DAS was from 2.95 to 2.49 g plant^{-1}. The weight loss of dry roots harvested at 165 and 180 DAS was from 3.18 to 2.80 and 3.25 to 2.81 g plant^{-1} at 135 DAH respectively.

4.5.3 Root moisture (%)

The roots harvested at different stages of crop growth, registered significant influence on moisture content during storage. The roots harvested at different stages have resulted in increased per cent of moisture during storage (Table 48). The roots harvested at 120 DAS have gained 0.19 per cent moisture from day one to 135 DAH. Similarly the roots harvested at 135,150 and 165 DAS has gained moisture % of 0. 20, 0.23 and 0.50 at 135 DAH respectively. The highest moisture gain (absorbtion) was observed in roots harvested at 180 DAS after storing 135 days (0.52%).

4.5.4 Alkaloid Content (%)

The total alkaloid content of stored roots was also influenced by storage periods and harvesting stages (Table 49). Irrespective of the harvesting stage, the total alkaloid content (%) decreased with increased storage period. The roots harvested at 120 DAS recorded 16.40 % loss of alkaloid at 135 DAH, while the alkaloid reduction from day one to 135 DAH at 135 DAS was 15.86 % .The decrease in alkaloid content was lowest (11.84%) in roots harvested at 180 DAS and stored for 135 days, which was on par with roots harvested at 165 DAS stored for 135 days.

Table 46: Root girth of ashwagandha influenced by stages of harvest and storage period

	Root girth (cm)									
	At harvest	65 DAH			90 DAH			135 DAH		
	Pooled(From table:39)	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
120 DAS	0.74	0.74	0.72	0.73	0.72	0.72	0.72	0.72	0.68	0.70
135 DAS	0.83	0.80	0.82	0.81	0.79	0.83	0.80	0.80	0.80	0.79
150 DAS	0.92	0.90	0.92	0.91	0.90	0.90	0.90	0.89	0.87	0.89
165 DAS	1.01	1.01	0.99	1.00	0.98	1.00	0.99	0.96	0.98	0.98
180 DAS	1.09	1.04	1.02	1.03	1.01	0.95	1.05	0.97	0.95	1.06
Mean	0.92	**0.90**	**0.90**	**0.90**	**0.88**	**0.88**	**0.89**	**0.87**	**0.86**	**0.88**
S.Em±	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01
C.D at 5%	0.04	0.06	0.07	0.04	0.06	0.06	0.04	0.06	0.06	0.04

Table 47: Dry root weight of ashwagandha influenced by stages of harvest and storage period

Dry root weight (g $plant^{-1}$)									
	65 DAH			90 DAH			135 DAH		
	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
120 DAS	1.98	2.02	2.00	1.94	2.00	1.97	1.79	1.81	1.80
135 DAS	2.35	2.29	2.32	2.23	2.11	2.17	2.19	2.03	2.11
150 DAS	2.76	2.84	2.80	2.66	2.64	2.65	2.58	2.40	2.49
165 DAS	3.15	3.09	3.12	3.10	3.08	3.09	2.82	2.78	2.80
180 DAS	3.17	3.11	3.14	3.10	3.02	3.06	2.87	2.75	2.81
Mean	**2.68**	**2.67**	**2.68**	**2.61**	**2.57**	**2.59**	**2.45**	**2.35**	**2.40**
S.Em±	0.06	0.06	0.04	0.06	0.06	0.04	0.04	0.06	0.04
C.D at 5%	0.18	0.17	0.12	0.19	0.18	0.12	0.12	0.19	0.11

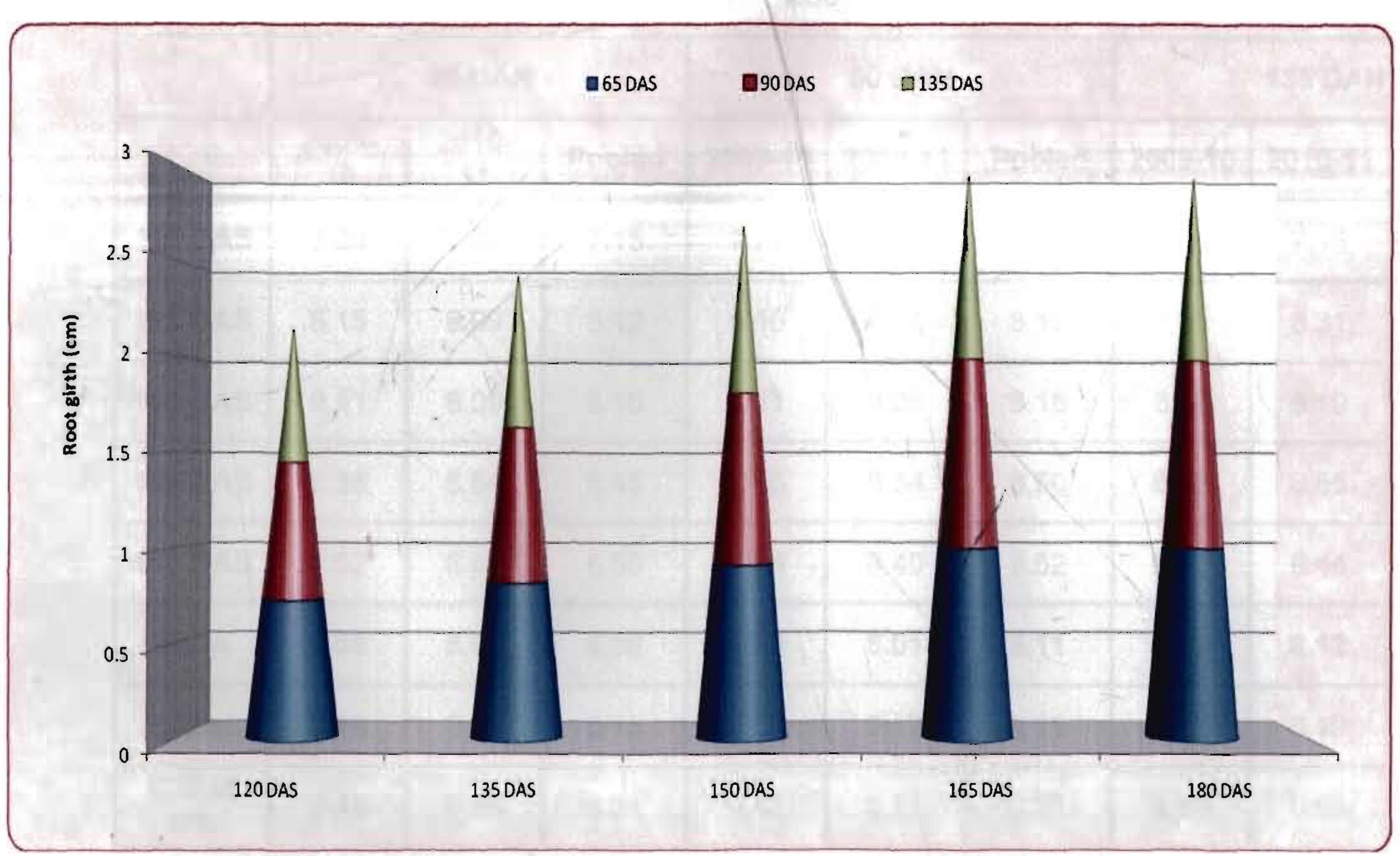

Fig.23 Root girth (cm) of ashwagandha as influenced by stages of harvest and storage period

Table 48: Root moisture content of ashwagandha influenced by stages of harvest and storage period

	Root moisture(%)								
	65 DAH			90 DAH			135 DAH		
	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
120 DAS	7.24	7.06	7.15	7.22	7.14	7.18	7.25	7.13	7.19
135 DAS	8.15	8.09	8.12	8.16	8.14	8.15	8.09	8.31	8.20
150 DAS	8.11	8.09	8.10	8.31	8.05	8.18	8.27	8.19	8.23
165 DAS	8.36	8.54	8.45	8.66	8.34	8.50	8.45	8.55	8.50
180 DAS	8.52	8.48	8.50	8.64	8.40	8.52	8.60	8.44	8.52
Mean	**8.08**	**8.05**	**8.06**	**8.20**	**8.01**	**8.11**	**8.13**	**8.12**	**8.13**
S.Em±	0.16	0.19	0.13	0.14	0.17	0.11	0.17	0.19	0.13
C.D at 5%	0.49	0.59	0.37	0.42	0.51	0.32	0.50	0.59	0.37

Note: Samples were kept at initial moisture content of 8% for all the treatments

Table 49: Alkaloid content of ashwagandha influenced by stages of harvest and storage period

Alkaloid content (%)										
	Initial alkaloid content at 0 days(Table:45)	65 DAH			90 DAH			135 DAH		
	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
120 DAS	0.250	0.218	0.220	0.219	0.210	0.214	0.212	0.208	0.210	0.209
135 DAS	0.290	0.262	0.260	0.261	0.251	0.249	0.250	0.245	0.243	0.244
150 DAS	0.320	0.310	0.312	0.311	0.253	0.255	0.254	0.275	0.275	0.275
165 DAS	0.380	0.360	0.364	0.362	0.342	0.344	0.343	0.335	0.333	0.334
180 DAS	0.380	0.362	0.364	0.363	0.354	0.353	0.355	0.334	0.336	0.335
Mean	**0.324**	**0.302**	**0.304**	**0.317**	**0.282**	**0.283**	**0.283**	**0.279**	**0.279**	**0.279**
S.Em±	0.010	0.012	0.011	0.012	0.010	0.012	0.012	0.010	0.010	0.010
C.D at 5%	0.040	0.028	0.026	0.028	0.023	0.024	0.024	0.020	0.022	0.021

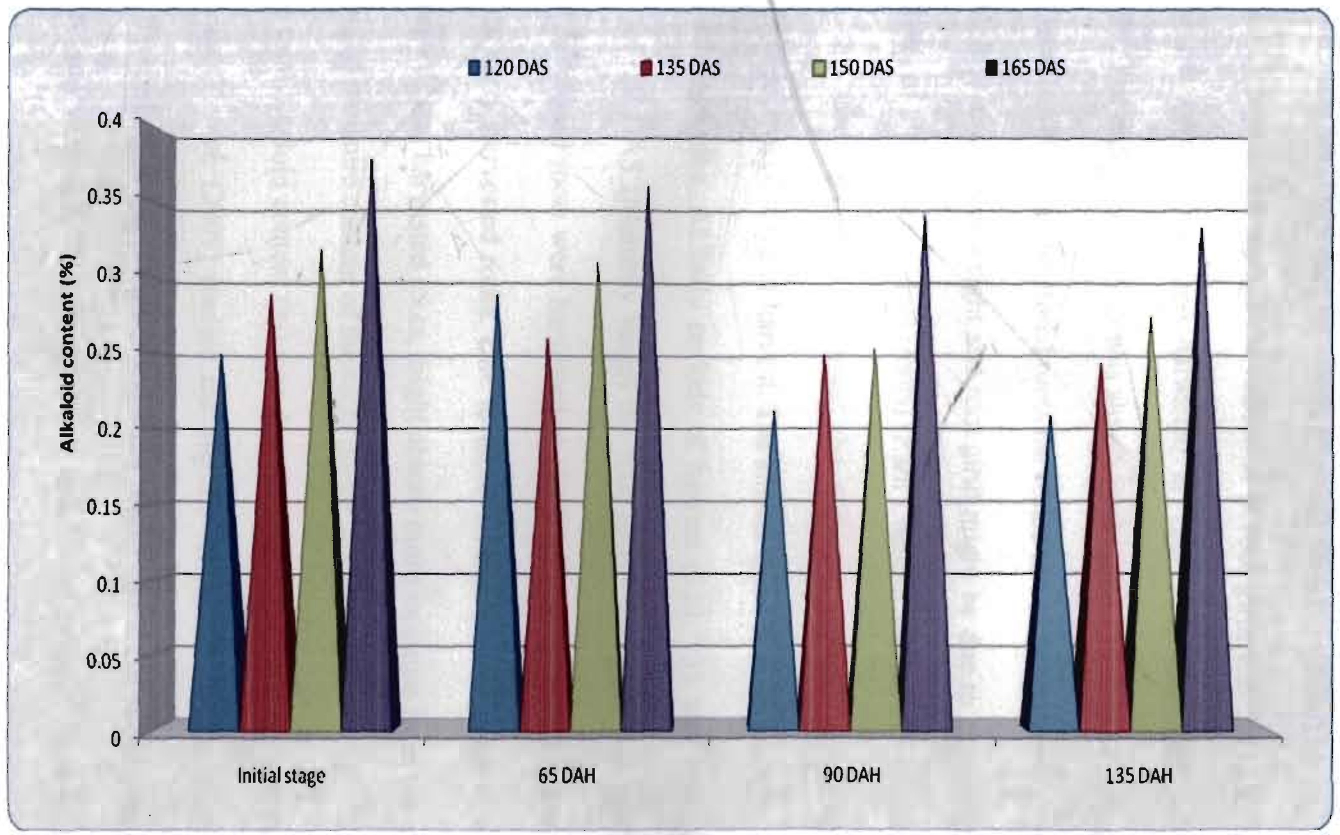

Fig.24 Alkaloid content (%) of ashwagandha as influenced by stages of harvest and storage period

As the storage period advances, there was a reduction in the root quality characters like root girth, root weight and total alkaloid content.

The dry root weight (g plant^{-1}) was reduced during storage irrespective of harvesting stage. After 135 days of storage, the loss in weight of roots from different harvest durations was 55.55, 15.6, 15.5, and 13.57 and 13.53% when harvested at 120, 135, 150, 165 and 180 DAS harvest stored products (roots) respectively.

At 135 days after, storage the reduction in root girth was 5.41, 3.61, 4.34, 3.40 and 11.92 per cent in the crop harvested at 120, 135, 150, 165 and 150 DAS respectively. The reduction in girth was almost linear upto 135 days of storage. The loss in weight was maximum in the stored roots harvested at 180 DAS after 135 storage.

The loss in dry root weight and root girth might be due to physiological loss in weight (PLW) of the stored product (roots) (Ram Chandra and Dinesh Kumar, 2007).

As the storage period advances, the moisture content of the stored roots increased irrespective of stage of harvest. The similar trend was observed by Patel *et al.* (2009) in ashwagandha. At early periods of harvest (120, 135 and 150 DAS) when compared to 180 DAS (Maturity stage) the root length and girth was low. The well grown and developed roots were harvested at 180 DAS having more surface area when compared to early harvested roots. Due to more surface area exposed to atmosphere during storage of late harvested roots, might absorb more moisture from the atmosphere led to increased moisture content of the roots during storage.

The total alkaloid content (%) was degraded during storage irrespective of stage of harvest. Patel *et al.* (2009) studied the physico- chemical stability and biological activity of *Withania somnifera* extract and reported the continued significant decline in withaferin-A and withaferin-B during 0 to 6 months of storage. Ram Chandra and

Dinesh Kumar (2007) in Safed musli and Anubha Upadhyay *et al*. (2011) in senna was also reported the decline of alkaloid content during storage.

SUMMARY

CHAPTER V

SUMMMARY AND CONCLUSIONS

Present investigation entitled on "Standardization of Agro-techniques for Ashwagandha (*Withania somnifera* Dunal.) in coastal districts of Andhra Pradesh" during late kharif seasons of 2009-10 and 2010-11 at College of Horticulture,Venkataramannagudem, West Godavari district , Andhra Pradesh. The study was divided into four field experiments and a laboratory experiment. First experiment was on "Effect of seed rate on growth and yield of Ashwagandha *(Withania somnifera* Dunal.*)"* with treatments T_1: 6 kg of seed ha^{-1}, T_2: 8 kg of seed ha^{-1}, T_3: 10 kg of seed ha^{-1} and T_4: 12 kg of seed ha^{-1}. The results obtained on various parameters are briefly summarized here under:

The study revealed that the growth attributes *viz.*, plant height, leaf area and number of primary branches per plant was significantly influenced by different seed rates at various stages of crop growth. Plant height increased rapidly till 135 DAS and reached a maximum height at harvest. The maximum plant height was recorded at a seed rate of 12 kg ha^{-1} over rest of the seed rates at all stages of crop growth. The leaf area increased with increased plant age. The leaf area upto 135 DAS rapidly increased, thereafter sudden fall at harvest which could be due to senescence of leaves. The higher number of primary branches per plant was recorded at lowest seed rate *viz.*, 6 kg ha^{-1}. The number of primary branches increased rapidly upto 135 DAS, thereafter from 135 DAS to at harvest, a linear growth was observed. At harvest, highest number of primary branches and lowest was observed at 6 kg ha^{-1} and 12 kg ha^{-1} seed rates, respectively.

The influence of different seed rates on days to 50% flowering was significant. The plants sown at 6 kg ha^{-1} seed rate completed 50% flowering earlier than those at a seed rate of 12 kg ha^{-1} i.e., plants at all seed rates completed 50% flowering in a time lag of 1.5 days . The number of days taken to harvest was also followed the same trend as that of 50% flowering. Early maturity was observed at 6 kg ha^{-1} while at 12 kg ha^{-1}, the crop recorded longest duration.

The root yield parameters like root length, root girth, number of primary and secondary branches, fresh and dry root yield was significantly influenced by different seed rates. The increased trend in root length was observed with increased age of plant. The maximum root length was observed at 12 kg ha^{-1} seed rate throughout the crop growth stage. At harvest, the longest roots and shortest roots was observed at 12 kg ha^{-1} and 6 kg ha^{-1} seed rates respectively. The girth of root is one of the important character in grading the roots. At harvest, the maximum root girth and minimum root girth was recorded at 6 kg ha^{-1} and 12 kg ha^{-1} seed rates respectively. The effect of seed rates on production of primary and secondary roots was significant. The maximum number of primary and secondary roots were recorded at lower seed rate *viz.*, 6 kg ha^{-1}.

The fresh and dry root yield was significantly influenced due to different seed rates. The fresh and dry root yield increased with increased seed rates. The dry root yield at 12 kg ha^{-1} seed was 2.14, 26.43 and 28.57 per cent higher than yield at 10 kg ha^{-1}, 8 kg ha^{-1} and 6 kg ha^{-1} seed rate respectively. The seed yield was also significantly influenced by different seed rates. The highest seed yield was recorded with higher seed rate i.e., 12 kg ha^{-1}. The seed yield decreased at lower seed rates. The per cent increase of seed yield at 12 kg ha^{-1} was 15.90 over 6 kg ha^{-1} seed. Higher gross income was obtained with the treatments, seed rate @ 12 Kg ha^{-1}

compared to seed rate at 10 Kg ha^{-1}owing to higher yield recorded with the treatments. Further the treatment at 6 Kg ha^{-1} seed rate were observed with lower dry root yield resulting in lower net income and BCR. The treatment, 12 Kg seed ha^{-1} had recorded the maximum BCR followed by seed rate at 10 Kg ha^{-1} .

Second experiment was on "Effect of spacing on growth and yield of ashwagandha (*Withania somnifera* Dunal.)" with treatments T_1: 30x30 cm, T_2: 30x10 cm, $T_{3:}$ 20x20 cm and $T_{4:}$ 20x10 cm. The results obtained on various parameters are briefly summarized here under:

The studies revealed that different spacing's had significant influence on growth and yield parameters of ashwagandha at all stages of crop growth. The plant height increased with the age of the crop reaching a maximum at harvest . Further, a rapid rate of increase in plant height was observed upto 90 DAS, thereafter, 90 DAS to 135 DAS, the growth rate of plant height was moderate and from 135 DAS to at harvest a linear increase in plant height was observed. Closer plant spacing (20x10 cm) resulted in higher plant height than wider spacing, 30x30 cm and 20x20 cm. At harvest, closer spacing, 20x10 cm, recorded maximum plant height. Leaf Area Index (LAI) was also influenced by different spacings at different stages of crop growth. LAI increased with advancement of age of the crop. The LAI increased upto 135 DAS rapidly at all spacings, thereafter, decline in LAI was observed from 135 DAS to harvest. At all stages of crop growth, maximum LAI was recorded at closer spacing, 30x10 cm and minimum at wider spacing, 30x30 cm. Highest LAI was noticed at 135 DAS with 20x10 cm spacing. The crop duration also influenced the LAI significantly. Significantly greater LAI was recorded at 135 DAS than at 90 DAS and at harvest. This might be due to leaf senescence occurred at harvest stage and led to less LAI.

Unlike plant height and LAI, significantly highest number of primary branches per plant was registered at wider spacing, 30x30 cm, than at closer spacing 20x10 cm. At all stages of crop growth, significant differences were observed in number of primary branches due to different spacings. Number of primary branches per plant increased with increase in duration of the crop at wider spacing (30x10 cm). At harvest, 30x30 cm spacing recorded highest number of primary branches and lowest at 20x10 cm spacing. Number of primary branches increased rapidly upto 90DAS, thereafter form 135 DAS to harvest, slow and static trend was observed.

The number of days taken to 50% flowering was significant due to different spacing treatments. The plants sown at wider spacing (30x30 cm) completed 50% flowering earlier than spacing at 20x10 cm. The difference between the wider spacing, 30x30 cm and closer spacing, 20x10 cm was only 1.6 days. The same trend was observed in number of days taken to harvest at different spacings. Early harvest was done at 30x30 cm, closely following 20x20 cm spacing.

The root yield and its attributes like root length, root girth, number of primary and secondary roots, fresh and dry root yield and seed yield was significantly influenced due to different spacings.

The root length increased with increased age of the plant at all spacing treatments. The longest root was noticed at closer spacing, 20x10 cm. The root growth was almost doubled in length at 90 DAS over 40 DAS and thereafter, a linear growth of root was observed. The root length at 20x10 cm was 9.37, 4.60 and 3.78 per cent higher than 30x30 cm, 20x20 cm and 30x10 cm spacings, respectively. The maximum root diameter was observed at wider spacing 30x30 cm. At this spacing (30x30 cm), the root girth was 13.85, 7.70 and 26.92 per cent higher than 30x10 cm, 20x20 cm and 20x10 cm spacing, respectively. The highest number of primary and secondary roots were observed at wider spacing compared to closer spacing. The highest number of primary and secondary roots at wider spacing (30x30 cm) was 2.60 and 1.50 respectively.

The fresh root yield (q ha^{-1}) was significantly higher at closer spacing 20x10cm. The fresh root yield increased with increased spacing. At closer spacing, 20x10 cm, the fresh root yield (weight qha^{-1}) was 4.54, 14.45 and 15.60 per cent higher than 30x10 cm, 20x20 cm and 30x30 cm respectively. Similarly the dry root yield (qha^{-1}) was also significantly increased with increased spacing. The highest dry root yield was recorded at closer spacing, 20x10 cm. The dry root yield at closer spacing, 20x10 cm was 4.90, 20.00 and 27.27 per cent higher than 30x10 cm, 20x20 cm and 30x30 cm spacing respectively. Similar trend was observed with seed yield (kg ha^{-1}). The seed yield was significantly higher at closer spacing, 20x10 cm. The seed yield (kg ha^{-1}) decreased with increased spacing. The maximum seed yield at 20x10 cm was 2.15, 14.34 and 21.94 per cent higher than 30x10 cm, 20x20 cm and 30x30 cm spacing respectively. Higher gross income was obtained with the 20X10 cm compared 30X10 cm owing to higher yield recorded with this. Further lower dry root yield was obtained at 30X30 cm resulting in lower net income and BCR. The treatment, at 30X10 cm had recorded the maximum BCR followed by spacing at 20X10 cm.

Third experiment was on "Influence of biofertilizers in combination with graded levels of P_2O_5 on growth and yield of ashwagandha (*Withania somnifera* Dunal.)" with treatments T_1: P_2O_5 @ 30 kg ha^{-1}, T_2: P_2O_5 @ 40 kg ha^{-1}, T_3: P_2O_5 @ 50 kg ha^{-1}, T_4: Azatobacter + P_2O_5 @ 30 kg ha^{-1}, T_5: Azatobacter + P_2O_5 @ 40 kg ha^{-1}, T_6: Azatobacter + P_2O_5 @ 50 kg ha^{-1}, T_7: Phosphobacteria + P_2O_5 @ 30 kg ha^{-1}, T_8: Phosphobacteria + P_2O_5 @ 40 kg ha^{-1}, T_9: Phosphobacteria + P_2O_5 @

50 kg ha^{-1}, T_{10}: Azatobactor, T_{11}: Phosphobacteria and T_{12}: Control. The results obtained on various parameters are briefly summarized here under:

The studies revealed that the growth parameters like plant height, number of branches per plant, leaf area increased significantly with increased P_2O_5 levels along with AZB and PSB at all stages of crop growth. The plant height increased with increment in P_2O_5 in combination with biofertilizers at all stages of crop growth. At harvest the maximum plant height was recorded with AZB + P_{50} combination but was on par with AZB + P_{40} and the minimum plant height recorded in control. The growth rate was less with AZB and PSB alone when compared with P_{50}, P_{40} and P_{30} treatments. In all the treatments, the plant height was rapid up to 135 DAS, there after, the growth rate was moderate.

Primary branches and leaf area per plant increased as the age of the plant advanced in all treatments. The increase in P_2O_5 level in combination with biofertilizers increased the no. of primary branches and leaf area. At harvest the highest number of primary branches was recorded at AZB + P_{50} followed by AZB+ P_{40} and PSB + P_{50}. The same trend was observed with leaf area also. The leaf area per plant increased rapidly up to 135 DAS in all the treatments. At harvest, the leaf area per plant declined, might be due to senescence of leaves at harvest stage.

The root yield attributes were also significantly influenced by different levels of P_2O_5 and biofertilizers. The root length, girth, fresh and dry root yields increased with increased levels of P_2O_5 in combination with AZB and PSB. The maximum root length was recorded with AZB and P_{50} followed by PSB + P_{50}. At harvest, the highest root length was recorded with AZB + P_{50} followed by AZB + P_{40} and PSB + P_{50}

The root girth was also maximum at AZB + P_{50} and AZB + P_{40} closely following PSB + P_{50} and PSB + P_{40}. Due to increased root length and girth at AZB +

P_{50} and AZB + P_{40} the resulting yield per hectare was also highest. The dry root yield increased with AZB + P_{50} . The seed yield was also increased with AZB + P_{50} followed by AZB + $P_{40.}$ Higher gross income was obtained with the treatments, AZB+P_{50} compared to AZB+P_{40} owing to higher yield recorded with this treatments. Further the control treatment was observed with lower dry root yield resulting in lower net income and BCR. The treatment, AZB + P_{50} had recorded the maximum BCR followed by AZB + P_{40}.

Fourth experiment was on "Effect of time of harvesting on root yield and quality of ashwagandha (*Withania somnifera* Dunal)" with five treatments *viz.*, T_1: 120 days after sowing; T_2: 135 days after sowing, T_3: 150 days after sowing, T_4: 165 days after sowing and T_5: 180 days after sowing. The results obtained on various parameters were briefly summarized here under:

The studies revealed that the higher root yield was obtained with crop harvested at 180 DAS can be attributed to higher values of yield parameters. The root length , root girth and dry root weight were significantly higher at 180 DAS. The crop harvested at 180 DAS had significantly higher alkaloid content in roots of ashwagandha (0.38%) compared to other stages of harvest. The maximum percentage of 'A' grade quality root was recorded from the crop harvested at 165 DAS and 180 DAS. At all the durations of crop harvest, 'B' grade quality roots of 60.13, 60.00, 72.88, 3.00 and 4.00 per cent were found at 120 DAS, 135 DAS, 150 DAS, 165 DAS and 180 DAS respectively. 'C' grade roots of 30.13, 29.00, 15.00, 10.09 and 12.00 per cent were noticed at 120, 135, 150, 165 and 180 DAS harvest stage respectively. The 'low' grade roots of 10.00, 11.00, 12.00, 10.00 and 7.88 per cent was recorded at 120, 135, 150, 165 and 180 DAS harvest stage respectively. The roots obtained at maturity stage, *i.e.* 180 DAS yielded higher per cent of ‘A’ grade roots, which was on par with roots harvested at 165 DAS.

Fifth experiment was on “Effect of time of harvesting on quality of ashwagandha (*Withania somnifera* Dunal.) during storage” with five treatments *viz.,* Storage of roots for 65 DAH, 90 DAH and 135 DAH harvested at 120 days after sowing (T_1), 135 days after sowing (T_2), 150 days after sowing (T_3), 165 days after sowing (T_4) and 180 days after sowing (T_5).

The studies revealed that as the storage period advances, there was a reduction in the root quality characters like root girth, root weight and total alkaloid content. The dry root weight (g plant^{-1}) was reduced during storage irrespective of harvesting stage. After 135 days of storage, the loss in weight of roots from different harvest durations was 55.55, 15.6, 15.5, and 13.57 and 13.53% when harvested at 120, 135, 150, 165 and 180 DAS harvest stored products (roots) respectively. At 135 days after storage the reduction in root girth was 5.41, 3.61, 4.34, 3.40 and 11.92 per cent in the crop harvested at 120, 135, 150, 165 and 150 DAS respectively. The reduction in girth was almost linear upto 135 days of storage. The loss in weight was maximum in the stored roots harvested at 180 DAS after 135 storage.

As the storage period advances, the moisture content of the stored roots increased irrespective of stage of harvest. At early periods of harvest (120, 135 and 150 DAS) when compared to 180 DAS (Maturity stage) the root length and girth was low due to which, more surface area of root was exposed to atmosphere during storage might be caused more absorption of moisture led to more moisture content of roots. The total alkaloid content (%) was degraded during storage irrespective of stage of harvest.

Recommendations:

1) Broadcasting of seed at the rate of 12 kg ha^{-1} was sufficient for getting higher yields and BCR.

2) Even though, highest root yield was obtained at 20X10 cm spacing as the BCR was highest at 30X10 cm, for raising ashwagandha crop a spacing of 30X10 cm was found optimum.

3) The combination of Azotobacter and Phosphorus 50 kg ha^{-1} resulted in higher yield and BCR.

4) Harvest the crop at maturity stage i.e., 180 DAS was found to be superior over all the treatments in increasing yield attributes and alkaloid content. Harvest the crop at 180 DAS was recommended.

5) All the quality characters of the root was found to be decreased with roots harvested at different stages, stored upto 135 days. As early as possible the roots may be utilized or sold with out further loss of quality characters during storage.

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The pattern of ‘Literature cited’ presented above is in accordance with the ‘Guidelines’ for thesis presentation for A N G R A U, Hyderabad, Andhra Pradesh.

APPENDIX

Appendix - I : Weekly meteorological data during the crop period (2009-10 and 2010-11)

Standard week	Mean Temperature (^{0}C)				Mean relative humidity				Rainfall (mm)		Rainy days	
	2009-10		2010-11		2009-10		2010-11					
	Max.	Min.	Max.	Min.	7.16 hr.	14.00 h r.	7.16 hr.	14.00 hr	2009-10	2010-11	2009-10	2010-11
34	31.18	25.19	32.14	26.29	89.63	75.44	90.43	76.43	-	5.25	-	1
35	29.14	26.76	30.14	25.86	91.33	81.74	90.43	82.71	5.20	-	1	-
36	27.66	24.00	28.86	25.00	88.61	82.20	91.71	83.00	-	5.40	-	1
37	30.00	25.50	31.00	26.00	90.23	76.24	91.29	77.43	4.10		-	-
38	30.23	24.73	31.43	25.43	88.46	70.26	87.43	69.29	-	4.87	-	1
39	32.20	24.86	33.00	25.86	86.42	68.45	85.43	66.57	4.07	1.80	2	1
40	30.23	24.67	31.43	25.57	91.44	70.50	92.43	68.00	5.50	3.96	2	1
41	31.53	23.84	32.43	24.86	82.31	56.74	83.29	52.71	-	-	-	-
42	34.57	24.14	30.86	25.00	78.71	55.28	85.00	69.14	-	4.60	-	1
43	32.71	22.85	30.86	25.00	80.00	66.14	91.71	76.71	10.8	16.20	2	3
44	34.41	20.42	27.00	23.43	74.28	51.57	90.71	79.86	-	11.40	-	2
45	34.71	20.14	30.43	23.57	74.00	47.00	90.71	64.14	-	12.50	-	3
46	31.71	22.14	30.14	24.00	80.85	66.71	90.29	68.29	31.8	10.10	3	2
47	32.00	21.70	30.29	23.86	78.14	58.71	90.86	62.43	-	-	-	-
48	29.42	20.85	30.57	22.43	80.71	59.86	87.57	59.71	4.20	-	1	-
49	32.42	20.28	25.86	22.71	80.42	52.14	88.29	76.43	-	12.80	-	2
50	32.84	20.28	28.29	22.29	79.57	51.00	92.14	56.43	-	-	-	-

Cont….for Appendix-I

51	31.71	19.42	27.71	22.29	79.14	49.57	83.29	45.14	-	-	-	-
52	32.37	19.00	27.57	20.57	83.50	53.50	86.14	53.29	-	-	-	-
1	30.57	19.14	28.14	21.14	85.71	52.28	84.14	52.71	-	-	-	-
2	30.28	19.85	29.00	18.43	82.00	55.28	86.29	51.29	-	-	-	-
3	30.42	18.57	29.71	21.57	81.00	49.71	88.29	58.14	-	-	-	-
4	31.14	18.71	29.86	18.86	84.57	49.14	87.43	57.29	-	5.60	-	1
5	32.45	19.56	30.00	19.71	86.45	50.12	84.29	55.43	5.50	-	2	-
6	32.67	19.78	31.12	19.86	87.65	50.56	86.29	50.15	-	-	-	-
7	33.44	20.12	32.56	20.15	88.65	51.18	87.56	53.25	-	-	-	-
8	33.66	20.54	32.86	20.58	89.12	51.58	84.62	55.62	-	-	-	-
Total Rainfall									71.17	94.48	14	19

Appendix-2

Cost of cultivation (Rs ha^{-1}) as influenced by seed rate in ashwagandha

Particulars	T_1	T_2	T_3	T_4
Seed	480	640	800	960
Land preparation	6250	6250	6250	6250
Fertilizers	548	548	548	548
FYM	7000	7000	7000	7000
Seed broadcasting	1200	1200	1200	1200
Thinning	1350	1350	1350	1350
Weeding	3000	3000	3000	3000
Irrigation	2800	2800	2800	2800
Plant protection	1200	1200	1200	1200
Harvesting	3600	3600	3600	3600
Miscellaneous	1500	1500	1500	1500
Total	28928	29088	29248	29408

Appendix-3

Cost of cultivation (Rs ha^{-1}) as influenced by spacing in ashwagandha

Particulars	T_1	T_2	T_3	T_4
Seed	800	800	800	800
Land preparation	7250	7250	7250	7250
Fertilizers	548	548	548	548
FYM	7000	7000	7000	7000
Seed dibbling	1500	2000	3000	3500
Thinning	1350	1350	1350	1350
Weeding	3000	3000	3000	3000
Irrigation	2800	2800	2800	2800
Plant protection	1200	1200	1200	1200
Harvesting	3000	3500	4000	4500
Miscellaneous	1500	1500	1500	1500
Total	29948	30948	32448	33448

Appendix-4

Cost of cultivation (Rs ha^{-1}) as influenced by P_2O_5 and biofertilizers in ashwagandha

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Seed	800	800	800	800	800	800	800	800	800	800	800	800
Land preparation	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250
Fertilizers	428	428	428	428	428	428	428	428	428	428	428	428
P_2O_5	120	160	200	120	160	200	120	160	200	-	-	-
Azotobacter	-	-	-	300	300	300	-	-	-	300	-	-
Phosphobacter	-	-	-	-	-	-	250	250	250	-	250	-
FYM	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000
Line sowing	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Thinning	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Weeding	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Irrigation	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800
Plant protection	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Harvesting	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
Miscellaneous	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Total	30248	30288	30328	30548	30588	30628	30498	30538	30578	30428	30378	30128

Appendix-5

Cost of cultivation (Rs ha^{-1}) as influenced by P_2O_5 and biofertilizers in ashwagandha

Treatments	Root yield (q ha^{-1})	Cost of root yield (Rs ha^{-1})	Seed yield (kg ha^{-1})	Cost of seed(Rs ha^{-1})	Cost of production (Rs)	Gross income (Rs)	Net income (Rs)	B:C ratio
$T_{1: P30\ kg}$ ha^{-1}	5.88	64680	133.67	10693.6	30248	75373.6	451258.6	1.491854
$T_{2: P40\ kg}$ ha^{-1}	6.50	71500	145.49	11639.2	30288	83139.2	52851.2	1.744955
$T_{3: P50\ kg}$ ha^{-1}	6.59	72490	147.21	11776.8	30328	84266.8	83938.8	1.778515
$T_{4:AZB+\ P30\ kg}$ ha^{-1}	6.33	69630	142.12	11369.6	30548	80999.6	50451.6	1.651552
$T_{5:\ AZB+\ P40\ kg}$ ha^{-1}	7.30	80300	161.62	12929.6	30588	93229.6	62641.6	2.047914
$T_{6:\ AZB+\ P50\ kg}$ ha^{-1}	7.46	82060	164.34	13147.2	30628	95207.2	64579.2	2.108502
$T_{7:\ PSB+P30\ kg}$ ha^{-1}	6.17	67870	139.34	11147.2	30498	79017.2	48519.2	1.590898
$T_{8:\ PSB+P40\ kg}$ ha^{-1}	6.82	75020	153.37	12269.6	30538	87289.6	56751.6	1.858393
$T_{9:\ PSB+P50\ kg}$ ha^{-1}	6.95	76450	155.89	12471.2	30578	88921.2	58343.2	1.908012
$T_{10:\ AZB}$	5.80	63800	132.02	10561.6	30428	74361.6	43933.6	1.443854
$T_{11:\ PSB}$	5.69	62590	131.21	10496.8	30378	73086.8	42708.8	1.405912

$T_{12: Control}$	5.21	57310	122.82	9825.6	30128	67135.6	37007.6	1.228346

Appdx 6: Economics of production as influenced by seed rate in ashwagandha

Treatments	Root yield (q ha^{-1})	Cost of root yield (Rs ha^{-1})	Seed yield (Kg ha^{-1})	Cost of Seed (Rs ha^{-1})	Cost of production (Rs)	Gross income (Rs)	Net income (Rs)	B:C ratio
T_1 : 6 kg ha^{-1}	5	55000	124.75	9980	28928	64980	36052	1.246267
T_2 : 8 kg ha^{-1}	5.15	56650	126.15	10092	29088	66742	37654	1.294486
T_3 : 10 kg ha^{-1}	6.85	75350	146.92	11753.6	29248	87103.6	57855.6	1.978104
T_4 : 12 kg ha^{-1}	7	77000	148.35	11868	29408	88868	59460	2.021899

Appdx 7: Economics of production as influenced by as influenced by spacing in ashwagandha

Treatments	Root yield (q ha^{-1})	Cost of root yield (Rs ha^{-1})	Seed yield (Kg ha^{-1})	Cost of Seed (Rs ha^{-1})	Cost of production (Rs)	Gross income (Rs)	Net income (Rs)	B:C ratio
T_1 : 30X30 cm	5.2	57200	118.75	9500	29948	66700	36752	1.227194
T_2 : 30X10 cm	6.8	74800	148.85	11908	30948	86708	55760	1.801732
T_3 : 20X20 cm	5.72	62920	130.3	10424	32448	73344	40896	1.260355
T_4 :20X10 cm	7.15	78650	152.12	12169.6	33448	90819.6	57371.6	1.715248

ANNEXURE 8

PRICES OF INPUTS

SI NO	Particulars	Prices
1	Seed cost	Rs. 80.00 kg^{-1}
	Manures	
2	FYM	Rs. 600.00 t^{-1}
	Fertilizers	
3	Urea	Rs. 5.60 kg^{-1}
4	SSP	Rs. 4.00 kg^{-1}
5	MOP	Rs. 5.10 kg^{-1}
	Chemicals	
6	Neem oil	Rs. 185 L^{-1}

ANNEXURE 9

PRICES OF OUTPUTS

SI NO	Particulars	Prices per Kg
1	Dry roots	Rs. 110.00
2	Seeds	Rs. 80.00