AGROTECHNIQUES FOR MITIGATING WATER STRESS IN VEGETABLE COWPEA (*Vigna unguiculata* (L.) Walp.)

by

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(2012-21-103)

THESIS

submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy

COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR-680 656
KERALA, INDIA

2016

DECLARATION

I hereby declare that the thesis entitled **"Agrotechniques for mitigating water stress in vegetable cowpea (*Vigna unguiculata* (L.) Walp.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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ACKNOWLEDGEMENTS

It is with great respect and devotion; I place on record my deep sense of gratitude and indebtedness to my chairperson **Dr. K. E. Savithri**, Professor (Agronomy), for her sustained and valuable guidance, constructive suggestions, unfailing patience, friendly approach, constant support and encouragement during the conduct of this research work and preparation of the thesis. I gratefully remember her knowledge and wisdom which nurtured this research project in right direction without which fulfillment of this endeavor would not have been possible.

No words can truly represent my profound gratitude and indebtedness to **Dr. P. Sreedevi**, Professor & Head, Department of Agronomy, member of my Advisory Committee for his unstinted support and guidance in the conduct of field experiments, constructive criticism, valuable suggestions and critical scrutiny of the manuscript.

I am deeply indebted to **Dr. C. George Thomas,** Professor, Department of Agronomy, and member of my Advisory Committee for his unbounded support, valuable suggestions.

I am deeply obliged to **Dr. K. Nandini,** Professor & Head (Plant Physiology), and **Dr. P.G. Sadhan kumar**, Professor & PI (AICVIP, Olericulture), member of my Advisory Committee for the generous and timely help they always accorded to me during the course of this study.

I am extremely delighted to place on record my profound sense of gratitude to **Mr. S. Krishnan**, Professor, Department of Agricultural Statistics, for his support, critical comments and valuable advice during the preparation of this manuscript.

It is with great pleasure I record my heartfelt gratitude and sincere thanks to **Dr. P.S. John,** Professor, Department of Agronomy for his wholehearted support and co -operation rendered throughout the course of my study.

My sincere thanks to **Dr. C.T. Abraham, Dr. P.A. Joseph, Dr. Lalitha Bai, Dr. Meera V. Menon, Dr. P. Prameela, Dr. Pathiyur Gopinath, Dr. K.E. Usha, Dr. Mercy George** and **Dr. Brijit**, Department of Agronomy for the valuable help and advice rendered during the course of my study.

I am thankful to **Dr. P.K. Sushama**, **Mr. Vishwesvaran,** and **Dr. Suresh Kumar**, Department of Soil Science and Agricultural Chemistry for sincere help during chemical analysis.

Let me express my sincere thanks to **Dr. Diji Bastin** (Plant Breeding) and library staffs for their whole hearted co-operation, mental support and academic assistance during the course of investigation.

I wish to express my sincere gratitude to **Ms. Vandana**, Farm officer, Dept. of Agronomy, **Miss Saritha, Mrs. Sreela, Ms. Sofia, Mrs. Deepika, Mrs. Valsala, Mrs. Elsy, Mrs. Shyamala, Mr. Arun, Mrs. Mayadevi, Mrs. Vyshaki, Mrs. Dhalia** and **Mrs. Sheena** for the sincere help, timely suggestions and encouragement which gave me enough mental strength to get through all tedious circumstances.

I am extremely thankful to the field labourers of Agronomy, especially to **Mrs. Vasantha,** for their valuable suggestions, co-operation and support during the conduct of field experiments.

I am happy to place on record my sincere thanks to my friends, seniors and juniors of Dept. of Agronomy for their innumerable help and support during the course of this study.

The award of senior research fellowship of the KAU is thankfully acknowledged.

Words can’t express my soulful gratitude to my family, for their selfless sacrifice, boundless patience and unflagging interest throughout the period of my course. I am affectionately dedicating this thesis to my family.

Finally I bow my head before **THE ALMIGHTY** whose blessings enabled me to undertake this venture successfully.

Syama S. Menon

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Sl. No.	Abbreviations used	Expansion
1.	PGRs	Plant growth regulators
2.	FYM	Farm yard manure
3.	PGPR	Plant growth promoting rhizobacteria
4.	CCC	Cycocel
5.	SA	Salicylic acid
6.	AA	Ascorbic acid
7.	NAA	Naphthaleneacetic acid
8.	Br.	Brassinolide
9.	CW	Coconut water
10.	WS	Water spray
11.	LWS	Lime water spray
12.	PM	Plastic mulch
13.	PRM	Plant residue mulch
14.	DAP	Diammonium phosphate
15.	KCl	Potassium chloride
16.	$ZnSO_4$	Zinc sulphate
17.	H_3BO_3	Boric acid
18.	NaCl	Sodium chloride
19.	$CaCl_2$	Calcium chloride
20.	KH_2PO_4	Potassium dihydrogen phosphate
21.	FP	Farmers practice
22.	Abs. control	Absolute control
23.	Control	Irrigation at 5 days interval
24.	RLWC	Relative leaf water content
25.	CSI	Chlorophyll stability index
26.	NRase	Nitrate reductase
27.	SMC	Soil moisture content
28.	DMP	Dry matter production
29.	LAI	Leaf area index
30.	FWUE	Field water use efficiency
31.	BDL	Below detectable level
32.	DAS	Days after sowing

INTRODUCTION

1. INTRODUCTION

Water is becoming a scarce commodity for irrigation especially under the present changing climatic scenario. Water stress is one of the major abiotic stresses that limits crop production. Water stress hampers important physiological and biochemical mechanisms in plants, which lead to reduction in growth and yield. Bray *et al.* (2000) reported that the relative decrease in potential crop yield due to abiotic stress factors including drought, ranges from 54 per cent to 82 per cent. Therefore, for sustaining food security, high priority should be given to minimize the detrimental effects of drought. Cultivation of drought tolerant crop varieties alone would not help to overcome the situation. It necessitates the development of alternate management technologies to mitigate water stress in crop plants for sustainable growth and yield.

Vegetables are the most susceptible group of crops to water stress, and consume more water through irrigation. Vegetable cowpea is an important protein catering vegetable, largely consumed in the state. Being a non-season bound crop, it can be grown throughout the year and is grown in a total area of 6714ha (FIB, 2016). Even though the crop performs well during summer season under irrigation, water scarcity limits its area under cultivation. It calls for alternate management technologies.

Phytohormones are well known to be involved in plant adaptation to water stress and may play an important role in growth and development (Wang *et al*., 2008). The exogenous application of plant hormones has been found to alleviate the negative effects of various abiotic stresses including drought (Fariduddin *et al*., 2009). Research works conducted in various crops revealed that exogenous application of plant growth regulators like CCC (Farooq and Bano, 2006), salicylic acid (Azooz and Youssef, 2010), ascorbic acid (Khalil *et al.*, 2010), naphthalene acetic acid (NAA) (Parmer *et al.*, 2012), brassinolide (Verma *et al.,* 2012) and cytokinins (Huang, 2006) were effective in mitigating the adverse effects of water stress and enhanced the crop stability to extreme water deficit conditions.

Seed hardening is a technique adopted to alleviate the adverse effects of moisture stress or to make the plant resistant to moisture stress. It will modify the physiological and biochemical nature of seeds so as to get the characters that are favourable for drought tolerance. If the stress effect can be alleviated at the germination stage, chances for attaining a good crop establishment would be high (Ashraf and Rauf, 2001). Usually, inorganic salts like NaCI, Na_2SO_4, KCI, KH_2PO_4, $CaCl_2$ and $MgSO_4$ are used as pre-hardening agents and the favourable influence of $CaCl_2$ on chick pea, NaCl and KH_2PO_4 on green gram under water stress was reported by Manjunath and Dhanoji (2011), Jisha and Puthur (2014) and Umair *et al.* (2011) respectively.

In the present scenario of climate change, globalization and health consciousness, mulching is one technique that can be followed by farmers to produce quality food in quantities through improving soil moisture conservation, suppressing weeds, regulating soil temperature and improving soil health. Mulching can be done either with plastic or plant residues. Favourable influence of plastic mulching on growth and yield of crops is well established. Rahman (2005) reported higher tomato yield under plastic mulching compared to non-mulched plants. However, considering the cost and pollution aspects of plastic mulching, as an alternative, use of locally available, cost effective, user friendly, environmentally safe organic mulch materials such as plant residues can be considered. Increased seed and biomass yield of soybean under wheat straw mulching was reported by Sekhon *et al*. (2005).

Antitranspirants are materials sprayed on the transpiring surface to reduce transpiration, which helps to conserve moisture in plants. The antitranspirants such as kaolin and lime water reduce leaf temperature and transpiration by way of reflecting solar radiation and atrazine by way of stomatal closure. Beneficial effect of kaolin spray and lime water spray on groundnut and that of atrazine on corn under water stress was reported by Naveen *et al.* (1992), Reddy and Setty (1995) and Kazempour and Tajbakhsh (2002) respectively.

Improving the mineral nutrient status of plants under drought is of great importance for the maintenance of crop productivity. Nutrient uptake by plants gets impaired due to inadequate soil moisture under drought condition. Proper nutrient management practices, which include application of organic manures, biofertilizers and foliar application of both macro and micro nutrients along with soil applied fertilizers help to meet the nutritional requirement of the crop under water stress situation. Application of nutrients improves drought tolerance in plants either by increasing the concentration of antioxidants or by improving the root growth or indirectly by activating the physiological, biochemical and metabolic processes in the plants.

Macronutrients like nitrogen, potassium and calcium can reduce the toxicity of reactive oxygen species by increasing the concentration of antioxidants like superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) in plant cells. Similarly, nutrients like phosphorus, potassium, magnesium and zinc improve root growth, which in turn, increases water uptake and helps in stomatal regulation thereby enhancing drought tolerance. Application of nutrients like potassium and calcium help to maintain high tissue water potential under drought condition and improve drought tolerance by osmotic adjustment. Micronutrients like copper and boron alleviate the adverse effects of drought indirectly by activating the physiological, biochemical and metabolic processes in the plants. Seed inoculation with plant-growth-promoting-rhizobacteria (PGPR) can improve the plants' tolerance to drought stress by improving water retention and soil aggregation around the plants roots. Favourable influence of inoculation of PGPR+Rhizobium in chick pea and *Pseudomonas fluorescens* in green gram under water stress was reported by Jabbari and Khaleghnezhad (2014) and Saravanakumar *et al.* (2011) respectively. A positive influence on grain yield of maize by application of farm yard manure under water stress due to its beneficial effect on physiological parameters was noticed by Paryan *et al*. (2012). However, not much work has been done in Kerala on the possibility of exploiting plant growth regulators, seed priming techniques, antitranspirant sprays and nutrient management practices for water stress mitigation in crop plants.

In view of the above, a study was under taken to develop a package for mitigating water stress in summer vegetable cowpea by assessing the effect of various plant growth regulators, antitranspirants, seed primers, moisture conservation measures and nutrient management practices on the growth and yield of vegetable cowpea.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Water stress is the most critical threat to food security in future especially under the present changing climatic scenario, as it is an important constraint to crop production and productivity. Water stress hampers important physiological and biochemical mechanisms inside plants leading to reduction in growth and yield and the extent of yield loss depends on severity, duration and growth stage at which the crop experiences water stress. Moreover, unavailability of sufficient irrigation water to meet the crop water requirement during the water stress period is also a problem faced by farmers. Development of drought tolerant crop varieties is one of the promising approaches to mitigate the adverse effects of water stress, but it solely does not solve the problem. Hence field experiments to find out some alternate management technologies to solve this problem were conducted in vegetable cowpea. Some technologies/management practices like exogenous application of plant growth regulators (PGRs), seed hardening/priming, foliar spray of antitranspirants, soil moisture conservation measures (mulching) and nutrient management (biofertilisers and foliar spray of macro and micronutrients) were found helpful to alleviate the negative effects of water stress in crop plants which are reviewed here under.

2.1. Effect of water stress on crop plants

2.1.1. Effect of water stress on seed germination and establishment

Water stress impairs seed germination and establishment of crop plants. Chang (1983) reported a reduction in germination percentage and vigour of soybean due to low soil moisture content below field capacity. Growth and biomass of radicle and plumule in germinating lentil was decreased by moisture stress (Singh and Ambawatia, 1989). Water stress to the tune of -5.0 to -10.0 bars decreased the germination percentage in vegetable pea (Kumar *et al.,* 1990). A reduction of α-amylase activity, increase in the total soluble sugars and bound fructose in cotyledons of water stressed chick pea seedlings was reported by Gupta *et al.* (1993). The most crucial effect of water stress on crops is impaired germination, poor crop stand and establishment (Harris *et al.*, 2002). Okcu *et al.* (2005) noticed that the impact of water stress on germination and seedling growth of peas was severe than that caused by salinity.

2.1.2. Effect of water stress on vegetative growth

Water stress at vegetative stage leads to growth reduction in plants. Plant growth depends on cell division, cell enlargement and differentiation involving genetic, physiological and morphological processes and their interactions which are affected by water deficit. Lower number of branches, dry matter accumulation and early maturity in faba bean under water stress conditions was observed by Nanda *et al.* (1988). Prolonged water stress decreased plant height, leaf area and leaf dry weight in chick pea (Gupta *et al.*, 1995). Most drought sensitive physiological process affected due to the reduction in turgidity is cell growth (Taiz and Zeiger, 2006). Reduced plant height, leaf area and crop growth in sunflower under drought was reported by Hussain *et al.* (2008) due to impaired mitosis, cell elongation and expansion. Water stress at vegetative stage showed significant impact on all vegetative growth parameters like plant height, wet and dry weight of shoots and roots and root length of black gram (Nilanthi *et al.,* 2014). Reduced water availability affects stomatal opening/closing and thereby reduced transpiration rate, which in turn decreases the availability, uptake, translocation, metabolism and efficient utilization of nutrients by the crop (Farooq *et al.,* 2009).

The only source of plants to acquire water from soil is roots. Therefore, root growth, its density, size and proliferation are key responses of plants to drought stress. Selection for a deep and extensive root system has been advocated to increase productivity of food legumes under moisture deficit conditions as it can optimize the capacity to acquire water as reported by Hidalgo (1977) and

Subbarao *et al.* (1995). Dry bean (*Phaseolus vulgaris*) adapted to drought stress had a heavy, deep penetrating root system (Barron, 1991) which helps in extracting water from deeper layers of soil (Kavar *et al.*, 2007).

Water stress increased root biomass (Turk *et al.*, 1980) and root length in cowpea (Alyemeny, 1997). On the contrary, moisture stress reduced the root volume in cowpea genotypes (Hamidou *et al.*, 2007). Water stress decreased the shoot: root ratio in beans (Lopes *et al.*, 1987) but it was increased in cowpea (Suliman and Ahmed, 2010) as shoot growth is more sensitive to increasing soil water stress than root growth.

Maintenance of high leaf water potential by stomatal regulation and robust root system in common bean resulted in better drought tolerance (Amede and Schubert, 2003). Drought stressed plants divert higher dry matter to roots and stems, while well watered plants divert the same to pods and grains (Kumar and Sharma, 2009). The number of roots and root biomass per plant of mung bean decreased with reduction in water potential (Dhole and Reddy, 2010). Root length decrease in drier parts and increase in wetter parts under water deficit (Sekhon *et al.,* 2010). Continuous drought reduces overall root growth, resulting from uncoupling between carbon production in leaves and use in root sinks (Muller *et al.,* 2011). Root growth enhanced under initial drought condition for better access to water and dehydration avoidance but prolonged drought led to shrinkage of roots, anatomical deformations and weak root-soil contact which limits water and ion supply. In legume crops, stress reduced the nodule size, weight and nitrogenase activity (Lipiec *et al.,* 2013). As water stress affects crop phenology, leaf area development and number of leaves per plant, it finally results in lower final dry matter weight of shoots and pod yield of mung bean (Abdel *et al.,* 2011). Water deficit decreased the dry matter partitioning to leaves and increased that to stems, decreased relative growth rate (RGR) and net assimilation rate (NAR) in soybean (Itoh and Kumura, 1986). In soybean, Wang Pei Wu *et al.* (1995) reported that water stress increased growth period and decreased plant dry weight, crop growth rate (CGR), leaf area index (LAI), net assimilation rate (NAR) and pod growth rate.

2.1.3. Effect of water stress on photosynthesis

Exposure of plants to water stress leads to reduction in photosynthesis. The first response of plants to acute water deficit is the closure of their stomata to prevent the transpirational water loss (Mansfield and Atkinson, 1990) and it was the main determinant for decreased photosynthesis under mild to moderate drought (Yokota *et al.,* 2002). Stomatal closure decreases the inflow of CO_2 into the leaves and heat dissipation from leaves increases due to reduced transpiration which in turn increase stomatal resistance (Frederick *et al.,* 1989). The adverse effects of water stress on photosynthesis of mung bean, was severe at post-flowering and pod development stages (Uprety and Bhatia, 1989). *Phaseolus vulgaris* closed its stomata very rapidly and complete stomatal closure was obtained at a leaf water potential of -0.6 MPa (Franca *et al.,* 2000)**.** Reduced light interception as a result of lower leaf area, less carbon fixation per unit leaf area and damaged photosynthetic apparatus leads to decrease in net photosynthetic rate of plants under drought (Bruce *et al*., 2002). Drought inhibits or slows down photosynthetic carbon fixation through limiting the entry of CO_2 into the leaf or directly by inhibiting metabolism inside plants (Apel and Hirt, 2004).

Drought stress caused changes in photosynthetic pigments (Anjum *et al.,* 2003), damaged the photosynthetic apparatus (Fu and Huang, 2001) and diminished activities of Calvin cycle enzymes, which in turn reduced the crop yield. Decreased leaf expansion, impaired photosynthetic machinery and premature leaf senescence ultimately led to reduction in photosynthesis (Wahid and Rasul, 2005). Decline in enzyme (Rubisco) activity (Bota *et al*., 2004, Zlatev and Lidon, 2012) and reduced availability of CO_2 in the chloroplast and change in photosystem II under drought disable the activity of electron transport (Loreto *et al.,* 1995, Barta *et al*., 2010) which, in turn, hinder photosynthesis.

Low external osmotic potential decreased photosynthesis of isolated mesophyll cells (Bunce, 1988). Decrease in photosynthetic rate to the tune of 50-71 per cent in pigeon pea under water stress was reported by Kuhad *et al.* (1989). Reduced relative water content (RWC) and leaf water potential, decreased the foliar photosynthetic rate of higher plants (Lawlor and Cornic, 2002). Reddy *et al.* (2004) noticed a loss of balance between the production of reactive oxygen species (ROS) and the antioxidant defense which in turn induces oxidative stress in proteins, membrane lipids and other cellular components. Drought stress decreased the leaf chlorophyll content (chlorophyll a, b ant total) of wheat (Ommen *et al*., 1999) which can be due to the higher degradation of chlorophyll more than its biosynthesis under water stress (Yang *et al.,* 2001). Similarly, Bano and Aziz (2003) reported an accelerated chlorophyll break down under water stress. An increase in temperature from 22 to 32°C resulted in reduction of photosynthesis and transpiration rate under water deficit conditions (Zhang *et al*., 2010).

2.1.4. Effect of water stress on translocation and partitioning of assimilates

Assimilate translocation to reproductive sinks is essential after anthesis for fruit and seed development. Yield reduction under stress can be either due to unavailability or non-utilization of assimilates. Drought stress enhances allocation of dry matter to the roots, which will enhance water uptake (Leport *et al*., 2006). Effect of drought resulted in reduced accumulation of plant biomass, increased tillering, early senescence and premature death, fruit discoloration and damage in plants (Wahid *et al*., 2007).

The export of sucrose from source to sink organs depends upon the current photosynthetic rate and concentration of sucrose in the leaves (Komor, 2000). Limited photosynthesis and sucrose accumulation in the leaves under stress hampers the export of sucrose to the sink organs and ultimately affect the reproductive development. Drought stress decreased the photosynthetic rate and disrupted the carbohydrate metabolism and sucrose level in leaves which contributed to a decreased export rate (Kim *et al.,* 2000).

Drought stress not only limits the size of the source and sink tissues but also impairs the phloem loading, assimilate translocation and dry matter partitioning. The capacity of the reproductive sink to utilize the incoming assimilates is also affected under drought stress which in turn leads to reproductive abortion (Zinselmeier *et al.,* 1999). Improper phloem unloading arrests the development of reproductive tissues (Goetz *et al.,* 2001). Drought induced carbohydrate deprivation, enhanced endogenous abscisic acid concentration, and impaired ability to utilize the incoming sucrose by the reproductive sinks are potential factors contributing to seed abortion in grain crops (Setter *et al*., 2001). Seed development stage of the crop competes with the roots and stem for nitrogen mobilized from the leaves (Sinha *et al*., 1990). In addition, drought stress also inhibits important functions of vacuolar invertase mediated sucrose hydrolysis and osmotic potential modulation. In drought-stressed maize, a lower invertase activity in the young ovaries, inhibited cell division in the developing embryo, which ultimately led to fruit abortion (Andersen *et al.,* 2002).

Exposure of chickpea to water stress reduced foliage dry matter and pod dry weight to the tune of 50 and 39 per cent respectively. The allocation to stem, leaves and pods was almost equal under water stress, unlike higher allocation to pods under irrigated conditions (Dhonde *et al.* (2006). Farooq *et al.* (2009) noticed that decreased assimilate partitioning and activities of starch synthesis enzymes lead to reduced grain filling in almost all crops.

Maintenance of higher growth rate, higher stomatal conductance and CO_2 assimilation rate even at a lower leaf water potential was observed in tropical pasture legume, siratro compared to soybean (Ohashi *et al.,* 2000).

2.1.5. Effect of water stress on physiological parameters

Plants can partly protect themselves against mild drought stress by accumulating osmolytes of which proline is one of the most common compatible osmolytes in drought stressed plants. The accumulation of proline is a clear evidence for drought stress in plants (Routley, 1966). Mafakheri *et al.* (2010) reported increased proline content in chickpea under drought stress.

A decreased leaf water potential, relative water content and transpiration rate in wheat exposed to drought stress was reported by Siddique *et al.* (2001). Shoot dry matter production, relative water content (RWC), osmotic potential and stomatal conductance in faba bean decreased whereas leaf temperature and transpiration efficiency increased under moisture deficit due to restricted transpirational cooling induced by stomatal closure (Khan, *et al.,* 2007). Under water stress, cowpea mainly relies upon dehydration avoidance and pigeon pea showed dehydration tolerance (Likoswe and Lawn, 2008).

A reduction in chlorophyll (a, b ant total) content of mung bean (Thalooth *et al.,* 2006), sunflower (Manivannan *et al.* (2007) and cowpea (Singh and Raja Reddy, 2011) under drought stress can be due to chloroplast damage caused by active oxygen species (Smirnoff, 1995). Asada (2006) observed an increased generation of reactive oxygen species (ROS) under drought. Transpiration rate, stomatal conductance and chlorophyll content decreased in chick pea when imposed to drought stress as a result of stomatal closure which restricts gas exchange between the atmosphere and leaf (Mafakheri *et al.,* 2010). Panda *et al.* (2013) reported that moisture stress at branching and branching + flowering in sesame reduced relative water content (RWC), membrane stability index (MSI), chlorophyll stability index (CSI), which in turn effected the seed yield.

2.1.6. Effect of water stress on yield attributes and yield

Drought-induced yield reduction depends upon the severity and duration of the stress period and the stage of crop at which it occurs. Prevailing drought reduces plant growth and development, leading to reduced flower production and grain filling. Water stress at the beginning of bean flowering resulted in a yield reduction to the tune of 36.85 per cent and stress at full flowering reduced seed yield by 33.68 per cent (Magalhaes *et al.,* 1979). Turk *et al*. (1980), Hiler *et al.* (1972) and Ahmed and Suliman (2010) noticed that reproductive stage is more sensitive to water deficit in cowpea causing a reduction in seed yield even though it can survive water stress during the vegetative stage. Water stress during flowering in cowpea (Turk and Hall, 1980) and bean (Fiegenbaum *et al.,* 1991) resulted in lower yield attributes and yield. Grain yield in cowpea is determined by three components: mean number of pods per plant that reach maturity, average number of seeds per pod and average weight of seed (Aryeetey and Laing, 1973) of which the most important yield component is the number of pods that reach maturity (Doku, 1970). Under drought stress, reduced number of pods per plant contributes to lower yield (Hamidou *et al.*, 2007, Abayomi and Abidoye, 2009). Post flowering water stress significantly reduced growth and number of cowpea seeds but not seed weight (Kumaga *et al.,* 2003).

Seed yield and harvest index of pigeon pea, reduced to the tune of 37 and 22 per cent respectively, by water stress at flowering and early pod development stage (Lopez *et al*., 1996). Similarly, yield reduction to the tune of 40 to 55 per cent in pigeon pea and 46 to 71 per cent in soybean was reported by Nam *et al.* (2001) and Samarah *et al.* (2006) respectively, under water stress. Stress at flowering and pod development stage led to 18 per cent and 30 per cent reduction in pod yield of ground nut (Vaghasia *et al.,* 2010). Water stress in black gram at reproductive stage significantly reduced all yield related parameters like number and weight of pods and seeds (Nilanthi *et al.,* 2014).

Chandel *et al*. (1995) and Frederick *et al.* (2001) observed a significant decrease in plant dry matter, nitrogen uptake and seed yield per plant under moisture stress in soybean. Grain as well as biological yield of chickpea cultivars decreased under water deficit conditions (Khamssi, 2011).

2.2. Effect of exogenous application of plant growth regulators on water stress mitigation

Phytohormones play an important role in growth and development and are well known to be involved in plant adaptation to water stress (Wang *et al*., 2008). Foliar application of plant growth regulators (PGRs), both natural and synthetic, was found promising for improving growth against abiotic stresses. The exogenous application of plant hormones has been found to counteract the adverse effects of various abiotic stresses (Fariduddin *et al*., 2009).

Chlormequat chloride (CCC) is a plant growth regulator typically used as the chloride salt, a colorless hygroscopic crystalline substance soluble in water and ethanol. ***Salicylic acid*** or *ortho*-hydroxybenzoic acid is a phenolic compound present in plants as free phenolic acid or as conjugate form formed by methylation or hydroxylation of aromatic ring. Natural derivative of salicylic acid is ***salicin*** occurring in white willow (*Salix alba*). There are two main routes for salicylic acid biosynthesis in plants (Shah, 2003), one is that, it is synthesized from phenylalanine *via* cinnamic acid. The decarboxylation of the side chain of cinnamic acid generate benzoic acid, which then undergo hydroxylation at the C-2 position forming salicylic acid (Ribnicky *et al*., 1998). The other pathway for the salicylic acid biosynthesis involves a 2-hydroxylation of cinnamic acid to o-coumaric which is then decarboxylated to salycilic acid (Alibert *et al.,* 1972). ***Ascorbic acid*** is a naturally occurring organic compound with antioxidant properties. Ascorbic acid application helps the plants for better resistance under the stress by inactivation and scavenging of free radicals. ***NAA (1-***

Naphthaleneacetic acid) is a synthetic plant hormone comes under the auxin family and it is a rooting agent, used for the vegetative propagation of plants from stem and leaf cuttings. ***Brassinosteroids*** are a class of polyhydroxysteroids that is considered as a sixth class of plant hormones. '*Brassinolide'* was the first isolated brassinosteroid from the pollen of *Brassica napus* in 1979, when it showed stem elongation and cell division. Several studies showed that exogenously applied brassinosteroids are effective in controlling plant growth under stressful conditions. ***Cytokinins (Kinetin)*** are a class of phytohormones that stimulate water uptake, increase cell division and promote organ development.

2.2.1. Effect of exogenous application of plant growth regulators on growth and development

Plants can partly protect themselves against mild drought stress by accumulating osmolytes mainly proline. Accumulation of proline under stress is the result of increased expression of proline synthetic enzymes or repressed activity of proline degradation (Delauney and Verma, 1993) and (Peng *et al.,* 1996). Proline accumulation may also be a part of the stress signal influencing adaptive responses (Maggio *et al.* 2002). Maiti *et al*. (2000) and Demir (1999) reported an increased proline accumulation as a mechanism of plant adaptation to abiotic stress. Alexieva *et al.* (2001) observed increased proline content under drought stress in pea. The proline content depends on plant age, leaf age, leaf position or leaf part. The increase in proline content due to drought stress was more severe at flowering stage than at the vegetative stage (Chiang and Dandekar, 1995). Exogenous application of PGRs also found to increase the concentration of osmolytes and thereby reduce the severity of stress inside plants.

Seed treatment with chlormequat increased root: top ratio in wheat (Wang *et al*., 1980). Exogenous application of CCC resulted in increased number and size of tubers, but it decreased growth of stem, leaves and stolon in potato (Sharma *et al*., 1998). Similarly in mung bean, exogenous application of CCC resulted in thickening of stem, which led to enhanced plant stability under water deficit conditions (Farooq, and Bano, 2006). The anti gibberellin CCC, induce reduction of aerial plant parts by directing the assimilates more to roots (Thalooth *et al.,* 2006). A decrease in plant height with an increase in relative water content in barley was noticed with increasing cycocel concentration (from 0 to 3000 mg/L) (Sharif *et al.,* 2007).

Salicylic acid can effectively improve plant growth under drought conditions. Exogenous application of salicylic acid improved drought tolerance in tomato, beans (Senaratna *et al.,* 2000), and in common bean, tomato (Sakhabutdinova *et al*., 2004). Salicylic acid decreased the generation of reactive oxygen species in photosynthetic tissues of *Arabidopsis thaliana* during osmotic stress (Borsani *et al*., 2001). Wheat raised from grains soaked in salicylic acid solution showed enhanced tolerance to drought (Hamada and Al-Hakimi, 2001). Exogenous application of salicylic acid improved the drought tolerance of winter wheat, which can be correlated with an increased antioxidant enzyme (catalase) activity (Horvath *et al*., 2007). Leaf area index of common bean was increased by 29 per cent by application of 0.5 mM salicylic acid under drought (Sadeghipour and Aghaei, 2012). Bideshki *et al.* (2013) reported an increased leaf area, root number, root length, total chlorophyll, anthocyanins, membrane permeability, plant, bulb and clove fresh weight of garlic with salicylic acid (@ 0.5 mM) application.

Higher plant height, number of leaves and branches per plant, leaf area, dry matter, days to maturity and seed yield in soybean was obtained with NAA application (100 mg/L) (Deotale *et al*., 1998).

Brassinosteroids (BRs) are new group of plant hormone with wide occurrence in the plants having unique biological effects on growth and development (Zhang *et al*., 2008). Brassinosteroids have an anti-stress effect on plants which helps to overcome drought by way of its stimulating effect on photosynthesis, nucleic acid, protein synthesis, vascular differentiation and activation of enzymes (Fariduddin *et al*., 2009; Zhang *et al*., 2008). Exogenous application of brassinosteroids may influence a range of diverse processes in plant growth and development (Ali *et al*., 2006; Behnamnia *et al*., 2009; Fariduddin *et al*., 2009). Increased photosynthesis rate (Shahbaz *et al*., 2008), shoot dry biomass and seed yield of *Brassica juncea* were considerably increased by the exogenous application of brassinosteroids (Ali *et al*., 2006).

Foliar spray of epi-brassinolide (0.001 ppm) increased plant growth, root activity and nitrate reductase activity in roots and leaves of gram (Jai Singh *et al.,* 1993). Exogenous application of brassinolide under drought conditions, improved the plant height, leaf area, cobs per plant and seedling dry weight in maize (Anjum *et al*., 2011) which can be attributed to the role of brassinolide in mediating increased protein synthesis which enables maintenance of tissue water potential and activities of antioxidant enzymes lowering the lipid peroxidation under drought.

Kinetin, one of the important cytokinin is used to alleviate severe effects of stress (Al-Hakimi, 2007). Improved germination of chick pea plants treated with kinetin (@ 6μM) under polyethylene glycol (PEG) induced stress condition was reported by Kaur *et al*. (1998) through its effect on chlorophyll content, growth and metabolism. Exogenous cytokinin application can positively affect stomatal conductance and stimulate transpiration in leaves (Huang, 2006).

2.2.2. Effect of exogenous application of plant growth regulators on physiological and biochemical parameters.

Maintenance of water status inside the plants is regulated by stomatal conductance and rate of transpiration (Ashraf, 2009). Water stress usually reduces the leaf water potential, nitrate reductase activity, photosynthesis and grain yield particularly in susceptible crop cultivars. Chlormequat (@ 1000 ppm) applied at

25 DAS, increased leaf water potential, nitrate reductase activity and photosynthesis in wheat (Sairam *et al.,* 1991). Cycocel application in lower concentration (0.64 mM) was efficient for increasing carbon exchange and stomatal conductance while higher concentration (3.20 mM) had more effect on relative water content and chlorophyll content in pigeon pea (Dayal *et al.,* 1993). Suppressed stomatal opening and increased the number of stomata per unit leaf in cowpea as a result of CCC application was observed by Imbamba (1993) resulting in increased relative water content. CCC treated soybean plants showed an increased leaf pigment and proline content under decreased soil moisture whereas it has no effect on seed protein content and oil content (El-Kheir *et al.,* 1994). The role of CCC in osmoregulation, by way of increased production of proline and sugar as osmoregulants was noticed by Rademacher (2000) and it also overcome the adverse effects of water stress on protein content. Thalooth *et al.* (2006) also observed that presowing soaking treatment of mung bean with CCC increased the chlorophyll content under water stress. Foliar spray of chlormequat decreased the protein content in maize leaves under a moderate soil moisture stress (40 per cent of field capacity) and increased them under severe stress (30 per cent FC) (Kimenov *et al.,* 1977). The accumulation of proteins is an adaptation mechanism as it bounds to membranes and regulates membrane water permeability which in turn influences water movement among tissues and organ (Ashraf, 2003).

Foliar application of CCC and salicylic acid increased photosynthesis, stomatal resistance, nitrate reductase activity and decreased transpiration rate (Singh *et al.,* 2007) and increased relative water content (Jiriaie and Sajedi , 2012) in wheat under dry condition. Exogenous application of salicylic acid (@ 0.724mM and 100mM) at flowering stage of hybrid sunflower improved the water potential, leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), relative leaf water contents and water use efficiency but reduced the protein content (Hussain *et al.,* 2009). Thind and Radhika (2011) reported that foliar application of salicylic acid (@ 30 µg/ml) under stress, increased the chlorophyll content, relative leaf water content and decreased sucrose synthase activity in wheat. Summer sesame seeds treated with salicylic acid (1000 ppm) recorded highest LAI, branches per plant, crop growth rate, relative water content (RWC), membrane stability index (MSI), chlorophyll stability index (CSI), dry matter accumulation, number of capsules per plant, seed yield and harvest index (Panda *et al*., 2013).

Singh and Usha (2003) noticed an improved carboxylase, superoxide dismutase and nitrate reductase activity, total chlorophyll and dry matter accumulation in wheat seedlings treated with salicylic acid under drought. Similarly, application of salicylic acid under water stress enhanced photosynthetic parameters, membrane stability index, leaf water potential, activities of nitrate reductase and carbonic anhydrase thus improved drought tolerance in tomato (Hayat *et al.,* 2008). Wheat seedlings supplemented with salicylic acid (1mM) under water stress, induced the activity of antioxidant enzymes (superoxide dismutase, catalase, ascorbate peroxidase and NADPH oxidase) (Senaratna *et al*., 2000 and Agarwal *et al.,* 2005). Exogenously applied salicylic acid ameliorated the adverse effects of drought stress on leaf relative water content of canola (Ullah *et al.,* 2012) and barley (Habibi, 2012).

Ascorbic acid application helps the plants for better resistance to water stress by inactivation and scavenging of free radicals. Ascorbate was oxidized to dehydroascorbate which reduce the harmful effects of reactive oxygen species and improve plant resistance to water stress (Dolatabadian *et al.,* 2009). Foliar spray of ascorbic acid increased the transpiration rate in okra under drought stress (Amin *et al.,* 2009). Foliar application of ascorbic acid (150mM) increased water stress resistance and thereby decreased the adverse effect in sunflower (Ebrahimian and Bybordi, 2012). Malik and Ashraf (2012) noticed a higher net photosynthetic rate, lower degradation of chlorophyll pigments, transpiration and stomatal conductance in ascorbic acid treated wheat plants.

Homobrassinolide treatment (0.1 or 1 ppm) in wheat increased nitrate reductase and glutamine synthetase activity, chlorophyll content and soluble protein content under water stress which can be attributed through increased membrane stability, water balance and enzyme protein synthesis (Sairam, 1993; 1994). Soybean treated with brassinolide increased the concentration of soluble sugars, proline, peroxidase and superoxide dismutase activity under drought stress (Zhang *et al*., 2008). Epibrassinolide treatment in tomato (@ 1µM) increased the relative water content (RWC), net photosynthetic rate, antioxidant enzyme activity while it decreased stomatal conductance, intercellular CO_2 concentration, H_2O_2 content and malondialdehyde (MDA) thereby alleviating water stress (Feng *et al*., 2010). Increased photosynthetic rate, transpiration rate, stomatal conductance, relative water content, chlorophyll stability index, leaf area, leaf dry weight, plant height, number of spikes per plant, number of grains per ear, test weight and grain yield of wheat with brassinolide application (@1.5ppm) was reported by Dhayal *et al*., (2012). Seed treatment of ground nut with brassinolide (@1ppm) improved the stress tolerance by way of increasing relative water content and antioxidant enzyme (peroxidase, catalase, polyphenol oxidase) levels (Savalia *et al.,* 2013).

2.2.3. Effect of exogenous application of plant growth regulators on yield attributes and yield

Chlormequat had no effect on yield of drought susceptible wheat cultivars but increased the yield of tolerant cultivars under stressed conditions (Sairam *et al.,* 1991). Foliar application of CCC (@ 1000 ppm) at 25 DAS increased the grain yield of wheat under water stress (Sairam, *et al.,* 1992). Similarly, application of CCC increased the pod number and weight of seeds per plant of soybean ((El-Kheir *et al.,* 1994). Pandey and Yadav (1999) reported that higher grain yield in wheat as a result of application of CCC (@ 1000 ppm) can be due to increased relative water content (RWC), dry matter accumulation, leaf area, productive tillers, grain yield per plant and harvest index coupled with reduced stomatal conductance. Presoaking groundnut (‘Trombay’) seeds in CCC (10^{-6} M) solution for 6 hours resulted in higher yield under drought conditions (Mathew and Pandey, 2006). Wheat yield under water stress was increased by application of salicylic acid and chlormequat chloride (Jiriaie and Sajedi, 2012).

Foliar application of salicylic acid enhanced flowering and pod formation in soybean (Kumar *et al*., 1999). Exogenous application of salicylic acid (0.1, 0.5 and 1.0 mM) had a stimulatory effect on physiological traits (chlorophyll, flag leaf area, RWC) and grain yield of maize hybrids, and thus alleviated the adverse effect of drought stress (Elgamaal and Maswada, 2013). Foliar spray of salicylic acid (0, 150 and 300 µM) increased the RWC, total chlorophyll and seed yield of corn under stress (Yaghoubian *et al.,* 2014). Growth, yield and oil content of sesame can be improved by application of salicylic acid at low concentration (0.05 mM) (Athari and Talebi, 2014).

Foliar spray of ascorbic acid (@150 ppm) by withholding irrigation at 8-leaf stage and silk appearance stage of corn, increased the yield (Dolatabadian *et al.,* 2009).

NAA application (@ 25 ppm) increased number of pods and grains per pod in gram (Bangal *et al.*, 1982, 1983). Planofix (NAA) applied at 40 and 50 DAS, increased number of pods per plant, pod yield and 100 seed weight in groundnut (Singh and Sharma, 1982). Similar findings were noticed by Suty (1984) in faba bean and Bai *et al*. (1987) in *Vigna radiata* as a result of foliar spray of NAA. Devasenapathy *et al*. (1987) observed an increased number of pods per plant by spraying NAA (@ 40 ppm) in groundnut once either at 45 DAS or twice at 45 and 55 DAS. NAA application at flowering increased number of branches, average pod weight (Merlo *et al*., 1987) and 100 seed weight of soybean (Ravikumar and Kulkarni, 1988).

Foliar spray of NAA (@ 20 ppm) at bud initiation and pod formation stages of chickpea resulted in highest seed yield (2.35 t/ha) which can be due to reduced the flower drop percentage (Upadhyay *et al.*, 1993). Shukla *et al.* (1997) also reported a 17.7 per cent higher seed yield in soybean with a double spray of NAA. This is in line with the findings of Khanzada *et al.* (2002). NAA application (@ 4.5% *a.i*) at 80 per cent reduction in soil moisture depletion maintained yield and yield attributes (more pods and seeds per plant, 100 seed weight, biological and seed yield) in chickpea (Aslam *et al.,* 2010).

Verma *et al.* (2012) reported an increased biological as well as seed yield in chick pea with foliar spray of brassinolide (@1ppm) under drought stress. Increased number of spikes per plant, number of grains per ear, test weight and grain yield of wheat with brassinolide application (@ 1.5 ppm) was reported by Dhayal *et al*. (2012).

The foregoing review reveals that foliar application of different plant growth regulators in various crops has a positive influence on mitigating water stress.

2.3. Effect of seed priming on water stress mitigation

Seed priming is a water based process carried out to increase uniform germination and seedling emergence and thereby enhanced plant establishment. It leads to partial germination of seeds by soaking them in water or in salt solution for specified period of time, which can be brought back to original moisture content by air drying just before radicle emergence. Singh and Kumar (1992) reported that soaking of chickpea seeds in water (for one day) and drying back to original moisture, activated the enzyme activity and enhanced the protein synthesis. Priming stimulates many metabolic processes involved in early stages of germination. An increased rate of cell division in the root tips of wheat (Bose and Mishra, 1992) after osmopriming, can be the reason for faster emergence rate. Enhanced germination and improved seedling performance in tomato by seed treating with osmolytes was reported by Liu *et al.* (1996). Seedlings from primed seeds grow vigorously and perform better under adverse conditions (Desai *et al*, 1997).

Seed priming/seed hardening is also a practice adopted to alleviate the moisture stress by modifying the plants resistant to moisture stress. Seed hardening modify the physiological and biochemical nature of seeds, so as to get the characters favourable for drought tolerance. Usually inorganic salts like NaCl, Na_2SO_4, KCl, KH_2PO_4, $CaCl_2$ and $MgSO_4$ and organic acids like succinic acid, CCC and auxins are used as pre-hardening agents. Pre-sowing treatments also initiate the formation of vital biomolecules, stimulate mitochondrial activity and preserve cellular ultra structures which helps the plants to resist adverse edapho-climate conditions and results in higher rate of photosynthesis, lower rate of respiration, efficient root system with higher root shoot ratio, retain more water and thereby less yield reduction when subject again to drought.

2.3.1. Effect of seed priming on growth and development

Pre-sowing hardening of *Phaseolus* bean seeds in a $CaCl_2$ (10^{-2}M) solution mitigated the adverse effect of water stress (Kolev and Rzhankova, 1986). Arjunan and Srinivasan (1989) noticed increased germination, vigour index, root shoot ratio, dry matter accumulation and more number of mature pods per plant by seed hardening of groundnut kernel with one per cent calcium chloride under drought stress. Rangasamy *et al.* (1993) recommended $CaCl_2$ @ 0.4 per cent and CCC @ 0.2 per cent as the best chemicals for hardening pigeon pea, ground nut and cowpea seeds (soaking duration 4, 6 and 4 hours respectively). Higher germination percentage (94%) in black gram seeds treated with 1 per cent KH_2PO_4 was reported by Srimathi and Sujatha, (2005). Osmopriming with NaCl resulted in better seedling establishment and yield in hybrid sunflower (Hussain *et al*., 2006). Soaking pigeon pea seeds in 2 per cent either $CaCl_2$ or KCl was good under stress, due to early and uniform germination which in turn lead to better crop establishment (Selvi *et al.,* 2009). Seed hardening with $CaCl_2$ (@ 2 per cent) under water stress increased the seed yield in chick pea due to improved morpho-physiological traits like plant height, number of leaves, leaf area, total dry matter accumulation and harvest index (Manjunath and Dhanoji, 2011). Improved germination and vigour of mung bean seeds primed with KH_2PO_4 (@ 0.6%) under field conditions was reported by Umair *et al.* (2011). NaCl priming improved the drought stress tolerance of green gram (Jisha and Puthur, 2014).

Seed treatment with calcium chloride was found beneficial in ragi under water stress (Karivaratharaju and Ramakrishna, 1985). Seed hardening with one per cent sodium chloride for 12 hours improved the germination percentage, root-shoot ratio and vigour index of pearl millet (Sundaram and Kannaiyan (1989). Punithavathi and Palaniswamy (2001) noticed a higher germination per cent, shoot and root length, vigour index and dry matter production in ragi seeds soaked in one per cent concentration of either KCl or $CaCl_2$.

2.3.2. Effect of seed priming on physiological and biochemical parameters

Patil (1987) reported an increased drought resistance in sorghum by seed treatment with 2 per cent $CaCl_2$ (for four hours), which can be attributed to improved germination, seedling growth, relative water content and root shoot ratio. Manjunath and Dhanoji (2011) observed increased chlorophyll content, chlorophyll stability index, proline content, relative water content and lower specific leaf area in chick pea due to seed hardening with 2 per cent $CaCl_2$.

2.3.3. Effect of seed priming on yield attributes and yield

Increased groundnut yield by treating seeds with one per cent calcium chloride (for eight hours) was reported by Sashidhar *et al*. (1977). Similarly, a yield increment to the tune of 20 per cent over untreated control was noticed by Arjunan and Srinivasan (1989) through seed hardening of groundnut with 1 per cent $CaCl_2$. Manjunath and Dhanoji (2011) also obtained higher seed yield in chick pea by seed hardening with 2 per cent $CaCl_2$ compared to untreated control.

Pre-soaking crop seeds in 1 per cent KH_2PO_4 solution for 4 hours increased the grain yield compared to unsoaked seeds (TNAU, 1983). Sen and Misra (1987) reported an increased wheat yield by treating the seeds with $CaCl_2$ (@ 0.25 %). Similarly, improved drought resistance and grain yield was noticed by Patil (1987) in sorghum after seed treatment with 2 per cent $CaCl_2$ (for four hours) under dry land conditions. Yield and quality of hybrid sunflower was improved by osmopriming with NaCl (Hussain *et al*., 2006).

The foregoing review reveals that seed priming/osmopriming with NaCl, $CaCl_2$ and KH_2PO_4 has a positive influence on mitigating water stress in various crops.

2.4. Effect of mulching on water stress mitigation

In rainfed areas, judicious use of water is essential for increasing area under crop production. One of the promising agro techniques under this situation is the use of various moisture conservation measures. Mulching has been advocated as an effective means of soil moisture conservation as it acts as an insulating barrier which helps to check evaporation from the soil surface. Mulching is an agricultural technique in which the use of organic materials (plant residues-straw, hay, groundnut hulls, leaf and compost, peat, wood products-saw dust and animal manures), and synthetic materials (paper, polyethylene, wax coated papers, aluminium, steel foils and asphalt spray emulsions etc.) are involved for the purpose of increasing soil productivity. This technique modifies soil and air microclimate through temperature moderation, and protects the roots of plants from heat, cold or drought.

2.4.1. Effect of mulching on growth and development

Chaudhari *et al*. (2002) reported that straw mulching in rainfed pearl millet resulted in tallest plants with highest dry matter accumulation, number of tillers, grain and stover yield. Hudu *et al*. (2005) observed an increase in plant height in mulched tomatoes compared to those plants on bare soil. Both wheat straw mulching and black polyethylene mulching either separately or in combination under stress in cucumber plants improved the leaf area, chlorophyll content, fruit size, yield and plant dry matter due to limited soil evaporation thereby improving irrigation water use efficiency (Kirnak and Demirtas, 2006).

2.4.2. Effect of mulching on physiological and biochemical parameters

Mulched pepper plants showed improved photosynthesis (Thakur *et al.,* 2002) compared to non mulched ones. Sekhon *et al*. (2005) reported an increased leaf area index and chlorophyll content in soybean under wheat straw mulching. Silver mulches reflected most of the photosynthetically active radiation (PAR) and it was lowest in black mulches. The mean root zone temperature of pepper under the plastic mulch decreased with increasing percentages of reflected PAR (Diaz-Perez, 2010).

2.4.3. Effect of mulching on yield attributes and yield

Mulching with black polythene increased the seed yield and total dry matter production in *Vigna radiata* (Kumar *et al.*, 1995). Plastic film mulching along with kaolin spray recorded higher number of pods per plant, 100 pod and kernel weight, shelling percentage, oil percentage, haulm yield, kernel yield and harvest index (Chitodkar *et al.,* 2005). Sekhon *et al*. (2005) noticed an increased seed and biomass yield of soybean to the range of 4.4 to 68.3 per cent and 17 to 122 per cent respectively under wheat straw mulching in different cropping seasons due to increased leaf area index, chlorophyll content and number of pods per plant.

Maize yield was increased to the tune of 1000 and 500 kg/ha by black plastic mulching and grass mulching respectively (Bandy, 1980). Plastic film mulching in spring wheat increased the number of tillers, length of the growing period, spikelet and grain numbers per spike and the duration from flowering to harvest (Min-Li *et al.,* 1999). Mulching mitigates negative effects of water stress on plant growth and fruit yield in field grown strawberry, particularly in semi-arid situations (Kirnak *et al.,* 2001). Straw mulching increased the grain yield of rainfed bajra (Chaudhari *et al*., 2002).

2.4.4. Effect of mulching on soil moisture conservation

Mulching is one of the agronomic practices for conserving soil moisture and modifying soil physical environment. A temperature difference of 8°C was observed between mulched and unmulched plots (at 5 cm depth) in maize due to decrease in soil temperature and improved soil moisture retention (Lal, 1974). Higher moisture retention and early germination in spring wheat was noticed in plastic film mulching compared to non-mulch control (Min-Li *et al.,* 1999). Cook *et al.* (2006) also reported the beneficial effect of mulching on soil water and temperature regimes. Mulch application (at 0, 2, 4, 8 and 16 t/ha/year) increased the available water capacity, total porosity and soil moisture retention by 18–35, 35–46 and 29-70 per cent respectively. An optimum mulch rate of 4 t/ha was needed for improving porosity and 8 t/ha for increasing available water capacity, moisture retention and aggregate stability (Mulumba and Lal, 2008). Optimum soil and canopy thermal environment, relative water content, leaf water potential, specific leaf weight and root length density was maintained in wheat during dry periods under rice husk mulching which helped in attaining good yield with less water use, enhancing water use efficiency (Chakraborty *et al.,* 2008).

The foregoing review reveals that mulching either with polythene/plastic or plant residues has a positive influence on mitigating water stress in various crops.

2.5. Effect of antitranspirants on water stress mitigation

Antitranspirants are chemicals capable of reducing the transpiration rate in plants when applied to plant foliage. Kaolin is a non abrasive, non toxic aluminosilicate clay mineral that is formulated as a wettable powder. Gawish (1992) suggested that reflecting type antitranspitants were non toxic and effective for a longer period than stomatal closing types. Nakano and Uehara (1996) reported that kaolin spray decreased leaf temperature by increasing leaf reflectance and reducing transpiration in many plant species at high solar radiation levels. Limewater is the common name for a diluted solution of calcium hydroxide which also acts as a reflecting agent when applied on leaves. Atrazine is basically a herbicide, which in lower concentration act as an antitranspirant by inducing stomata closure (Arvin and Bahraminejad, 2008). Atrazine as antitranspirant reduces the crop growth, affect the closure and opening of leaf stomata, also forms thin layer on leaf surface.

2.5.1. Effect of antitranspirants on growth and development

Khaled *et al.* (1970) reported that a uniform white coating of kaolin (225 mg dm^{-2}) on the upper surface of Valencia orange leaves reduced transpiration (22–28%) by improved reflection of solar radiation thereby nullifying the adverse effect of moisture stress on dry matter production under high light intensities and also increased the water use efficiency by 32.8 per cent. Foliar applications of kaolin in sunflower improved the growth parameters by increasing the reflection of solar radiation and thereby reducing water loss through transpiration (Thakuria *et al.,* 2004a).

2.5.2. Effect of antitranspirants on physiological and biochemical parameters

Leaf temperature of rapeseed, treated with kaolin was lower than ambient air temperature which resulted in higher relative leaf water content (Patil and De, 1978). Tomato plants treated with kaolin resulted in 53 per cent reduction in stomatal conductance and thereby 21 per cent increase in marketable yield (Cantore, *et al*., (2009).

2.5.3. Effect of antitranspirants on yield attributes and yield

Atrazine (2-chloro-ethylamino-6-isopropylamino-s-triazine) application (@ 200 and 300 g/L) in sorghum twice, before and after flowering under limited irrigation increased the seed yield (Fuehring, 1973 and Fuehring, 1975). Yadav and Kumar (1998) reported an increased biological yield of corn plants by foliar spray of atrazine (@100ppm) under limited irrigation. Similar effect of atrazine on corn under limited irrigation was reported by Kazempour and Tajbakhsh (2002). Thakuria *et al*. (2004b) observed an increased seed yield in sunflower with application of atrazine. Application of atrazine (@100ppm) increased potato tuber yield under drought condition (Arvin and Bahraminejad, 2008). Foliar spray of atrazine (@ 120 g *a.i.*/ha) at seed filling stage of safflower increased the seed yield (Faramarzi *et al.,* 2010). Foliar application of atrazine (@ 80 and 120 g *a.i.*/ha) at flowering stage of rainfed safflower (cv. Sina), increased photosynthetic rate, seed and oil yield whereas a higher dose up to 160 g *a.i.*/ha showed toxic effect on seed and oil yield (Bagheri *et al*., 2012).

Foliar spray of lime @ 1 per cent to moisture-stressed ground nut plants resulted in higher pod yield over control (Reddy and Setty 1995).

Application of mulch + kaolin spray in ground nut resulted in highest yield (3.34 t/ha) and water use efficiency (Joshi *et al.,* 1987)**.** Naveen *et al.* (1992)

reported that 3 per cent kaolin spray on groundnut (at 35 and 55 DAS) during dry periods resulted in 139 per cent increase in yield over control. 'Kaolin' effectively increased the photosynthetic activity and water use efficiency of potato plants than 'Vaporgard' under drought stress (Moftah and Al-Humaid, 2005). Abd El – kader *et al.* (2006) reported an increased dry matter accumulation in banana with foliar application of kaolin. Application of kaolin (@ 6%), at flowering and seed formation stage of soybean under stress, increased plant height, node number, stem diameter, number of pods per plant, thousand seed weight, seed yield (23 per cent compared to control), biological yield and harvest index but did not affect the number of seeds per pod (Javan *et al.,* 2013).

The foregoing review reveals that antitranspirants like kaolin, atrazine and lime water spray has a positive influence on mitigating water stress in various crops.

2.6. Effect of nutrient management on water stress mitigation

Some of the main functions of mineral elements in plants include maintenance of charge balance, electron carriers, structural components, enzyme activation, and providing osmotic potential for turgor and growth. The detrimental effects of drought can be minimized by adequate and balanced supply of mineral nutrients. Mineral-nutrient status of plants plays a critical role in increasing plant resistance to drought stress (Marschner, 1995). Plants are unable to get optimal amount of nutrients, which in turn have negative effects on the growth and quality under soil moisture stress.

Drought results in increased generation of the reactive oxygen species (ROS) in stressed plants which increase the photooxidative effect and in turn damage the chloroplast membrane. Application of macronutrients like nitrogen, potassium, calcium and micronutrients like zinc, silicon and manganese reduce ROS toxicity by increasing the concentration of antioxidants like superoxide dismutase (SOD), catalase (CAT) and peroxidise (POD) in the plant cells. These antioxidants scavenge ROS thereby reduce photooxidation and maintain the integrity of chloroplast membrane which in turn increase photosynthetic rate in crops. Antioxidant enzymes like catalases and peroxidases have the ability to eliminate free radicals and protect damage to membranes and DNA in plant cells during abiotic stress conditions (Scandalios, 1994). Similarly, nutrients like phosphorus, potassium, magnesium and zinc improve the root growth which in turn increases the water uptake which helps in stomatal regulation and enhances the drought tolerance. Application of nutrients like potassium and calcium helps to maintain high tissue water potential and improve drought tolerance by osmotic adjustment. The micronutrients like copper and boron alleviate the adverse effects of drought indirectly by activating the physiological, biochemical and metabolic processes in the plants.

2.6.1. Effect of macronutrients on water stress mitigation

Macronutrients like nitrogen, potassium and calcium can reduce the toxicity of reactive oxygen species by increasing the concentration of antioxidant enzymes in the plant cells which help in mitigating water stress. Similarly, nutrients like phosphorus, potassium, magnesium and zinc improve the root growth which in turn increases water uptake and helps in stomatal regulation thereby enhancing drought tolerance. Application of nutrients like potassium and calcium help to maintain high tissue water potential under drought condition and improve drought tolerance by osmotic adjustment (Waraich *et al*, 2011a). When water level inside the plant declines below a threshold level, stomata get closed which leads to a decrease in transpiration, and consequent reduction in water transport through the plant. It affects the ability of roots to absorb water and nutrients (Waraich *et al*, 2011b). Drought induced nitrogen deficiency leads to inhibition of growth under water deficit (Heckathorn *et al.*, 1997) which in turn results in reduction in leaf size through decrease in cell number and size (MacAdam *et al,* 1989). Raun and Johnson (1999) suggested that inorganic fertilization will mitigate the adverse effects of water stress on crop growth and development.

Phosphorus is the principal element involved in plant energy processes due to its critical role in ATP (Adenosine triphosphate). Turner (1985) pointed that phosphorus deficiency seems to be one of the earliest effects of mild to moderate drought stress in soil grown plants. Dry soil condition reduces the uptake of phosphorus by crops (Pinkerton and Simpson, 1986) while its translocation is restricted even under mild water stress (Rasnick, 1970). Brooks (1986) noted that phosphorous deficiency induced reduction in leaf growth and photosynthetic rate can be attributed to decline in stomatal conductance and ribulose 1, 5 bisphosphate (RuBP) carboxylase regeneration capacity. Starch accumulation under phosphorus limited condition indicates that photosynthates are not used for plant growth (Fredeen *et al*., 1989). Relative leaf growth rate is one of the most sensitive parameter affected by phosphorus deficiency (Kirschbaum and Tompkins, 1990), which in turn affects the photosynthetic rate per unit area. Phosphorus deficiency also reduces the nitrate uptake and assimilation by the nitrate reductase (Pilbeam *et al*., 1993). Phosphorus being a constituent of nucleic acids, phospholipids, dinucleotides, and adenosine triphosphate, is required for the storage and transfer of energy, photosynthesis, enzyme regulation and transport of carbohydrates (Hu and Schmidhalter, 2001).

Potassium plays an important role for the survival of plants under stress conditions. Potassium is essential for photosynthesis, translocation of photosynthates to sink, maintenance of turgour, activation of enzymes, and reducing excess uptake of ions such as sodium and iron from saline and flooded soils (Mengel and Kirkby, 2001). Drought stress induced ROS production will be enhanced, due to potassium deficiency induced disturbances in stomatal opening, water relations, and photosynthesis (Mengel and Kirkby, 2001). Furthermore, chloroplasts lose high amounts of potassium under drought conditions which will depress photosynthesis (Sen Gupta and Berkowitz, 1987). Increase in severity of drought stress result in corresponding increase in potassium demand to maintain photosynthesis and protect chloroplasts from oxidative damage.

2.6.1.1. Effect of application of macronutrients on growth and development

Nitrogen application helps in effective carbon partitioning which increases the accumulation of soluble sugars, especially starch and it improves leaf growth (Rufty *et al,* 1988). Disturbance in protein metabolism was reported by Ranieri *et al.* (1989) as a result of water stress. Reduced protein content of wheat under water stress conditions was due to increased RNAase activity induced by dehydration (Martin and Dasilva, 1972). Verga *et al*. (1992) reported that soil application of nitrogen before sowing increased the protein content in soybean and no change was observed when applied during later developmental stages. Similarly, increased protein and starch content in wheat with urea application was observed by Kettlewell and Juggins (1992). Trapni *et al*. (1999) observed that high nitrogen availability increased cell division and expansion which led to increased leaf area in sunflower. Lawlor (2002) reported that adequate nitrogen supply determines plant metabolic processes, based on proteins, leading to increase in vegetative/reproductive growth and yield.

Leaf turgor and stomatal conductance in cotton was altered by phosphorus nutrition (Radin, 1984). Application of phosphorus improved plant growth under drought conditions (Garg *et al.,* 2004). Ajouri *et al*. (2004) reported that seed priming with solutions containing phosphorus under drought conditions improved the establishment of barley. Phosphorus improves the root growth which results in increased water and nutrient uptake. This increases nitrate reductase activity which in turn improves nitrate assimilation under drought condition. Phosphorus also improves cell turgidity in crops by maintaining high leaf water potential which in turn increases the stomatal conductance and photosynthetic rate under drought (Waraich *et al*., 2011a).

Potassium is essential for the translocation of photo assimilates to roots and thereby increased water uptake. Govindan and Thirumurugan (2000) revealed that growth parameters like plant height, leaf area index and dry matter production in green gram were higher with foliar spray of KCl (@ 1%).

2.6.1.2. Effect of application of macronutrients on physiological and biochemical parameters

Changes in leaf photosynthesis in response to variations in nitrogen supply was observed by Goudriaan and Keulen (1979) and Just *et al.* (1989), which can be attributed to the influence of lamina nitrogen on leaf photosynthesis (Sinclair and Horie, 1989). Higher nitrogen application to water-stressed plants improved nitrate uptake and increased nitrate reductase activity (Kathju *et al.,* 1990). Marschner (1995) observed increased antioxidative defense mechanisms resulting in reduced photooxidation of chloroplast pigments, and reduced leaf senescence by nitrogen application. Nitrogen deficiency reduces photosynthesis which can be attributed to reduced chlorophyll contents and rubisco activity (Toth *et al.,* 2002). Nitrate reductase, the enzyme needed for nitrogen assimilation, decreased under water-stress in sunflower (Azedo-Silva *et al*., 2004) and in wheat (Larsson *et al*., 1989).

The positive effects of phosphorus on plant growth under drought was attributed to increased stomatal conductance (Bruck *et al.,* 2000), photosynthesis (Ackerson, 1985), higher cell-membrane stability and water relations (Sawwan *et al*., 2000).

Plants suffering from drought have a larger internal requirement for potassium (Cakmak and Engels, 1999) as it is required for maintenance of photosynthetic CO_2 fixation. Sufficient potassium in plants under drought stress improved photosynthesis (Sen Gupta *et al.,* 1989). Similar results in legumes were observed by Sangakkara *et al.,* (2000). Decreased grain yield in crops under restricted irrigation was eliminated by increased potassium supply (Abd El-Hadi *et al*., 1997). Increased crop tolerance to water stress by effective utilization of soil moisture under potassium nutrition was noticed by Waraich *et al* (2011a).

Osmotic potential and cell turgidity was maintained by potassium (Lindhauer, 1995) and it regulates the functioning of stomata under water stress conditions (Kant & Kafkafi, 2002). This in turn enhances the photosynthetic rate, plant growth and yield under stress conditions (Egila *et al.,* 2001). Cakmak (1997) revealed the maintenance of high pH in stroma and reduced photooxidative damage to chloroplasts by potassium supply under stress. An adequate potassium supply increase root elongation, induce solute accumulation, maintain cell membrane stability, turgidity and relative water content thus facilitate osmotic adjustment, and thereby improve the ability of plants to tolerate drought stress.

Balakrishnan *et al.* (1993) found that KCl sprays (@1%) resulted in higher yield (which was positively correlated with proline content) and dry matter production in brinjal. Foliar spray of 3 per cent KCl as stress mitigating agrochemical, improved the nitrate reductase activity in sugarcane (Patil *et al.,* 2010)**.**

Ashry *et al.* (2005) reported that potassium spray in wheat reduced the negative effect of drought on growth and yield through its role in photosynthesis, protein synthesis, control of ionic balance, enzyme activation, plant stomatal regulation and water use. Zareian *et al.* (2013) also noticed the positive effects of 3 per cent K_2O spray in wheat plants by way of highest values for net photosynthesis, leaf stomatal conductance and transpiration rate.

2.6.1.3. Effect of application of macronutrients on yield attributes and yield

Soil application of inorganic fertilizers along with 2 per cent diammonium phosphate (DAP) spray (at flowering and 15 days after the first spraying) resulted the highest plant height, branches and pods per plant, seeds per pod, 1000-seed weight, dry matter production, seed yield, net income and benefit: cost ratio in rainfed cowpea (Parasuraman, 2001). Similar findings were reported by Bhowmick (2006) in rainfed chickpea and Bhowmick (2008) in lentil as a result of foliar spray of diammonium phosphate. Higher number of pods per plant, seeds per pod, pod and seed dry weight and seed yield was obtained in mung bean by foliar application of potassium under water stress (Thalooth *et al*., 2006). Black gram in rice fallows which received the foliar spray of 2 per cent DAP +1 per cent KCl at flowering and pod filling stages of crop growth recorded the highest yield attributes and yield (Geetha and Velayutham 2009). Foliar spray of potassium at any critical crop growth stage of wheat under drought increased the grain yield (Aown *et al.,* 2012). Foliar application of KCl in sunflower (at anthesis stage) under drought increased the achene yield due to water conservation (Hussain *et al*., 2012). Application of inorganic fertilizers along with foliar spray of 2 per cent DAP and 0.5 per cent chelated micronutrients (Zn, Fe, B and Mo), in rainfed black gram, resulted in higher growth parameters, yield and B:C ratio (Shashikumar *et al*., 2013).

2.6.2. Effect of micronutrients on water stress mitigation

Micronutrients activate certain physiological, biochemical and metabolic processes in plants which help the macro nutrients in alleviation of drought. Zinc is an important micronutrient essential for plant growth and development. Maize plants grown under zinc deficiency showed symptoms such as stunted stems and chlorotic leaves (Liu, 1996). The different mechanisms by which zinc nutrition minimize the detrimental effects of drought in crop plants includes 1) influence auxin levels as it is a co-enzyme for production of tryptophane, a precursor to the formation of auxin. Increased auxin level due to zinc application enhances the root growth which in turn improves the drought tolerance in plants 2) zinc application reduce the activity of membrane-bound NADPH oxidase and enhance antioxidant enzymes (superoxide dismutase (SOD), catalase (CAT) and peroxidise (POD)) which in turn decreases the photoxidation damage caused by ROS under water stress.

A primary function of boron is related to cell wall formation in plants. Boron improves drought tolerance in plants by improving sugar transport, flower retention, pollen formation and seed germination and it leads to increased seed and grain production. Boron nutrition under drought condition reduces stunting (resetting), barren ears (due to poor pollination), hollow stems and hollow heart in fruits.

2.6.2.1. Effect of application of micronutrients on growth and development

Zinc plays an important role in biomass production of tomato (Kaya and Higgs, 2002). Thalooth *et al.* (2006) noticed an improved height, number of leaves, branches and pods per plant by spraying mung bean plants with zinc (300 ppm Zn-EDTA), potassium (2% KNO_3) and magnesium (50 ppm $MgSO_4$) at 30 and 50 DAS, due to its favorable influence of enzyme action, photosynthetic pigments, biological activity and metabolism. Zinc is needed for chlorophyll production, pollen function, fertilization and germination (Cakmak, 2008). Foliar application of zinc sulfate and manganese sulfate (@ 3000mg/L) under water stress increased the germination and seed protein concentration in safflower (Dehnavy *et al.,* 2009).

2.6.2.2. Effect of application of micronutrients on physiological and biochemical parameters

Zinc deficiency reduced the transpiration rate of pecan plants (Hu and Sparks, 1991). Zinc deficiency decreased the stomatal conductance, intercellular CO_2 concentration and there by photosynthesis in cauliflower whereas it lowered osmotic potential and increased water saturation deficit in cabbage (Sharma *et al.,* 1994). Reduced photosynthesis as a result of decreased carbonic anhydrase activity due to zinc deficiency was reported by Fischer *et al.* (1997) and Hacisalihoglu *et al.* (2003). Foliar spray of zinc in mung bean enhanced photosynthesis, improved nitrogen fixation, grain protein and yield (Ved *et al.*, 2002). Zinc influences auxin level which in turn enhances the root growth thereby improving drought tolerance in plants (Bennett and Skoog, 2002). Zinc application reduces the activity of membrane-bound NADPH oxidase which in turn decreases photoxidation damage by ROS and also enhances the activities of antioxidant enzymes (Waraich *et al*, 2011b).

Foliar spray of boric acid (@ 10ppm) on radish leaves increased the soluble and total sugars, polysaccharides, phosphorus, magnesium, calcium and boron contents, but decreased the total soluble nitrogen, copper and iron content under water stress (Abdalla *et al.,* 1992). Nitrate reductase activity, in water stressed soybean plants increased with foliar application of boron (@ 0.45 kg/ha) (Bellaloui, 2011). Karim *et al.* (2012) noticed an increased photosynthetic rate, pollen viability, number of fertile spikes, grains per spike, and water use efficiency (WUE) in wheat by foliar application of micronutrients (zinc, boron and manganese).

2.6.2.3. Effect of application of micronutrients on yield attributes and yield

Zinc application increased the grain yield of drought resistant chickpea genotypes (Khan *et al.*, 2003). Mahobia *et al.* (2005) obtained highest seed and stalk yield in rainfed pigeon pea by foliar spray of borax (@ 1000 ppm) at 50 per cent flowering and 20 days thereafter. Zinc application in mung bean plants increased the straw and biological yield under water stress (Thalooth *et al*., 2006). Foliar application of zinc and boron in wheat increased the grain yield under drought (Karim *et al.,* 2012). Similarly, foliar spray of zinc sulphate (@ 1 per cent) in sunflower under water stress resulted in increased seed yield (Shahri *et al*., 2012)**.** Zarmehri *et al.* (2013) observed that zinc sulphate application in maize improved the cob weight and grain yield under water stress. Zinc sulphate spray (@ 1.5 per cent) increased the seed yield and relative water content to the tune of 5 per cent and 7 per cent respectively compared to no spray in corn under stress (Vazin, 2012).

The foregoing review reveals that foliar spray of macro and micro nutrients has a positive influence on mitigating water stress in various crops.

2.6.3. Effect of biofertilizers on water stress mitigation

A biofertilizer contains living microorganisms which when applied to seeds, plants, or soil, colonizes the rhizosphere or interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant. Some of the biofertilizers such as Rhizobium, Azotobacter, Azospirilium and blue green algae (BGA) have been in use for a long time. Similarly, plant growth promoting rhizobacterias (PGPRs) are important group of microorganisms used in biofertilizers as they inhabit the rhizosphere of plants for nutrients from plant root exudates. They helps in (1) increased plant growth by way of soil nutrient enrichment by nitrogen fixation, phosphate solubilization, siderophore production and phytohormones production (2) increased plant protection by influencing various enzyme (cellulase, protease, lipase and β-1,3 glucanase) production and enhance plant defense by triggering induced systemic resistance against pests and pathogens. Furthermore, PGPR microbes also contain some useful variation for tolerating abiotic stresses like extremes of temperature, pH, salinity, drought, heavy metal and pesticide pollution.

The plant growth promoting rhizobia mainly belongs to the family Rhizobiaceae, Phyllobacteriaceae and Bradyrhizobiaceae. Vessey (2003) categorized the plant growth promoting bacteria as extracellular PGPR (ePGPR) and intracellular PGPR (iPGPR). Extracellular PGPR includes the genera *Bacillus, Pseudomonas, Erwinia, Caulobacter, Serratia, Arthrobacter, Micrococcus, Flavobacterium, Chromobacterium, Agrobacterium, Hyphomycrobium* and intracellular PGPR includes the genera *Rhizobium, Bradyrhizobium, Sinorhizobium, Azorhizobium, Mesorhizobium* and *Allorhizobium.* Beneficial role of endophytic bacteria in agricultural crops, including growth promoting activity, modulation of plant metabolism and phytohormone signalling, leading to adaptation to environmental abiotic or biotic stress was reported by Miliute *et al.* (2015).

Ashraf *et al*. (2004) found that plant growth promoting rhizobacteria (PGPR) strains induced drought stress tolerance in wheat plants. PGPRs having the enzyme 1-aminocyclopropane-1-carboxylic-acid (ACC) deaminase can increase the availability of phosphorous and iron through phosphatase enzymes and siderophore production and can produce indole-3-acetic acid (IAA) (Yang *et al.,* 2009). Cucumber plants treated with PGPR strains (*Burkholdera cepacia, Acinetobacter calcoaceticus* and *Promicromonospora* sp.) showed an ameliorative effect, by maintaining the growth under drought stress (Kang *et al*., 2014).

Pseudomonas fluorescens promotes plant growth by producing phytohormones (auxin (IAA), gibberellins and cytokinins), specific amino acids and other growth promoters (Marschner and Timonen, 2006). Arshad *et al.* (2008) observed that they have the high capacity for phosphate solubilization, and certain strains of *Pseudomonas fluorescens* promote the ACC deaminase activity, which helps the plant to resist drought stress. PGPRs improve water retention and soil aggregation around the plants roots, which in turn helps to increase the plants' tolerance to many abiotic and biotic stresses, including drought stress (Timmusk *et al.,* 2013).

2.6.3.1. Effect of biofertilizers on growth and development

Plant growth promoting rhizobacteria (*Bacillus, Pseudomonas, Achromobacter, Acetobacter, Azospirillum, Burkholderia, etc*.) are capable of producing different plant hormones (auxins, gibberellins, cytokinins, and ethylene) which contribute to increase in growth and development in plants under abiotic stress (Bashan and de-Bashan, 2005). Jaleel *et al.* (2007) reported an increased fresh and dry weight of *Catharanthus roseus* by *Pseudomonas fluorescens* treatment (@ 1 ppm) under drought stress. Hayat *et al*. (2010) found that inoculation of bacterial strains in plant species helped in vigorous root growth (formation of lateral roots and root hairs), which enhanced the capacity of plants to tolerate various abiotic stresses. *Pseudomonas fluorescens* increased the vigour index, fresh and dry weight of green gram seedlings by improving the antioxidant enzyme activity and by greater accumulation of proline under water stress conditions (Saravanakumar *et al.,* 2011). Maize plants inoculated with *Pseudomonas fluorescens* strain '153' enhanced phytohormone (abscisic acid, auxin, gibberellin and cytokinin) and proline content in the leaves under water deficit stress condition (Ansary *et al*., 2012). Certain bacterial strains colonize the rhizosphere of various plant species and promote plant growth by improving soil structure and moisture retention as well as by enhancing plant mineral nutrient absorption (Kim *et al.* 2012).

Root associated PGPRs with ACC deaminase activity, degrade ACC, the precursor for ethylene and thereby stimulate plant growth by reducing ethylene production under stress (Glick *et al.,* 2007). Mayak *et al.* (2004) noticed that PGPR strain with ACC deaminase (*Achromobacter piechaudii* 'ARV8'), when inoculated to pepper and tomato, conferred induced systemic tolerance against drought. Lettuce plants infected with *Pseudomonas mendocina* and *Glomus intraradices* showed high antioxidant enzyme activity which contributed to enhanced tolerance against drought (Kohler *et al.* 2008). Increased plant growth, nitrogen content, and nodulation in common bean, by improving hormone balance and stomatal conductance due to co-inoculation of *Rhizobium tropici* and *Paenibacillus polymyxa* under drought stress was observed by Figueiredo *et al.* (2008).

2.6.3.2. Effect of biofertilizers on physiological and biochemical parameters

PGPR (*Rhizobium japonicum*, *Azotobacter chroococcum* and *Azospirillum brasilense*) application in soybean improved the membrane stability, chlorophyll content, nitrogen content and diminished proline accumulation (Abbasi *et al*., 2013). Inoculation of soybean plants with PGPRs showed a decrease in antioxidant enzyme activity but was found to be the best under drought stress (Abbasi and Zahedi, 2013). Use of plant growth promoting rhizobacteria during water stress in barley led to an increase in membrane stability (Rezaei and Pazoki, 2015).

Proline, soluble carbohydrates and chlorophyll content in basil plants treated with *Pseudomonas* sp. and *Bacillus lentus* increased with increase in water stress (Heidari *et al.,* 2011). Alfalfa plants inoculated with engineered strains of *Sinorhizobium meliloti* (with *ipt* gene) showed an elevated zeatin concentration and antioxidant enzymes in their leaves which helped in better survival under severe drought conditions (Xu *et al*., 2012). Sarma and Saikia (2013) found that *Pseudomonas aeruginosa* ('GGRJ21') strain in mung bean improved water stress tolerance by accelerating the accumulation of antioxidant enzymes, cell osmolytes, and by upregulation of stress responsive genes under water stress. Relative water content, net photosynthetic rate, stomatal conductance and grain yield of chickpea was improved with inoculation of rhizobium and PGPRs (Jabbari and Khaleghnezhad, 2014).

2.6.3.3. Effect of biofertilizers on yield attributes and yield

Treating *Catharanthus roseus* seedlings with native PGPRs, can be used for enhancement of biomass yield and alkaloid contents as it provides an eco-friendly approach under water deficit stress (Jaleel *et al.,* 2007). Inoculation of chickpea seeds with rhizobium strains and PGPR resulted in better water relations and photosynthetic rate which finally led to more grain yield (Jabbari and Khaleghnezhad, 2014).

The foregoing review reveals that seed inoculation with PGPR+ Rhizobium and *Pseudomonas* has a positive influence on mitigating water stress in crop plants.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Field experiments were conducted during the summer season (January to March) of the year 2014 and 2015, to evaluate various agrotechniques for mitigating water stress in vegetable cowpea (*Vigna unguiculata* (L.) Walp.). There were three experiments in the first year, from which the best treatments were selected and their individual and possible combinations were evaluated in an experiment in the subsequent year. The details of the materials used and the methods adopted for the study are presented in this chapter.

3.1. Details of the study area

3.1.1. Cropping history of the experimental site

The study area was under bulk banana crop before the first year experiment, and under bulk cassava crop before the second year experiment.

3.1.2. Location

The experiment was conducted at the Agronomy Research Farm of College of Horticulture, Kerala Agricultural University. Geographically, the area is situated at 10^0 31'N latitude and $76^0$13'E longitude and at an altitude of 40.3m above mean sea level.

3.1.3. Climate and weather

The experimental site enjoys typical humid tropical climate. The weather data recorded during the cropping period (January to March 2014 and 2015) are given in Appendix - I & II and illustrated in Fig.5. In the first year of experimentation, there was no rainfall during the entire crop period. The maximum and minimum temperature was 34.8^0C and 23.4^0C respectively and the wind speed was 5.1km/hr. In the second year of experimentation also, there was no rainfall upto 67 DAS with include the stress imposed period. However, a total rainfall of 77.6mm was received during the rest of the crop period. The maximum and minimum temperature was 34.2^{0}C and 23.3^{0}C respectively and the wind speed was 4.9km/hr.

3.1.4. Soil

The soil of the experimental site is sandy clay loam in texture (Order: Ultisol). Physico-chemical properties of the soil are given in Table- 1.

Table-1. Physico-chemical properties of the soil

Particulars	**Content**		**Method used**
A) **Particle size composition**			
Sand (%)	57.20		Robinson international pipette method (Piper, 1966)
Silt (%)	19.64		Robinson international pipette method (Piper, 1966)
Clay (%)	23.16		Robinson international pipette method (Piper, 1966)
Field capacity (%)	12		Field Method (Michael, 2009)
Permanent wilting point (%)	5		Sunflower Method (Michael, 2009)
Bulk density (Mg/m^3)	1.58		Core sampler Method (Michael, 2009)
B) **Chemical composition**	First year	Second year	**Method used**
pH	5.4	5.6	1:2.5 soil water ratio Beckman glass electrode (Jackson,1958)
Organic C (%)	1.2	1.4	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	156.1	262.8	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg/ha)	21.9	17.6	Bray-1 Extractant Ascorbic acid reductant method (Watnabe and Olsen, 1965)
Available K_2O (kg/ha)	378.8	315.3	Neutral Normal Ammonium Acetate extractant flame photometry (Jackson, 1958)
Available Na ((kg/ha)	BDL*	BDL*	Flame photometry (Jackson, 1958)
Available Ca (mg/kg)	179.5	218.7	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available Mg (mg/kg)	99.1	131.6	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available S (mg/kg)	2.14	3.32	$CaCl_2$ extract- turbidimetry method (Chesnin and Yein, 1951)
Available Fe (mg/kg)	7.53	6.01	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available Mn (mg/kg)	57.7	48.1	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available Zn (mg/kg)	1.82	2.1	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available Cu (mg/kg)	5.52	5.67	Atomic Absorption Spectrophotometer (Jackson, 1958)
Available B (mg/kg)	0.53	0.53	Hot water soluble boron (Tandon,1993)

*BDL- Below Detectable Level

3.2. Materials

3.2.1. Variety

The vegetable cowpea variety *Kashi Kanchan,* released from Indian Institute of Vegetable Research, Varanasi was used for the experiment. It is a bush type (height 50-60 cm), photo-insensitive, early flowering (40-45 days after sowing), short duration (65-70days) vegetable cowpea variety which bears dark green, soft and fleshy pods with less fibre content. Pods are about 30-35 cm long, tender and bears about 40–45 pods/plant. The variety gives green pod yield of about 8-10 t/ha under favorable situations.

3.2.2. Plant Growth Regulators

Plant Growth Regulators	Trade name	Source
CCC (Cycocel)	Lihocin	BASF India Ltd.
Salicylic acid	Salicylic acid	Nice Chemicals Pvt. Ltd.
Ascorbic acid	Ascorbic acid	Merck Specialities Pvt. Ltd.
NAA (Naphthaleneacetic acid)	NAA	Sisco Research Laboratories Pvt. Ltd.
Brassinolide	Double	Godrej Agrovet Ltd.
Coconut water	-	College farm

3.2.3. Seed primers, mulches and antitranspirants

Materials used	Source
A. Seed primers	
$CaCl_2$	Merck Specialities Pvt. Ltd.
NaCl	Merck Specialities Pvt. Ltd.
KH_2PO_4	Merck Specialities Pvt. Ltd.
B. Mulches	
Plastic mulch	Pauljo Pvt. Ltd., Irinjalakuda
Plant residue mulch	College farm
C. Antitranspirants	
Kaolin	Loba Chemic Pvt. Ltd.
Lime water spray ($Ca(OH)_2$)	Nice Chemicals Pvt. Ltd.
Atrazine	TNAU

3.2.4. Nutrient sources

Nutrient sources	Source
FYM	College farm
PGPR mix I and rhizobium	CoA, Vellayani
Pseudomonas	BCCP, CoH, Vellanikkara
DAP	TNAU
KCl	Nice Chemicals Pvt. Ltd.
$ZnSO_4$	Merck Specialities Pvt. Ltd.
Boric acid	Merck Specialities Pvt. Ltd.

3.3. Experiment details

There were three experiments in the first year (Jan – Mar 2014) from which the best treatments were selected and their individual and possible combinations were evaluated in a single experiment in the subsequent year (Jan – Mar 2015). The treatment details of three experiments are given below.

3.3.1. Experiment I

First experiment was conducted to study the effect of exogenous application of plant growth regulators in mitigating water stress in vegetable cowpea. The experiment was laid out in randomized block design (RBD) with 15 treatments replicated thrice. The plant growth regulators tried and the dosages used are given in Table-2.

Table- 2. Treatment details of first experiment

Tr. No.	Treatments	Dosage
1	CCC (Cycocel)	10 mg/L
2	CCC (Cycocel)	20 mg/L
3	Salicylic acid	1%
4	Salicylic acid	2%
5	Ascorbic acid	1%
6	Ascorbic acid	2%
7	NAA (Naphthaleneacetic acid)	20 mg/L
8	NAA (Naphthaleneacetic acid)	40 mg/L
9	Brassinolide	0.5 mg/L
10	Brassinolide	1 mg/L
11	Coconut water	500 L/ha
12	Water spray	500 L/ha
13	Control (Irrigation at 5 days interval)	
14	Farmers' practice (Irrigation at 2 days interval)	
15	Control (Irrigation at 5 days interval with no irrigation during water stress imposed period)	

3.3.2. Experiment II

Second experiment was conducted to study the effect of seed priming, antitranspirants and moisture conservation practices in mitigating water stress in vegetable cowpea. The experiment was laid out in randomized block design (RBD) with 11 treatments replicated thrice. The different seed primers, antitranspirants and mulches tried are given in Table-3.

Table- 3. Treatment details of second experiment

Tr. No.	Treatments
1	Seed priming with 2% $CaCl_2$
2	Seed priming with 0.5% NaCl
3	Seed priming with 1% KH_2PO_4
4	Mulching (plastic)
5	Mulching (plant residues)
6	Kaolin spray (2%) at 25 DAS
7	Lime water spray (2% $Ca(OH)_2$) at 25 DAS
8	Atrazine spray (0.1kg/ha) at 25 DAS
9	Control (Irrigation at 5 days interval)
10	Farmers' practice (Irrigation at 2 days interval)
11	Control (Irrigation at 5 days interval with no irrigation during water stress imposed period)

3.3.3. Experiment III

Third experiment was conducted to study the effect of nutrient management in mitigating water stress in vegetable cowpea. The experiment was laid out in randomized block design (RBD) with 12 treatments replicated thrice. The various nutrient management practices tried are given in Table- 4.

Table 4. Treatment details of third experiment

Tr. No.	Treatments
1	FYM alone @ 20t/ha as basal and @ 2t/ha at fortnightly interval
2	PGPR mix I with rhizobium as seed treatment
3	Pseudomonas (1%) as soil drenching at sowing + foliar spray at 25 days after sowing
4	2%DAP as foliar spray at 25 days after sowing
5	1% KCl as foliar spray at 25 days after sowing
6	2% DAP+1% KCl as foliar spray at 25 days after sowing
7	0.5% $ZnSO_4$ as foliar spray at 25 days after sowing
8	0.2% Boric acid as foliar spray at 25 days after sowing
9	PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)
10	Control (Irrigation at 5 days interval)
11	Farmers' practice (Irrigation at 2 days interval)
12	Control (Irrigation at 5 days interval with no irrigation during water stress imposed period)

3.3.4. Experiment IV

The promising treatments from the above three experiments conducted during the first year were selected and their combination effect were studied during the subsequent year. The experiment was laid out in randomized block design (RBD) with 18 treatments replicated thrice. The various management practices tried are given in Table- 5.

Table 5. Treatment details of fourth experiment

Tr. No.	Treatments
1	Seed priming with 0.5% NaCl
2	PGPR mix I with rhizobium as seed treatment
3	Mulching with plant residues
4	Water spray
5	Salicylic acid 2% spray
6	DAP 2% + KCl 1% spray
7	$ZnSO_4$ 0.5% spray
8	Lime water spray 2%
9	Seed priming with 0.5% NaCl + mulching with plant residues
10	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues
11	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues +water spray
12	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues + salicylic acid 2% spray
13	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues + DAP 2% + KCl 1% spray
14	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues + $ZnSO_4$ 0.5% spray
15	Seed priming with 0.5% NaCl + PGPR mix I with rhizobium as seed treatment + mulching with plant residues + lime water 2% spray
16	Control (Irrigation at 5 days interval with no irrigation during water stress imposed period)
17	Control (Irrigation at 5 days interval)
18	Farmers' practice (Irrigation at 2 days interval)

3.4. Methods

The details of various field operations from land preparation to harvest are given below.

3.4.1. Land preparation, manure and fertilizer application and sowing

The selected area for the experiments was ploughed; stubbles were removed and levelled. At the time of final ploughing, farm yard manure @ 20 t/ha was applied uniformly and incorporated well into the soil. The first year experiments were conducted in mini plots of size 1.5m x1.5m (Fig.1, 2, 3). The second year experiment was conducted in plots of size 3.6m x3.6m (Fig.4). All the plots were separated each other by a distance of one meter in order to prevent the seepage of irrigation water from one plot to other. Fertilizers were applied @ 20:30:10 kg N, P_2O_5 and K_2O /ha respectively in the form of urea, factomphos and muriate of potash as basal dose before sowing. The seeds were dibbled at a spacing of 30cm x 30cm.

3.4.2. Irrigation

After sowing the plots were irrigated daily upto five days after sowing for uniform germination of seeds and thereafter all treatment plots other than control plots in first, third, fourth experiments and antitranspirant sprayed plots of second experiment were irrigated at 5 days interval with skipping irrigation at 20, 25, 30 and 35 DAS to impose water stress. In second experiment, plots sown with primed seeds and mulched plots were irrigated at 10 days interval. Irrigation was given at 2cm depth.

3.4.3. Plant growth regulators, coconut water and water spray

In the first experiment, the plant growth regulators (CCC, salicylic acid, ascorbic acid, NAA and brassinolide), coconut water and water were sprayed using a knap sack sprayer as per treatments on 25th day after sowing (10 days after imposing water stress). Spray fluid used was 500L/ha.

3.4.4. Seed priming, mulching and antitranspirant spray

In the second experiment, for priming, seeds were soaked in solutions of 2% $CaCl_2$, 0.5% NaCl and 1% KH_2PO_4 for four hours, dried under shade before sowing. Plastic mulching was done with polythene mulch material having silver top and black bottom with 30 micron thichness and plant residue mulching was done with cut grass at 2.5 inch thickness at 5 DAS. Antitranspirants (kaolin, lime water and Atrazine) were sprayed on 25th day after sowing (10 days after imposing water stress). Spray fluid used was 500L/ha.

3.4.5. Application of nutrient sources

In the third experiment, seeds treatment with PGPR mix I and rhizobium @ 50g/kg seeds was done by mixing the seeds with culture using minimum quantity of water and dried under shade for 10-15 minutes before sowing. Soil drenching of pseudomonas @1kg/acre was done by mixing it well with FYM in the ratio 1:20 and applied in soil at the time of sowing. In the FYM alone treatment, an additional dose of FYM @ 2t/ha was applied at fortnightly interval by applying the same at the base of the plants followed by earthing up. Foliar spray of nutrients (DAP, KCl, ZnSO4 and Boric acid) as per treatments was done on 25th day after sowing (10 days after imposing water stress). Spray fluid used was 500L/ha.

In the fourth experiment, the treatments were applied as in the first year experiments. All treatment plots including seed priming and mulching were irrigated at 5 days interval with skipping irrigation at 20, 25, 30 and 35 DAS to impose water stress.

3.4.6. After cultivation

Gap filling was done on 4th day after sowing to maintain the plant population. One weeding was done at 15 DAS.

3.4.7. Plant protection

Aphid attack was noticed during both the years which was controlled by spraying Confidor @ 0.5ml/L during first year and Tagfolder @ 4ml/L during second year.

3.4.8. Harvesting

Vegetable pods were harvested by picking as and when they matured.

3.5. Observations recorded

3.5.1. Growth parameters

From each net plot, five plants in the first year and 10 plants in the second year were selected randomly and marked for recording the biometric observations. Plant height, number of leaves and number of branches were recorded at 15 days interval, leaf area at 20 days interval upto 60 DAS.

3.5.1.1. Plant height

Plant height was measured from ground level to the tip of growing point and the mean was expressed in cm.

3.5.1.2. Number of leaves

Number of fully opened leaves in the plants was counted and the mean was recorded.

3.5.1.3. Number of branches

Total number of branches in the plants was counted and the mean was recorded.

3.5.1.4. Leaf area index

Total leaf area of selected plants was measured using Li-cor leaf area meter and the leaf area index was expressed as the ratio of leaf area to unit land area.

$$\text{Leaf area index(LAI)} = \frac{\text{Leaf area}}{\text{Land area}}$$

3.5.1.5. Dry matter accumulation

Three plants from each plot were uprooted, air dried and oven dried (80 ± 5^0C) for 24 hours till constant weight was achieved and dry weight was recorded and expressed as kg/ha.

3.5.1.6. Days to flowering

Number of days taken for 50% of the plants to flower in each plot was recorded.

3.5.1.7. Root: shoot ratio

The plants for recording drymatter accumulation were separated into stems and roots and dry weight recorded separately. From this, root: shoot ratio was worked out.

$$\textbf{Root: shoot ratio} = \frac{\textbf{Dry weight of root}}{\textbf{Dry weight of shoot}}$$

3.5.1.8. Root length

The root length of the plants used for recording drymatter accumulation and root: shoot ratio was measured from base of the plant to the tip of the longest root and the mean was expressed in cm.

3.5.2. Yield and yield attributes

3.5.2.1. Number of pods per plant

Matured pods on the observation plants at the time of harvest were counted and the mean was recorded.

3.5.2.2. Pod length

Matured pods from the observation plants were picked and the length of individual pod was measured and the mean was expressed in cm.

3.5.2.3. Number of seeds per pod

The number of seeds present in the pods used for measuring pod length was counted and the mean was recorded.

3.5.2.4. Pod weight

Pods from the observation plants were picked as and when matured; weighed immediately after picking and the mean pod weight was expressed in grams.

3.5.2.5. Pod yield per plant

Pods from the observation plants were picked as and when matured; weighed immediately after picking and the mean green pod yield was expressed in g/plant.

3.5.2.6. Pod yield per plot

Pods from each net plot were picked as and when matured; weighed immediately after picking and the total yield of green pods obtained from each net plot was expressed in g/plot and pod yield/ha was worked out and recorded.

3.5.2.7. Stover yield

After harvest, plants in the net plot were uprooted and fresh weight was recorded and expressed in kg/ha.

3.5.2.8. Number of harvests

Number of pickings of vegetable pods as and when they matured was recorded.

3.5.2.9. Duration of the crop

Number of days from sowing to the last harvest in each plot was recorded.

3.5.3. Economics (from second year experiment)

The prevailing labour charge in the locality and cost of inputs were considered for computing gross expenditure and expressed in rupees per hectare. The yield of vegetable cowpea and its prevailing local market price were considered for computing gross return and expressed in rupees per hectare. Benefit cost ratio was worked out by dividing the gross return with gross expenditure.

3.5.4. Incidence of pests and diseases (from second year experiment)

Incidence of aphid was noticed and visual scoring was done in the field as mild, moderate and severe.

3.5.5. Physiological and biochemical observations (from second year experiment)

3.5.5.1. Stomatal conductance

Measured from each plot at 15 days interval using Infra Red Gas Analyzer (IRGA)

3.5.5.2. Transpiration rate

Measured from each plot at 15 days interval using IRGA

3.5.5.3. Photosynthetic rate

Measured from each plot at 15 days interval using IRGA

3.5.5.4. Nitrate reductase activity

Nitrate reductase activity in the leaves was determined calorimetrically as per the method suggested by Nicholas *et al*. (1976).

3.5.5.5. Chlorophyll content

Chlorophyll content of leaves was calculated using the formula suggested by Yoshida *et al.* (1972). Fresh leaf samples were collected from each plot. Then a known weight from each sample was taken and the chlorophyll was extracted using Dimethyl Sulphoxide (DMSO). Then the intensity of color was read using Spectronic 20 spectrophotometer at 663nm and 645nm.

3.5.5.6. Chlorophyll stability index (CSI)

Chlorophyll stability index was determined calorimetrically as per the method suggested by Leopold *et al*. (1981).

$$\mathrm{CSI} = \frac{\text{Total chlorophyll content in treated plots}}{\text{Total chlorophyll content in control plots}} \times 100$$

3.5.5.7. Relative water content/ Relative leaf water content (RLWC)

Relative leaf water content was estimated using the method suggested by Barrs (1986). Fresh fully opened leaves from top were taken and cut into small pieces. Then a known weight from each sample was taken and immediately weighed to get the fresh weight and hydrated to full turgidity for four hours. After four hours, the samples were taken out, wiped off the surface moisture quickly and lightly with filter paper, and immediately weighed to obtain fully turgid weight. The samples were oven dried at 80^0C for 24 hours and weighed to determine dry weight.

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

3.5.5.6. Proline content in the plant

Free proline content in the leaves was determined calorimetrically as per the method suggested by Bates *et al*. (1973).

3.5.6. Soil moisture studies

Soil moisture content at sowing and at 15 days interval upto 60 DAS was estimated using thermo-gravimetric method. The soil samples were collected from each plot at a depth of 0-20cm just before irrigation using an auger in airtight steel containers. Then the containers with soil samples were weighed and oven dried at 105^0C for 24 hours until all the moisture was driven off. Then the containers were taken out and cooled at room temperature and weighed again. The difference in weight gives the weight of soil moisture in the samples and expressed as percentage.

$$Pw = \frac{Wm - Wd}{Wd} \times 100$$

Where, Pw- percentage of soil moisture by weight; Wm- weight of moist sample and Wd- weight of oven dry sample.

3.5.7. Soil analysis

Soil samples were collected at the time of land preparation, before the application of FYM and fertilizers and after the complete harvest of crop. The pH, organic carbon, available N, available P and available K, Ca, Mg, S, Fe, Mn, Zn, Cu and B in the samples were determined using standard procedures as shown in Table -1.

3.5.8. Plant analysis

3.5.8.1. Nutrient content

Plant samples were analysed for N, P, K, Na, Ca, Mg, S, Fe, Mn, Zn, Cu and B using the standard procedures.

The macro and micronutrient content of plants and pods at harvest were analyzed by standard procedures (Jackson, 1958). Total N content of plant samples was determined by Microkjeldal digestion and distillation method. Plant sample was digested in a diacid mixture and the P content was determined by Vanadomolydophosphoric yellow color method. Intensity of color was read using Spectronic 20 spectrophotometer at 420nm. Potassium content in the diacid digest was estimated using Flame photometer. Ca, Mg, micronutrients such as Fe, Mn, Zn and Cu were estimated using Atomic Absorption Spectrophotometer (AAS). Sulphur and boron were determined by turbidimetric method using Spectronic 20 spectrophotometer (Williams and Steinbergs, 1959) and dry ashing method (Tandon, 1993) respectively.

The nutrient uptake by plants were calculated by adding the product of the nutrient content of plant and the plant dry weight and the product of nutrient content of pods and pod dry weight and expressed in kg/ha.

3.5.8.2. Protein content in the pod and stover

The nitrogen content in the pod and stover were estimated by Microkjeldal digestion and distillation method (Jackson, 1958). The nitrogen content thus obtained was multiplied by 6.25 to get the protein content.

3.6. Field water use efficiency (FWUE)

Field water use efficiency was worked out by using the formula:-

$$\frac{\text{Yield (kg/ha)}}{\text{Quantity of water applied (mm)}}$$

3.7. Statistical analysis

The data were subjected to analysis of variance using the statistical package ‘MSTAT-C’ (Freed, 1986).

N

1.5m

R1		R2		R3	
T15	Bulk	T11	Bulk	T14	Bulk
T1	T6	T15	T10	T8	T13
T4	T9	T7	T1	T9	T5
T5	T2	T6	T3	T3	T2
T14	T13	T12	T9	T6	T12
T10	T7	T8	T4	T11	T7
T11	T3	T2	T5	T1	T4
T8	T12	T14	T13	T15	T10

1.5m

Fig 1. Lay out of first experiment

N

1.5m

R1		R2		R3	
T4	Bulk	T3	Bulk	T10	Bulk
T10	T1	T10	T11	T6	T9
T6	T9	T5	T4	T2	T4
T3	T5	T2	T9	T3	T7
T7	T8	T7	T6	T5	T1
T11	T2	T8	T1	T11	T8

1.5m

Fig 2. Layout of second experiment

N

1.5m

R1		R2		R3	
T11	T10	T3	T9	T1	T7
T5	T12	T6	T2	T9	T5
T1	T4	T11	T10	T12	T3
T7	T9	T1	T8	T4	T8
T2	T8	T5	T12	T2	T6
T3	T6	T7	T4	T10	T11

1.5m

Fig 3. Layout of third experiment

N

3.6

m

3.6m

R1		R2		R3	
T3	T16	T14	T7	T4	T10
T7	T8	T1	T12	T11	T2
T11	T10	T9	T5	T9	T13
T17	T13	T15	T6	T8	T1
T6	T4	T3	T11	T12	T7
T12	T14	T17	T16	T17	T5
T1	T2	T10	T13	T15	T3
T1	T5	T8	T2	T6	T14
T9	T18	T4	T18	T16	T18

Fig 4. Layout of second year experiment

Plate 1 & 2. General view of the first year field experiments (2014)

Plate 3 & 4. General view of the second year field experiment (2015)

RESULTS

4. RESULTS

Field experiments to evaluate various agrotechniques for mitigating water stress in vegetable cowpea (*Vigna unguiculata* (L.) Walp) were conducted during the summer season (January to March) of the year 2014 and 2015, at Agronomy Research Farm, College of Horticulture, Kerala Agricultural University. There were three experiments in the first year which were laid out as mini plot experiments in Randomised Block Design. First experiment dealt with the effect of exogenous application of plant growth regulators (PGRs) in mitigating water stress in vegetable cowpea with 15 treatments replicated thrice. Second experiment was to study the effect of seed priming, antitranspirants and soil moisture conservation practices in mitigating water stress in vegetable cowpea with 11 treatments replicated thrice. Third experiment dealt with the effect of nutrient management in mitigating water stress in vegetable cowpea with 12 treatments replicated thrice. The best treatments from the first year experiments were selected and their individual and possible combinations were evaluated in an experiment with 18 treatments replicated thrice in randomized block design (RBD) during the subsequent year. The results of the experiments are presented below.

4.1. Effect of plant growth regulators in mitigating water stress

The experiment was conducted to evaluate the effect of exogenous application of plant growth regulators in mitigating water stress in vegetable cowpea.

4.1.1. Growth characters

Effect of exogenous application of plant growth regulators on various growth characters of vegetable cowpea are presented in Table 6. General growth of the crop was less than normal due to the extreme dry condition prevailed during the entire crop growth period (Appendix I & II).

4.1.1.1. Plant height

The most noticeable morphological feature affected by water stress is the plant height. Though the variety attains a height of 50-60cm under normal conditions, water stress decreased it to the range of 10-13cm at 60 days after sowing (DAS). None of the treatments could bring about any significant influence on height of cowpea plants at any stage of growth. However at 60 DAS, the treatments which received spraying of either plant growth regulators (except brassinolide 1ppm) or coconut water or water during the water stress imposed period resulted in an increasing trend of plant height from 1 to 25 per cent compared to that which received no treatment during the period. Among the plant growth regulators applied, NAA 40 ppm recorded the highest plant height of 13.67 cm followed by application of 2% salicylic acid (12.9cm).

4.1.1.2. Number of leaves

Number of leaves of cowpea plants was not significantly influenced by any of the treatments at 15 and 30 DAS. However, at 45 DAS, plants irrigated on alternate days (farmer's practice) recorded the highest leaf number of 15.3 which was on par with those irrigated at 5 days interval (12.6). Among the PGRs, NAA 40ppm recorded the highest number of leaves per plant followed by water spray and salicylic acid 2%. At 60 DAS, there was a decline in the number of leaves per plant in farmers practice and irrigation at 5 days interval due to attainment of early maturity. By 60 DAS, the treatments which received either PGRs (except ascorbic acid 2%) or water during the water stress imposed period resulted in an increasing trend in number of leaves from 7 to 38 per cent compared to that which received no treatment during the period. Among the PGRs, NAA 40ppm and salicylic acid

Table 6. Effect of plant growth regulators (PGRs) on plant biometry

Treatments	Plant height (cm)				No. of leaves				No. of branches			Leaf area index(LAI)			Root length (cm)	Root Shoot ratio	Days to flowering
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	20 DAS	40 DAS	60 DAS			
1. CCC 10	5.80	6.03	7.76	11.83	3.06	5.50	7.40	8.40	0.00	0.06	2.06	0.07	0.26	0.30	15.80	0.23	46.00
2. CCC 20	6.13	6.36	7.70	12.33	3.20	6.33	8.26	9.46	0.00	0.13	2.46	0.06	0.23	0.28	14.76	0.20	48.66
3. SA 1 %	5.40	5.60	7.23	11.83	3.06	5.73	7.66	8.33	0.00	0.40	2.90	0.06	0.27	0.33	15.73	0.23	47.00
4. SA 2%	5.86	6.36	7.76	12.90	3.13	5.46	9.26	10.46	0.06	0.80	2.90	0.07	0.28	0.33	17.36	0.26	45.33
5. AA 1%	5.60	5.80	7.96	12.10	3.26	6.00	7.66	8.16	0.00	0.26	2.06	0.06	0.20	0.31	14.93	0.20	47.00
6. AA 2%	5.63	5.86	7.43	11.90	3.20	5.60	7.26	7.60	0.00	0.20	1.36	0.06	0.20	0.31	14.80	0.20	48.00
7. NAA 20	5.70	5.90	7.70	12.43	3.06	5.60	8.93	9.53	0.00	0.33	2.33	0.06	0.25	0.29	16.30	0.23	48.00
8. NAA 40	5.86	6.00	8.20	13.66	3.20	6.00	9.80	10.53	0.00	1.06	2.76	0.07	0.28	0.33	16.46	0.26	48.00
9. Br. 0.5	6.00	6.06	7.53	12.00	3.13	5.73	8.40	9.53	0.00	1.06	2.76	0.05	0.28	0.30	15.73	0.16	46.00
10. Br. 1	5.70	6.16	7.63	10.70	3.13	5.73	7.73	9.36	0.00	0.40	1.86	0.06	0.25	0.31	15.23	0.23	48.66
11. CW	5.66	5.96	7.16	11.03	3.06	5.26	6.96	7.43	0.00	0.46	1.46	0.06	0.23	0.31	15.80	0.23	48.66
12. WS	6.03	6.16	7.80	11.86	3.13	6.36	9.73	9.66	0.00	0.46	2.33	0.07	0.31	0.33	16.86	0.20	45.33
13. Control	5.33	5.53	8.80	13.06	3.20	7.33	12.60	8.80	0.40	2.86	3.86	0.06	0.31	0.28	16.63	0.20	44.33
14. FP	5.63	6.03	9.06	13.56	3.13	7.60	15.33	12.20	0.26	3.00	4.66	0.07	0.36	0.35	19.86	0.20	44.33
15. Abs. control	6.10	6.40	7.33	10.93	3.00	5.43	7.40	7.63	0.00	0.13	2.10	0.04	0.17	0.19	11.93	0.10	48.66
CD(0.05)	NS	NS	NS	NS	NS	NS	3.01	2.06	NS	1.27	NS	0.01	0.02	0.02	2.62	NS	NS
SEd	-	-	-	-	-	-	1.47	1.01	-	0.59	-	0.004	0.009	0.009	1.28	-	-

2% were found to be on par with farmer's practice which recorded the highest number of leaves.

4.1.1.3. Number of branches

No branches were observed at 15 DAS. At 30 DAS, branches were noted only in plots irrigated on alternate days (farmer's practice) and at 5 days interval and in plots sprayed with salicylic acid 2%. None of the treatments could bring about any significant influence on number of branches of cowpea plants at 30 and 60 DAS. However at 45 DAS, significantly higher number of branches was noticed in plots irrigated on alternate days (farmer's practice) and at 5 days interval. At 60 DAS, the treatments which received spraying of either plant growth regulators (except CCC10ppm, ascorbic acid 1% and brassinolide 1ppm) or water during the water stress imposed period resulted in an increasing trend of number of branches from 9.5 to 38 per cent compared to that which received no treatment during the period.

4.1.1.4. Leaf area index

A progressive increase in leaf area index was noticed up to 60 DAS in all treatments except in farmers practice and irrigation at 5 days interval. The decline in leaf area index in plots irrigated on alternate days and at 5 days interval at 60 DAS was due to the leaf fall as a result of attainment of early maturity. In general, all the treatments recorded significantly higher leaf area index compared to absolute control at all of stages of observation. Leaf area index at 20 DAS did not show much variation among the treatments. However at 40 DAS, leaf area index varied significantly among the treatments and it was highest in farmers practice followed by the treatment irrigated at 5 days interval. Plots sprayed with water during the stress imposed period recorded leaf area index on par with the treatment irrigated at 5 days interval followed by brassinolide 0.5%, salicylic acid 1 and 2%, NAA 40 ppm, and CCC 10ppm. At 60 DAS, farmers practice recorded the highest leaf area index and it was found to be on par with salicylic acid 1 and 2%, NAA 40 ppm and water spray.

4.1.1.5. Root length

All the treatments recorded significantly higher root length compared to absolute control. Highest root length of 19.8 cm was observed in farmers' practice which was on par with salicylic acid 2% (17.3cm). Application of PGRs resulted in an increase in root length ranging from 23 to 45 per cent compared to absolute control which received no treatment during the water stress period.

4.1.1.6. Root:shoot ratio

Root shoot ratio of cowpea plants were not significantly influenced by various treatments. However, numerically higher root shoot ratio was recorded by salicylic acid 2% and NAA 40 ppm and the lowest ratio by absolute control. Even though a higher root length was obtained in plants irrigated on alternate days (farmer's practice) and at 5 days interval, a lower root shoot ratio was obtained in those treatments as these treatments produced a higher shoot growth also.

4.1.1.7. Days to flowering

Under favorable condition the variety flowers in 40-45 DAS. All the water stress imposed treatments showed a slight delay of one to four days (45 to 49 DAS) in attaining 50 per cent flowering compared to those received irrigation on alternate days (farmer's practice) and at 5 days interval (44 DAS). This can be due to the delay in attaining sufficient vegetative growth before flowering as a result of imposed water stress. Comparatively early flowering (44 DAS) was noted in farmer's practice and in treatments that received irrigation at 5 days interval. Salicylic acid 2% and water spray resulted in 50 per cent flowering at 45 DAS.

4.1.2. Physiological parameters

Observations on physiological parameters were recorded during the water stress imposed period (10 days after the exogenous application of PGRs, coconut water and water). Effect of treatments on various physiological parameters of cowpea plants are presented in Table 7.

4.1.2.1. Stomatal conductance

Highest stomatal conductance was observed in farmers practice followed by the treatment irrigated at 5 days interval and the lowest in brassinolide 1 ppm followed by CCC 10 ppm, CCC 20 ppm and water spray. Among PGRs, ascorbic acid 1 and 2 % recorded a higher stomatal conductance.

4.1.2.2. Transpiration rate

Highest transpiration rate was observed in farmers practice followed by the treatment irrigated at 5 days interval and the lowest in brassinolide 1 ppm followed by CCC 20 ppm and water spray. Among PGRs, ascorbic acid 1 and 2 % recorded a higher transpiration rate.

4.1.2.3. Photosynthetic rate

Highest photosynthetic rate was observed in farmers practice followed by the treatment irrigated at 5 days interval and the lowest in brassinolide 1 ppm followed by CCC 10 ppm, CCC 20 ppm and water spray. Among PGRs, ascorbic acid 1 and 2 % recorded a higher photosynthetic rate.

4.1.2.4. Chlorophyll content

Highest chlorophyll content was recorded by farmers practice and the lowest by absolute control. Exogenous application of either PGRs, or coconut water or water during the water stress imposed period could increase the chlorophyll content to the tune of 5 to 53 per cent compared to no treatment during the period. Among PGRs, salicylic acid recorded the highest chlorophyll content and it was on par with irrigation at 5 days interval and coconut water.

4.1.2.5. Relative leaf water content

Highest relative leaf water content was recorded by farmers practice and the lowest by absolute control. Exogenous application of either PGRs, or coconut water or water during the water stress imposed period increased the relative leaf water content to the range of 2 to 78 per cent compared to no treatment during the period. Among the PGRs, salicylic acid 2% recorded the highest relative leaf water content (78% over absolute control) which was on par with the treatment irrigated at 5 days interval, foliar spray of coconut water, ascorbic acid 1%, CCC 20 ppm, water and NAA 40 ppm.

Table 7. Effect of PGRs on physiological parameters of crop

Tr. No.	Treatments	RLWC* (%)	Total chlorophyll (mg/g plant)	Photosynthetic rate (µ mol CO_2 /m^2 /sec)	Transpiration rate (m mol H_2O/ m^2/ sec)	Stomatal conductance (mol H_2O / m^2/ sec)
1	CCC 10	17.17	0.13	13.51	2.27	0.20
2	CCC 20	27.27	0.15	13.74	2.16	0.21
3	SA 1 %	19.57	0.14	13.95	2.27	0.22
4	SA 2%	29.80	0.19	16.61	2.71	0.24
5	AA 1%	27.37	0.15	20.12	3.03	0.29
6	AA 2%	22.87	0.15	19.97	3.06	0.29
7	NAA 20	18.50	0.16	17.18	2.74	0.26
8	NAA 40	23.26	0.16	14.48	2.56	0.25
9	Br. 0.5	22.53	0.13	18.29	2.92	0.28
10	Br. 1	18.43	0.13	12.82	1.90	0.17
11	CW	27.53	0.19	14.71	2.36	0.25
12	WS	26.90	0.17	13.53	2.18	0.20
13	Control	30.73	0.20	24.36	3.25	0.74
14	FP	38.00	0.21	28.01	3.48	0.89
15	Abs. control	16.76	0.12	14.86	2.37	0.26
	CD(0.05)	7.536	0.013	0.359	0.072	0.018
	SEd	3.69	0.006	0.17	0.035	0.008

*Relative leaf water content

4.1.3. Yield attributes and yield

Effect of exogenous application of various plant growth regulators on yield and yield attributes of vegetable cowpea are presented in Table 8. General yield of crop was low due to effect of extreme dry condition prevailed during the crop period (Appendix I & II) on vegetative growth, flowering and yield attributes.

4.1.3.1. Number of pods per plant

The variety *Kashi Kanchan* has a potential to produce about 40-45 pods/plant under favourable climatic conditions. Highest number of pods per plant was recorded by farmers' practice which was irrigated on alternate days followed by those irrigated at 5 days interval and the lowest by absolute control which received no treatment during water stress imposed period. Exogenous application of salicylic acid 2%, recorded the highest pod number per plant even though it was on par with all other PGRs.

4.1.3.2. Pod length

Under favourable condition pod length of variety *Kashi Kanchan* ranges from 30-35cm. Due to extreme dry condition prevailed during crop season, the pod length recorded by various treatments in the experiment ranged from 25 to 29cm. The data showed that pod length of cowpea plants was not significantly influenced by exogenous application of any of the PGRs, coconut water or water. However, application of NAA 20 and 40 ppm resulted in a slightly higher pod length compared to other treatments.

4.1.3.3. Number of seeds per pod

None of the treatments could influence the number of seeds per pod of cowpea plants. However, the highest number of seeds per pod was recorded by farmers' practice which received irrigation on alternate days and the lowest by absolute control. A comparatively higher number of seeds per pod were recorded by exogenous application of salicylic acid 2% spray, NAA 20 and 40 ppm and water spray.

4.1.3.4. Pod weight

Pod weight of cowpea plants was not significantly influenced by exogenous application of any of the treatments. However, all the treatments showed an increasing trend in pod weight ranging from 27 to 43 per cent compared to absolute control. Among PGRs, salicylic acid 2% brought about 43 per cent increase in pod weight compared to no treatment during the water stress imposed period.

4.1.3.5. Pod yield (per plant, per plot and per hectare)

Pod yield per plant was significantly influenced by various treatments. Highest pod yield per plant was recorded by farmers' practice which received irrigation on alternate days. Among PGRs, salicylic acid 2% recorded the highest pod yield per plant and it was found to be on par with farmers' practice. Exogenous application of NAA 40 ppm and water spray recorded pod yield per plant on par with treatment irrigated at 5 days interval. The lowest pod yield was recorded by exogenous application of brassinolide 1ppm which was on par with absolute control and CCC10 ppm.

The general yield of the crop was very low due to the exposure of cowpea plants to extreme dry condition from sowing to harvest and aphid attack. Moreover the experiment was conducted in miniplots of size 1.5m x 1.5m and per plot yield recorded was from a net plot size of $0.81m^2$. Pod yield per plot also showed the same trend as that of pod yield per plant. Highest pod yield per plot was obtained from farmers' practice which was irrigated on alternate days. Among PGRs, salicylic acid 2% recorded the highest pod yield per plot (124% higher than absolute control) and it was found to be on par with farmers' practice. Exogenous application of NAA 40 ppm and water spray recorded pod yield per plot on par with treatment irrigated at 5 days interval. The lowest pod yield was recorded by exogenous application of brassinolide 1ppm which was on par with absolute control and CCC10 ppm.

The yield potential of variety *Kashi Kanchan* was reported to be 15-17t of vegetable pods/ha. However, the highest pod yield was recorded by farmers' practice which was only 3348 kg/ha due to the reasons as mentioned above. Among PGRs, salicylic acid 2% recorded the highest pod yield of 2962 kg/ha

Table 8. Effect of PGRs on yield attributes and yield of crop

Treatments	Pod No. /plant	Pod length (cm)	Seeds /pod	Pod weight (g)	No. of harvest	Pod yield /plant (g)	Pod yield /plot (g)	Pod yield (kg/ha)	Stover yield (kg/ha)	DMP(at harvest) (kg/ha)
1. CCC 10	2.33	24.66	12.33	8.16	1.00	13.83	124.50	1537.03	2719.75	844.44
2. CCC 20	2.66	26.43	12.83	8.66	1.66	14.66	132.00	1629.63	3339.50	934.56
3. SA 1 %	2.33	26.06	12.56	8.63	2.00	16.80	151.20	1866.66	3508.23	940.74
4. SA 2%	3.33	26.63	13.50	8.90	3.00	26.66	240.00	2962.96	3195.06	978.18
5. AA 1%	3.00	25.70	12.43	8.73	2.00	19.36	174.30	2151.85	2407.40	888.06
6. AA 2%	3.00	26.13	12.10	8.56	1.66	15.66	141.00	1740.74	2865.43	911.93
7. NAA 20	2.66	29.13	13.26	8.13	2.00	17.56	158.10	1951.85	3376.13	982.30
8. NAA 40	3.00	29.70	13.53	8.63	3.00	24.96	224.70	2774.07	4024.69	1375.72
9. Br. 0.5	2.66	27.20	12.83	8.73	2.00	21.40	192.60	2377.77	3531.68	1165.43
10. Br. 1	2.00	26.66	12.46	8.13	1.00	9.36	84.30	1040.74	2532.09	709.46
11. CW	2.66	26.63	12.36	8.03	1.66	16.60	149.40	1844.44	2508.64	896.29
12. WS	3.00	26.46	13.93	8.06	3.00	24.80	223.20	2755.55	3225.51	1109.05
13. Control	5.66	27.46	13.76	8.40	3.00	25.00	225.00	2777.77	4768.72	1422.22
14. FP	8.00	27.76	14.00	7.93	4.00	30.13	271.20	3348.14	5097.94	1661.72
15. Abs. control	1.33	25.80	11.36	6.20	1.00	11.90	107.10	1322.22	2290.94	644.93
CD(0.05)	1.38	NS	NS	NS	0.58	4.48	40.39	498.67	415.96	184.68
SEd	0.67	-	-	-	0.28	2.19	19.7	244.4	203.8	90.5

which was found to be on par with farmers practice, irrigation at 5 days interval, NAA 40ppm and water spray (2777 kg/ha, 2774 kg/ha & 2755 kg/ha). The lowest pod yield was recorded by exogenous application of brassinolide 1ppm which was on par with absolute control and CCC10 ppm.

4.1.3.6. Stover yield (per plot and per hectare)

In general, the crop recorded a lower stover yield due to less vegetative growth as a result of exposure of plants to unfavourable weather condition prevailed during the crop season combined with aphid attack. However, the stover yield of the crop was significantly influenced by various treatments and the trend was same for both per plot and per hectare stover yield. The highest stover yield was recorded by farmers practice (5097kg/ha) and the treatment which received irrigation at 5 days interval (4768kg/ha) and the lowest by absolute control. Among PGRs, NAA 40ppm recorded the highest stover yield (76 percent higher than that obtained in absolute control) followed by brassinolide 0.5ppm, salicylic acid 1%, NAA 20 ppm, CCC 20ppm, water spray and salicylic acid 2%.

4.1.3.7. Dry matter accumulation

Dry matter accumulation in cowpea plants during the cropping period was significantly influenced by various treatments. Farmers practice recorded a significantly higher dry matter accumulation (1661.7kg/ha) compared to all other treatments where as absolute control recorded the lowest (644.9kg/ha). All treatments which received spraying of either plant growth regulators or coconut water or water during the water stress imposed period could bring about 10 to 113 per cent increase in total dry matter production compared to no treatment during the crop period. Among the PGRs, NAA 40 ppm recorded the highest dry matter accumulation and it was on par with the treatment irrigated at 5 days interval. The next best treatment was brassinolide 0.5% and it was on par with water spray and NAA 20ppm.

4.1.3.8. Number of harvests

In general, the number of harvests was low due to low pod yield as a result of exposure of plants to unfavourable weather conditions during the entire crop period combined with attack of aphids. The data showed that various treatments significantly influenced the number of harvests of the crop. The highest number of harvests (4 harvests) was done in farmers practice followed by the treatment which was irrigated at 5 days interval, water spray, NAA 40ppm and salicylic acid 2% (3 harvests) and the lowest of one harvest was in brassinolide 1ppm, CCC 10ppm and absolute control.

4.1.3.9. Duration of the crop

Kashi Kanchan is a short duration vegetable cowpea variety, the duration of which is reported as 60-65 days. It was observed that the plants in treatments which received irrigation on alternate days and at 5 days interval attained final maturity (65 days) earlier than the remaining treatments. Absolute control as well as exogenous application of either PGRs, or coconut water or water extended the duration of the crop by one week (72 days) without any variation among them.

4.1.4. Quality parameters

Effect of exogenous application of various plant growth regulators on quality parameters like protein content in pod and stover of vegetable cowpea are presented in Table 9.

4.1.4.1. Protein content in pod

Protein content in cowpea pods was significantly influenced by various treatments. Higher protein content in pod was recorded by water spray, farmers practice, salicylic acid 2%, NAA 40 ppm, irrigation at 5 days interval and ascorbic acid 2% to the tune of 25 to 37 per cent compared to absolute control. However, brassinolide 0.5ppm and salicylic acid 1% recorded significantly lower protein content than absolute control.

4.1.4.2. Protein content in stover

Protein content in stover also varied significantly among treatments. Higher stover protein content was noticed in farmers practice, NAA 40 ppm and ascorbic acid 1% which were on par with salicylic acid 2%, brassinolide 1ppm and the treatment irrigated at 5 days interval and significantly superior to the remaining treatments.

Table 9. Effect of PGRs on protein content of crop

Tr. No.	Treatments	Pod (%)	Stover (%)
1	CCC 10	18.12	4.77
2	CCC 20	19.58	4.43
3	SA 1 %	13.95	4.68
4	SA 2%	22.70	5.08
5	AA 1%	15.41	5.16
6	AA 2%	21.04	4.75
7	NAA 20	18.75	4.63
8	NAA 40	22.50	5.39
9	Br. 0.5	13.33	4.44
10	Br. 1	19.58	5.08
11	CW	18.12	4.77
12	WS	23.12	4.56
13	Control	22.29	5.06
14	FP	22.71	5.39
15	Abs. control	16.87	4.62
	CD(0.05)	2.28	0.35
	SEd	1.12	0.17

4.1.5. Nutrient uptake by the crop

Analysis of plant and pod samples from each treatment plots at final harvest was done to estimate primary (N, P, K), secondary (Ca, Mg, S), micro (Fe, Mn, Zn, Cu, B) and beneficial (Na) nutrient contents (Appendix III) and their uptake by the crop was calculated. Among these, content of sodium and copper in cowpea plants in all treatments were found to be below detectable level. Effect of application of various plant growth regulators on nutrient uptake by vegetable cowpea is shown in Table 10 and 11.

4.1.5.1. Primary nutrients

In general, unfavourable weather especially extreme dry condition led to a reduced uptake of all nutrients by the crop and thereby a lower growth and yield. However, it was observed that uptake of nitrogen (N) was significantly influenced by various treatments. Significantly higher nitrogen uptake by the crop was noted in farmers' practice (30.1 kg/ha) which was irrigated on alternate days and in treatment irrigated at 5 days interval and the lowest by absolute control. Among the exogenously applied treatments during the water stress imposed period, water spray, NAA 40 ppm and salicylic acid 2% resulted in significantly higher nitrogen uptake compared to other treatments and to the tune of 126-145% higher than absolute control.

Phosphorus (P) uptake by the crop also varied significantly among treatments with the highest uptake of 4.8kg/ha in farmers practice irrigated on alternate days followed by the treatment irrigated at 5 days interval. Lowest uptake was recorded by absolute control followed by brassinolide 1ppm. Application of NAA 40 ppm, water spray, brassinolide 0.5ppm, salicylic acid 2% and NAA 20 ppm were statistically on par with each other and resulted in a significantly higher P uptake compared to other treatments.

Potassium (K) uptake was also significantly influenced by various treatments and the highest was observed in farmers practice and the lowest in absolute control. Among the exogenously applied treatments, NAA 40 ppm recorded the highest K uptake (123 % higher than that of absolute control) and it was also on par with the treatment irrigated at 5 days interval and brassinolide 0.5ppm.

4.1.5.2. Secondary nutrients

Calcium (Ca) uptake by the crop was significantly influenced by the treatments. Highest calcium uptake was noticed in farmers practice and the lowest in absolute control. Exogenous application of NAA 40 ppm (9.1kg/ha) was found to be on par with farmers practice with regard to Ca uptake. The next best treatment was brassinolide 0.5 ppm which recorded a calcium uptake on par with irrigation at 5 days interval.

Magnesium (Mg) uptake by the crop was significantly influenced by various treatments. The highest Mg uptake was recorded by farmers practice followed by exogenous application of NAA 40ppm and treatment irrigated at 5 days interval. Lowest Mg uptake was noticed in absolute control.

Sulphur (S) uptake by the crop was significantly influenced by various treatments. The highest S uptake was recorded by treatment irrigated at 5 days interval and it was on par with farmers practice followed by exogenous application of NAA 40 ppm, salicylic acid 1% and NAA 20 ppm. Lowest S uptake was noticed in absolute control.

4.1.5.3. Micro nutrients

Application of various treatments significantly influenced the iron (Fe) uptake by the crop. Among all the treatments NAA 40 ppm (244% higher than absolute control) was significantly superior to all other treatments and it was followed by farmers practice, salicylic acid 1% and NAA 20 ppm. The lowest Fe uptake was observed in absolute control which was found to be on par with ascorbic acid 1% and coconut water.

Manganese (Mn) uptake by the crop showed the same trend as that of magnesium uptake with the highest in farmers practice followed by NAA 40 ppm and the treatment irrigated at 5 days interval where as the lowest was noticed in absolute control.

Zinc (Zn) uptake by the crop was significantly influenced by various treatments. Highest zinc uptake was recorded by farmers practice followed by the treatment irrigated at 5 days interval and the lowest by absolute control. Among PGRs, application of brassinolide 0.5ppm, NAA 40 ppm and CCC 20 ppm were on par with a higher Zn uptake and in turn were on par with irrigation at 5 days interval.

Boron (B) uptake by the cowpea crop was significantly varied among the treatments. The highest boron uptake was recorded by farmers practice and the lowest by absolute control. Among PGRs, NAA 40 ppm was found superior in boron uptake and it was on par with irrigation at 5 days interval and other treatments except brassinolide 0.5ppm and coconut water.

Table 10. Effect of PGRs on primary and secondary nutrient uptake by the crop

Tr. No.	Treatments	Nutrient uptake (kg/ha)					
		N	P	K	Ca	Mg	S
1	**CCC 10**	12.63	2.33	24.55	5.05	1.87	0.49
2	**CCC 20**	13.36	2.40	25.26	5.58	2.01	0.47
3	**SA 1 %**	10.58	2.48	30.48	6.12	2.09	0.71
4	**SA 2%**	21.12	2.88	27.15	4.72	2.03	0.57
5	**AA 1%**	13.32	2.35	23.53	4.68	1.71	0.41
6	**AA 2%**	14.19	2.23	22.49	5.34	2.24	0.59
7	**NAA 20**	15.68	2.88	24.75	5.65	2.34	0.69
8	**NAA 40**	22.60	3.38	37.48	9.12	3.47	0.72
9	**Br. 0.5**	13.56	2.97	34.53	7.29	2.96	0.59
10	**Br. 1**	9.89	1.62	22.67	4.72	1.61	0.44
11	**CW**	12.99	2.12	23.83	5.61	2.28	0.42
12	**WS**	22.82	3.24	27.84	5.69	2.13	0.56
13	**Cntrl**	28.55	4.01	35.45	7.32	3.18	0.94
14	**FP**	30.13	4.87	44.06	10.05	4.36	0.93
15	**Abs. cntrl**	9.31	1.25	16.82	3.59	1.55	0.29
	CD(0.05)	4.69	0.604	5.01	1.035	0.41	0.11
	SEd	2.29	0.29	2.45	0.50	0.20	0.05

Table 11. Effect of PGRs on micro nutrient uptake by the crop

Tr. No.	Treatments	Nutrient uptake (kg/ha)			
		Fe	Mn	Zn	B
1	**CCC 10**	0.39	0.81	0.05	0.02
2	**CCC 20**	0.49	1.17	0.06	0.02
3	**SA 1 %**	0.63	1.03	0.05	0.02
4	**SA 2%**	0.55	1.00	0.05	0.02
5	**AA 1%**	0.33	0.59	0.04	0.02
6	**AA 2%**	0.43	0.93	0.04	0.02
7	**NAA 20**	0.62	1.01	0.06	0.02
8	**NAA 40**	0.87	1.71	0.07	0.02
9	**Br. 0.5**	0.51	1.49	0.07	0.02
10	**Br. 1**	0.39	0.88	0.03	0.01
11	**CW**	0.33	0.88	0.04	0.01
12	**WS**	0.41	0.79	0.04	0.02
13	**Control**	0.62	1.55	0.07	0.02
14	**FP**	0.71	2.02	0.09	0.03
15	**Abs. control**	0.25	0.44	0.02	0.01
	CD(0.05)	0.089	0.18	0.009	0.006
	SEd	0.04	0.08	0.004	0.002

4.1.6. Soil characters

Soil samples collected from each treatment after the final harvest of the crop were analysed for pH, organic carbon, primary, secondary and micro nutrients and the data are presented in Table 12 and 13.

4.1.6.1. Soil pH

Soil pH in various treatments after the experiment (5.1-5.8) did not show much variation compared to that before the experiment (5.4). However a slight increase in soil pH was noticed in CCC 10 and 20ppm, salicylic acid 2%, ascorbic acid 2%, brassinolide 1ppm and the treatment irrigated at 5 days interval.

4.1.6.2. Soil organic carbon

Organic carbon status of soil after the experiment did not show much variation among various treatments and it ranged from 1.01 to 1.2 per cent compared to that of 1.2 per cent before the experiment.

4.1.6.3. Primary nutrients

Available nitrogen content in the soil was 156.1 kg/ha before the experiment and it got reduced to the extent of 122 to 142 kg/ha after the experiment and there was no significant variation among treatments. However, numerically higher nitrogen content was observed in NAA 40 ppm, CCC 10 ppm and brassinolide 1 ppm

Available phosphorus content in soil before the experiment was 21.9 kg/ha which showed a reduction to the tune of 12 to 18 kg/ha. Highest P content was noticed in treatment irrigated at 5 days interval followed by water spray where as the lowest in CCC 20 ppm.

Available potassium content in the soil before the experiment was 378.8 kg/ha and it showed a slight reduction after the experiment (296-354 kg/ha). However, the available K content after the experiment varied significantly among treatments. Highest K content was recorded by brassinolide 1 ppm which was on par with coconut water and NAA 40 ppm and the lowest by brassinolide 0.5 ppm

4.1.6.4. Secondary nutrients

Application of different treatments significantly influenced the Ca, Mg and S content in soil.

Available calcium content in soil before the experiment was 179.5 mg/kg. A reduction in soil calcium content to the range of 147 to 178 mg/kg was noticed after the experiment. However, higher Ca content was recorded by NAA 20 ppm and the lowest in brassinolide 0.5 ppm.

Available magnesium content before the experiment was 99.1mg/kg soil and it showed a slight increase from 115 to186 mg/kg after the experiment. Highest Mg content was observed in absolute control followed by farmers practice where as the lowest was in CCC 10ppm.

Available sulphur in soil was 2.14 mg/kg before the experiment and it ranged from 2 to 3.2mg/kg soil after the experiment. Soil S content after the experiment was highest in water spray, which was on par with brassinolide 1ppm, absolute control and NAA 40 ppm.

Table 12. Effect of PGRs on primary and secondary nutrient content in soil

Tr. No.	Treatments	pH	Org. C (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)
1	**CCC 10**	5.8	1.10	142.91	15.01	328.09	168.87	115.08	2.61
2	**CCC 20**	5.6	1.23	130.59	12.30	331.39	154.02	118.88	2.78
3	**SA 1 %**	5.4	1.01	130.59	13.66	333.26	163.17	123.28	2.86
4	**SA 2%**	5.6	1.02	130.59	14.33	312.91	157.57	130.08	3.03
5	**AA 1%**	5.3	1.10	122.37	13.21	324.79	169.42	135.08	2.08
6	**AA 2%**	5.5	1.20	138.80	12.75	314.23	166.27	140.08	2.40
7	**NAA 20**	5.1	1.21	138.80	15.46	309.07	178.17	145.08	2.65
8	**NAA 40**	5.2	1.21	142.91	13.43	348.01	156.72	150.71	3.11
9	**Br. 0.5**	5.4	1.03	130.59	13.21	296.20	147.57	156.33	2.49
10	**Br. 1**	5.8	1.00	142.91	15.91	354.17	153.62	161.33	3.20
11	**CW**	5.3	1.00	124.43	15.01	349.47	160.87	166.33	2.29
12	**WS**	5.4	1.06	138.80	16.14	319.66	165.72	171.33	3.26
13	**Control**	5.6	1.10	138.80	18.39	339.24	165.22	176.33	2.93
14	**FP**	5.3	1.03	134.69	13.66	341.11	170.27	181.33	3.02
15	**Abs. control**	5.1	1.22	130.59	12.75	326.37	159.77	186.33	3.14
	CD(0.05)	0.302	0.058	NS	0.006	8.80	0.005	1.855	0.22
	SEd	0.14	0.03	-	0.002	4.31	0.002	0.91	0.11

4.1.6.5. Micronutrients

Soil micronutrient status after the experiment also varied significantly among treatments.

Available iron content in the soil after the experiment showed a reduction to the range of 4.5 to 5.9 mg/kg compared to its content before the experiment (7.5mg/kg). Significantly highest Fe content in soil after the experiment was observed in water spray followed by CCC 10 ppm. Absolute control and coconut water spray was found to be the lowest in soil Fe status.

Available manganese content before the experiment was 57.7mg/kg which showed a reduction to the range of 27 to 47 mg/kg after the experiment. Highest Mn content after the experiment was recorded by absolute control and farmers practice where as the lowest was in ascorbic acid 1%.

Available zinc in soil was 1.82mg/kg before the experiment. After the experiment it ranged from 1.5 to 3.4 mg/kg. The treatment, brassinolide 0.5 ppm recorded the highest available Zn content after the experiment. A lower content was recorded by absolute control.

Available copper content in the soil before the experiment was 5.52mg/kg. It ranged to the tune of 5.1 to 7.6mg/kg after the experiment. Salicylic acid 2% showed the highest copper content after the experiment where as the lowest was in absolute control, NAA 40 ppm and water spray.

Available boron content in soil before the experiment was 0.53mg/kg. Boron content in the soil after the experiment showed a slight increase (0.5 - 0.9mg/kg) and it was highest in brassinolide 0.5 ppm. The lowest was noticed in CCC 10 ppm and NAA 20 ppm.

Table 13. Effect of PGRs on micro nutrient content in soil

Tr. No.	Treatments	Fe	Mn	Zn	Cu	B
		(mg/kg)				
1	CCC 10	5.83	34.10	2.29	5.89	0.53
2	CCC 20	5.16	37.44	2.15	6.94	0.76
3	SA 1 %	4.75	38.53	2.94	7.09	0.61
4	SA 2%	5.25	38.37	2.72	7.65	0.63
5	AA 1%	5.17	27.59	1.73	6.88	0.57
6	AA 2%	5.49	35.04	2.27	6.40	0.57
7	NAA 20	5.56	37.18	2.44	6.84	0.53
8	NAA 40	5.15	36.42	2.07	5.23	0.80
9	Br. 0.5	5.65	41.02	3.43	5.54	0.92
10	Br. 1	5.03	42.37	1.81	5.46	0.88
11	CW	4.65	30.24	1.71	5.95	0.61
12	WS	5.98	32.96	2.38	5.30	0.57
13	Control	5.01	36.00	1.76	7.07	0.61
14	FP	5.46	46.09	2.74	5.45	0.90
15	Abs. control	4.57	47.21	1.52	5.14	0.82
	CD(0.05)	0.26	2.79	0.003	0.53	0.005
	SEd	0.12	1.36	0.001	0.25	0.002

4.1.7. Soil moisture content

Soil samples were collected from a depth of 20 cm at sowing and subsequently at 15 days interval till last harvest to estimate the soil moisture content (SMC) and the data are presented in Table 14.

Soil moisture content in the field at sowing of cowpea seeds was 8.7 per cent. After sowing, uniform irrigation was given up to 5 days irrespective of treatments for germination and establishment of the crop. After 5 days, irrigation was given at 5 days interval till 15 DAS in all treatments except farmer's practice and the irrigated control, which was irrigated at alternate days and 5 days interval respectively. Further, irrigation was withheld up to 40DAS for imposing water stress in absolute control and in treatments which were sprayed with PGRs, coconut water and water. From 40 DAS, irrigation was restarted in the above treatments at 5 days interval.

In general, moisture status in the soil was very low during the entire crop period especially in water stress imposed treatments. A gradual decline in soil moisture was observed in these treatments up to 30 DAS. However at 45 DAS, water stress release from these treatments resulted in a slight increase in soil moisture content and again from 60 DAS onwards it showed a slight progressive decline.

Soil moisture status at all stages (15, 30, 45 and 60 DAS) was significantly influenced by various treatments and the highest soil moisture content was observed in farmers practice followed by the treatment irrigated at 5 days interval (except at 15 DAS).

At 15 DAS, since the crop was irrigated uniformly, soil moisture content ranged from 9 to 9.9 per cent among the treatments except in farmers practice. At 30 DAS (15 days after withholding irrigation), the soil moisture content in the water stress imposed treatments was 75.6 to 88.4 per cent less than that in farmers practice which were irrigated on alternate days. At 45 DAS, as the irrigation was restarted, soil moisture content increased to the range of 9 to 9.8 per cent from 6.9 to7.4 per cent at 30 DAS in the water stress imposed treatments whereas at 60 DAS, water stress imposed treatments including absolute control showed a reduction in soil moisture content ranging from 8.1 to 8.9 per cent. At final harvest of the crop, a still reduction in soil moisture content was noticed in all treatments compared to that at 60 DAS and it ranged from 6.1 to 7.3 per cent.

Table 14. Effect of PGRs on soil moisture content

Tr. No.	Treatments	Soil moisture content (%)				
		15DAS	30DAS	45DAS	60DAS	At final harvest
1	CCC 10	9.90	6.90	9.73	8.60	6.43
2	CCC 20	9.23	7.10	9.83	8.47	6.57
3	SA 1 %	9.83	7.00	9.73	8.90	6.77
4	SA 2%	9.23	7.33	9.23	8.17	6.37
5	AA 1%	9.00	6.90	9.10	8.50	6.20
6	AA 2%	9.20	7.23	9.00	8.77	6.77
7	NAA 20	9.73	7.10	9.43	8.20	6.80
8	NAA 40	9.20	7.23	9.73	8.87	6.80
9	Br. 0.5	9.47	7.30	9.83	8.87	6.13
10	Br. 1	9.67	7.40	9.33	8.77	6.63
11	CW	9.83	6.90	9.37	8.87	6.90
12	WS	9.90	7.33	9.73	8.77	6.77
13	Control	9.77	12.93	10.77	10.30	6.20
14	FP	13.90	13.07	13.37	12.93	7.33
15	Abs. control	9.67	7.10	9.37	8.67	6.43
	CD(0.05)	0.55	0.406	0.487	0.503	0.38
	SEd	0.26	0.19	0.23	0.24	0.18

4.2. Effect of seed priming, antitranspirants and moisture conservation practices in mitigating water stress

The experiment was conducted to evaluate the efficacy of seed priming, mulching and use of antitranspirants in mitigating water stress in vegetable cowpea.

4.2.1. Growth characters

Effect of seed priming, antitranspirant spray and mulching on various growth characters of vegetable cowpea are presented in Table 15. General growth of the crop was less than normal due to the extreme dry condition prevailed during the entire crop growth period (Appendix I & II).

4.2.1.1. Plant height

The general height of cowpea plants was less due to the unfavourable weather conditions prevailed during the crop season and it ranged from 9.4 to 11.5 cm at 60 DAS. However, plant height at 15 and 45 DAS was significantly influenced by various seed priming, antitranspirant spray and mulching practices.

At 15 DAS, the tallest plants (6.8cm) were observed in plant residue mulching (PRM) followed by lime water spray (5.9cm) and the smallest in seed priming with NaCl. Various seed primers could not bring about any significant influence in plant height at 15 DAS. However, PRM recorded a significantly higher plant height compared to plastic mulching.

At 30 DAS also, PRM resulted in tallest plants even though there was no significant difference among treatments. However by 45 DAS, farmers practice recorded the tallest plants and it was on par with PRM, seed priming with $CaCl_2$, mulching with polythene, irrigation at 5 days interval, seed priming with KH_2PO_4 and lime water spray, where as the absolute control recorded the smallest ones.

Spraying of antitranspirants, kaolin and atrazine during water stressed imposed period were not found effective on plant height and were on par with absolute control.

At 60 DAS, seed priming with KH_2PO_4, PRM and lime water spray recorded numerically higher plant height as that in farmers practice even though they were on par with the remaining treatments.

4.2.1.2. Number of leaves

Number of leaves of cowpea plants was not significantly influenced by any of the treatments at 15, 30 and 60 DAS. However, at 45 DAS, plants irrigated on alternate days (farmer's practice) recorded the highest leaf number of 12.3 which was on par with those irrigated at 5 days interval (10.7) and there was no significant difference among various seed primers, mulches and antitranspirants. However, seed priming with NaCl, plastic mulching and lime water spray recorded 32, 30 and 43 per cent higher number of leaves per plant than absolute control.

At 60 DAS, there was a decline in the number of leaves per plant in farmers practice and in irrigation at 5 days interval due to attainment of early maturity. The treatments which received seed priming, antitranspirant spray or mulching resulted in an increasing trend in number of leaves from 15 to 66 per cent compared to that which received no treatment during the period. Moreover, seed priming with NaCl, plastic mulching and lime water spray recorded numerically higher number of leaves than other seed primers, PRM and other antitranspirants respectively even though they were on par with each other.

Table 15. Effect of seed primers, mulches and antitranspirants on plant biometry

Treatments	Plant height (cm)				No. of leaves				No. of branches			Leaf area index (LAI)			Root length (cm)	Root Shoot ratio	Days to flowering
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	20 DAS	40 DAS	60 DAS			
1. $CaCl_2$	5.60	5.83	7.73	10.50	3.06	6.53	7.50	9.33	0.13	0.46	2.00	0.05	0.20	0.27	14.66	0.20	46.33
2. NaCl	5.26	5.80	7.20	10.23	3.06	6.50	7.96	10.16	0.00	1.26	3.33	0.05	0.24	0.30	15.16	0.26	47.33
3. KH_2PO_4	5.70	6.26	7.53	11.06	3.20	5.86	6.36	8.73	0.00	1.00	2.53	0.06	0.20	0.24	15.03	0.20	45.66
4. PM	5.56	6.10	7.73	9.53	3.20	6.80	7.80	9.23	0.33	1.06	2.33	0.06	0.20	0.33	15.26	0.26	48.66
5. PRM	6.86	7.06	8.26	11.03	3.00	6.50	6.66	8.36	0.00	0.40	2.10	0.06	0.24	0.29	15.00	0.26	48.66
6. Kaolin	5.60	5.93	7.03	9.73	3.06	5.26	6.80	7.36	0.00	0.13	1.36	0.06	0.17	0.24	14.53	0.20	49.00
7. LWS	5.96	6.66	7.43	11.50	3.20	6.16	8.63	9.20	0.06	0.53	2.60	0.06	0.29	0.37	15.00	0.20	48.66
8. Atrazine	5.50	6.10	6.76	9.73	3.00	5.96	6.30	7.03	0.00	0.13	1.20	0.05	0.15	0.24	13.33	0.20	49.00
9. Control	5.53	5.93	7.60	9.93	3.13	6.76	10.73	7.90	0.00	1.00	2.36	0.06	0.39	0.36	15.30	0.20	45.00
10. FP	5.46	6.06	8.43	11.33	3.13	6.86	12.33	11.46	0.00	2.06	3.73	0.06	0.39	0.38	15.60	0.20	45.00
11. Abs. control	5.76	6.06	6.43	9.46	3.00	5.20	6.00	6.16	0.00	0.06	1.36	0.04	0.15	0.16	11.16	0.20	49.00
CD(0.05)	0.62	NS	1.12	NS	NS	NS	2.48	NS	NS	0.91	0.82	0.01	0.01	0.009	2.06	0.054	3.02
SEd	0.29	-	0.53	-	-	-	1.18	-	-	0.43	0.39	0.004	0.004	0.004	0.98	0.02	1.44

4.2.1.3. Number of branches

There were no branches at 15 DAS. At 30 DAS, branches were noted only in seeds primed with $CaCl_2$, plastic mulched and lime water sprayed plots. At 45 and 60 DAS, farmers practice recorded the highest number of branches per plant and it was on par with seed priming with NaCl whereas spraying of antitranspirants, kaolin and atrazine during water stressed imposed period were not found effective and were on par with absolute control. Mulching with either plastic or plant residue was found statistically on par with the treatment irrigated at 5 days interval. Among antitranspirants, lime water spray recorded a higher number of branches per plants at 60 DAS.

4.2.1.4. Leaf area index

Leaf area index (LAI) of cowpea plants increased progressively up to 60 DAS in all treatments except in farmers practice and irrigation at 5 days interval. The decline in leaf area index in these treatments at 60 DAS was due to the leaf fall as a result of attainment of early maturity. In general, all the treatments (except atrazine at 40 DAS) recorded significantly higher leaf area index compared to absolute control at all of stages of observation.

Leaf area index at 20 DAS did not show much variation among the treatments. However at 40 DAS, leaf area index varied significantly among treatments and it was highest in treatments irrigated on alternate days and at 5 days interval. Among seed primers, mulches and antitranspirants, highest leaf area index was recorded by NaCl, plant residue mulch and lime water spray respectively. Plants sprayed with atrazine recorded the lowest LAI and it was on par with absolute control.

At 60 DAS, farmers practice recorded the highest leaf area index and it was found to be on par with limewater spray which in turn was on par with irrigation at 5 days interval. Plastic mulching recorded significantly higher LAI compared to plant residue mulching. Among seed primers, the highest LAI was recorded by NaCl.

4.2.1.5. Root length

All the treatments recorded significantly higher root length compared to absolute control. Highest root length of 15.6 cm was observed in farmers' practice which was on par with other treatments except atrazine spray and absolute control. All drought mitigation treatments resulted in an increase in root length ranging from 20 to 37 per cent compared to absolute control.

4.2.1.6. Root:shoot ratio

Root shoot ratio of cowpea plants were significantly influenced by various drought mitigation treatments. Highest root shoot ratio was recorded by mulching with either plant residue or polythene and seed priming with NaCl which were significantly superior to all other treatments.

4.2.1.7. Days to flowering

The variety *Kashi Kachan* flowers in 40-45 DAS under favorable conditions. Comparatively early flowering (45 DAS) was noted in treatments irrigated on alternate days and at 5 days interval which were on par with seed priming treatments. All water stress mitigating treatments showed a slight delay of one to four days (46 to 49 DAS) in attaining 50 per cent flowering.

4.2.2. Physiological parameters

Observations on physiological parameters were recorded at 35 DAS (10 days after the foliar spray of antitranspirants). Effect of treatments on various physiological parameters of cowpea plants are presented in Table 16.

4.2.2.1. Stomatal conductance

Highest stomatal conductance was observed in farmers practice followed by plant residue mulching and seed priming with $CaCl_2$ and the lowest in kaolin and lime water spray as antitranspirants.

4.2.2.2. Transpiration rate

Transpiration rate recorded the same trend as that of stomatal conductance. Highest transpiration rate was observed in farmers practice followed by plant residue mulching and seed priming with $CaCl_2$ and the lowest in kaolin and lime water spray as antitranspirants.

4.2.2.3. Photosynthetic rate

Photosynthetic rate also followed the same trend as that of stomatal conductance and transpiration rate. Highest photosynthetic rate was observed in farmers practice followed by the plant residue mulching and seed priming with $CaCl_2$ and the lowest in kaolin and lime water spray as antitranspirants.

4.2.2.4. Chlorophyll content

Among water stress mitigation treatments, higher chlorophyll content was recorded by seed priming either with NaCl or $CaCl_2$, mulching either with polythene or plant residues and lime water spray as antitranspirant and they were on par with the treatments irrigated on alternate days and at 5 days interval. Lower chlorophyll content was recorded by atrazine and kaolin as antitranspirant spray and they were on par with absolute control. Water stress mitigation treatments (except kaolin and atrazine as antitranspirants) could increase the chlorophyll content of cowpea plants to the tune of 8 to 70 per cent compared to absolute control.

4.2.2.5. Relative leaf water content

Highest relative leaf water content was recorded by farmers practice. Among water stress mitigation treatments, higher relative leaf water content was recorded by seed priming either with NaCl or KH_2PO_4 and mulching either with polythene or plant residues and they were on par with treatments irrigated on alternate days (farmers practice) and at 5 days interval. Lime water spray was found to be on par with the above treatments except farmers practice. Lowest relative leaf water content was recorded by kaolin followed by atrazine as antitranspirants, seed priming with $CaCl_2$ and absolute control. Various water stress mitigation treatments (except kaolin, atrazine and seed priming with $CaCl_2$) increased the relative leaf water content to the range of 15 to 41 per cent compared to absolute control.

Table 16. Effect of seed primers, mulches and antitranspirants on physiological parameters of crop

Tr. No.	Treatments	RLWC* (%)	Total Chlorophyll (mg/g plant)	Photosynthetic rate (μ mol CO_2/m^2 /sec)	Transpiration rate (m mol H_2O/ m^2/ sec)	Stomatal conductance (mol H_2O / m^2/ sec)
1	**$CaCl_2$**	22.60	0.17	19.12	2.99	0.28
2	**NaCl**	33.90	0.20	13.93	2.19	0.22
3	**KH_2PO_4**	31.50	0.14	13.90	2.19	0.23
4	**PM**	33.10	0.16	16.39	2.49	0.23
5	**PRM**	32.37	0.17	21.27	3.17	0.29
6	**Kaolin**	11.83	0.12	13.63	2.15	0.20
7	**LWS**	27.63	0.19	13.65	2.16	0.20
8	**Atrazine**	16.90	0.08	14.42	2.27	0.24
9	**Control**	31.10	0.19	14.15	2.20	0.22
10	**FP**	35.60	0.21	27.90	3.32	0.89
11	**Abs. control**	24.07	0.12	15.99	2.43	0.27
	CD(0.05)	7.75	0.051	0.19	0.015	0.005
	SEd	3.7	0.02	0.09	0.007	0.002

*Relative leaf water content

4.2.3. Yield attributes and yield

Effect of various seed primers, mulches and antitranspirants on yield and yield attributes of vegetable cowpea are presented in Table 17. General yield of the crop was low due to the effect of extreme dry condition prevailed during the crop period (Appendix I & II) on vegetative growth, flowering and yield attributes combined with aphid infestation.

4.2.3.1. Number of pods per plant

Number of pods per plant was significantly influenced by various treatments. Highest number of pods per plant was recorded by farmers' practice which was irrigated on alternate days followed by seed priming with NaCl, treatment irrigated at 5 days interval and polythene mulching. The lowest number of pods was noticed in absolute control which received no treatment during water stress imposed period. Among antitranspirants, exogenous application of lime water recorded a higher number of pods per plant (77% over absolute control) even though it was on par with kaolin and atrazine.

4.2.3.2. Pod length

The data showed that pod length of cowpea plants was significantly influenced by seed primers, mulches and antitranspirants. However, longest pods were observed in seed priming with $CaCl_2$, which was on par with other treatments except kaolin, atrazine and absolute control.

4.2.3.3. Number of seeds per pod

None of the treatments could influence the number of seeds per pod of cowpea plants. However, the highest number of seeds per pod was recorded by farmers' practice which received irrigation on alternate days and the lowest by absolute control. A numerically higher number of seeds per pod was recorded by plastic mulching and seed primed with KH_2PO_4.

4.2.3.4. Pod weight

Pod weight of cowpea plants was significantly influenced by various treatments. Seed priming either with NaCl or KH_2PO_4 or $CaCl_2$ and mulching with plant residues recorded a higher pod weight and were on par with the treatment irrigated at 5 days interval. Among antitranspirants, lime water spray recorded a significantly higher pod weight compared to kaolin and atrazine. All water stress mitigation treatments showed an increasing trend in pod weight ranging from 29 to 77 per cent compared to absolute control.

4.2.3.5. Pod yield (per plant, per plot and per hectare)

Pod yield per plant was significantly influenced by various treatments. Highest pod yield per plant was recorded by farmers' practice which received irrigation on alternate days followed by the treatment irrigated at 5 days interval whereas the lowest by absolute control. Among water stress mitigation treatments, plastic mulching recorded the highest pod yield per plant and it was found to be on par with plant residue mulching. Among seed primers, NaCl was found to be superior in pod yield per plant than $CaCl_2$ and KH_2PO_4. Lime water spray recorded 25 to 27 percent higher pod yield per plant compared to atrazine and kaolin respectively.

Pod yield per plot also showed the same trend as that of pod yield per plant. Highest pod yield per plot was obtained from farmers' practice followed by the treatment irrigated at 5 days interval whereas the lowest by absolute control. Among water stress mitigation treatments, plastic mulching recorded the highest pod yield per plot (181% higher than absolute control) and it was found to be on par with plant residue mulching. Seed priming with NaCl resulted in 35 per cent increase in pod yield compared to $CaCl_2$ and KH_2PO_4. Among antitranspirants, lime water was found better than kaolin and atrazine spray in terms of yield per plot.

Pod yield per hectare also showed the same trend as that of pod yield per plant and per plot. The highest pod yield per hectare was recorded by farmers' practice (5111 kg/ha) and the lowest by absolute control. Among water stress mitigation treatments, plastic mulching recorded the highest pod yield of 2344 kg/ha which was found to be on par with plant residue mulching (2177 kg/ha). Among seed primers, NaCl recorded significantly highest pod yield per hectare compared to $CaCl_2$ and KH_2PO_4. Among antitranspirants, lime water spray, was found to be better than kaolin and atrazine even though the effect was not significant.

4.2.3.6. Stover yield (per plot and per hectare)

Stover yield of the crop per plot and per hectare showed the same trend and was significantly influenced by various treatments. The highest stover yield was recorded by farmers practice (6065 kg/ha) and the treatment which received irrigation at 5 days (4422 kg/ha) interval and the lowest by absolute control. Among water stress mitigation treatments, plastic mulching recorded the highest stover yield (197 percent higher than that obtained from absolute control) and it was on par with plant residue mulching and seed priming with NaCl. Among antitranspirants, lime water spray recorded 63 and 108 per cent higher stover yield per hectare than atrazine and kaolin respectively.

4.2.3.7. Dry matter accumulation

Dry matter accumulation in cowpea plants during the cropping period was significantly influenced by various treatments. Farmers practice recorded significantly higher dry matter accumulation (2471 kg/ha) compared to all other

Table 17. Effect of seed primers, mulches and antitranspirants on yield attributes and yield of crop

Treatments	Pod No. /plant	Pod length (cm)	Seeds /pod	Pod weight (g)	No. of harvest	Pod yield /plant (g)	Pod yield /plot (g)	Pod yield (kg/ha)	Stover yield (kg/ha)	DMP(at harvest) (kg/ha)
1. $CaCl_2$	2.66	27.76	12.70	8.40	1.66	13.00	117.00	1444.44	2885.18	940.41
2. NaCl	4.00	26.20	12.43	8.53	2.00	17.56	158.10	1951.85	3038.27	1177.77
3. KH_2PO_4	2.66	26.73	12.90	8.43	1.66	13.06	117.60	1451.85	2960.90	826.33
4. PM	3.13	26.60	13.06	8.33	2.00	21.10	189.90	2344.44	3553.08	1155.55
5. PRM	2.70	26.20	12.26	8.46	1.66	19.60	176.40	2177.77	3124.28	999.58
6. Kaolin	1.66	22.96	12.16	6.23	1.66	10.60	95.40	1177.77	1311.11	532.51
7. LWS	2.33	27.10	12.43	8.23	2.00	13.53	121.80	1503.70	2725.92	840.74
8. Atrazine	1.66	22.33	12.33	6.26	1.66	10.86	97.80	1207.40	1674.07	605.92
9. Control	4.00	26.66	14.83	8.96	3.00	32.96	296.70	3662.96	4422.22	1406.17
10. FP	7.66	26.40	14.90	8.20	4.00	46.00	414.00	5111.11	6065.02	2471.19
11. Abs. control	1.33	21.66	11.26	4.80	1.00	7.50	67.50	833.33	1194.23	395.06
CD(0.05)	1.036	1.778	NS	0.629	0.779	3.38	30.46	376.15	529.54	184.07
SEd	0.49	0.85	-	0.030	0.37	1.61	14.57	179.9	253.3	88.01

treatments where as absolute control recorded the lowest (395 kg/ha). All treatments tried for mitigating water stress could bring about 35 to 198 per cent increase in total dry matter production compared to no treatment during the crop period. Among the seed primers, NaCl recorded the highest dry matter accumulation. Dry matter accumulation in polythene mulched treatments was found to be on par with that in plant residue mulched ones. Among antitranspirants, lime water spray recorded the highest dry matter accumulation.

4.2.3.8. Number of harvests

As in the case of first experiment, the number of harvests was low due to low pod yield as a result of exposure of plants to unfavourable weather conditions during the entire crop period combined with infestation of aphids. The data showed that various treatments significantly influenced the number of harvests of the crop. The highest number of harvests (4 harvests) was done in farmers practice followed by the treatment which was irrigated at 5 days interval (3 harvests) and the lowest of one harvest was in absolute control. Among seed primers, mulches and antitranspirants, NaCl, polythene mulch and lime water spray were found to be the best treatments which in turn were on par with each other (2 harvests).

4.2.3.9. Duration of the crop

Cowpea plants in treatments which received irrigation on alternate days and at 5 days interval attained final maturity (65 days) earlier than the remaining treatments. All other treatments extended the duration of the crop by one week (72 days) without any variation among them.

4.2.4. Quality parameters

Effect of either seed primers, or mulches or antitranspirants on protein content in pod and stover of vegetable cowpea are presented in Table 18.

4.2.4.1. Protein content in pod

Various water stress mitigation treatments significantly influenced the protein content in pod of cowpea. The highest protein content in pod was observed in farmers' practice it was on par with irrigation at 5 days interval and seed priming either with NaCl or KH_2PO_4. Mulching either with plant residues or with polythene and spraying antitranspirants during the water stress imposed period could not bring about any significant change in pod protein content compared to absolute control. All water stress mitigation treatments except seed priming with $CaCl_2$, showed an increasing trend in pod protein content to the tune of 1.2 to 24 per cent compared to absolute control.

4.2.4.2. Protein content in stover

Protein content in stover also varied significantly among various treatments. Among water stress mitigation treatments, seed priming either with $CaCl_2$ or NaCl, polythene mulching and lime water spray recorded significantly higher stover protein content and they were on par with farmers practice and the treatment irrigated at 5 days interval.

Table 18. Effect of seed primers, mulches and antitranspirants on protein content of crop

Tr. No.	Treatments	Pod (%)	Stover (%)
1	**$CaCl_2$**	13.33	5.50
2	**NaCl**	20.42	5.35
3	**KH_2PO_4**	18.75	4.39
4	**PM**	16.88	5.50
5	**PRM**	18.12	4.42
6	**Kaolin**	18.54	4.69
7	**LWS**	17.50	5.50
8	**Atrazine**	16.67	4.38
9	**Control**	18.96	5.31
10	**FP**	21.04	5.50
11	**Abs. control**	16.46	4.38
	CD(0.05)	2.35	0.328
	SEd	1.12	0.16

4.2.5. Nutrient uptake by the crop

Analysis of plant and pod samples from each treatment plots at final harvest was done to estimate primary (N, P, K), secondary (Ca, Mg, S), micro (Fe, Mn, Zn, Cu, B) and beneficial (Na) nutrient contents (Appendix IV) and their uptake by the crop was calculated. Among these, content of sodium and copper in cowpea plants in all treatments were below detectable level. Effect of various seed primers, mulches and antitranspirant sprays on elemental uptake by vegetable cowpea is shown in Table 19 and 20.

4.2.5.1. Primary nutrients

In general, unfavourable weather especially extreme dry condition led to a reduced uptake of all nutrients by the crop and thereby a lower growth and yield. However, uptake of nitrogen (N) was significantly influenced by various treatments. Significantly higher nitrogen uptake by the crop was noted in farmers' practice (41.2 kg/ha) which was irrigated on alternate days followed by the treatment irrigated at 5 days interval and the lowest by absolute control. Seed priming with NaCl resulted in significantly higher nitrogen uptake compared to all other water stress mitigation treatments. Mulching either with polythene or with plant residues was found beneficial for improving N uptake by the crop. Among antitranspirants, lime water spray was found to be better, with an N uptake 36 to 41 per cent higher than that of kaolin and atrazine respectively.

Phosphorus (P) uptake by the crop also varied significantly among treatments with the highest uptake of 7.2 kg/ha in farmers practice irrigated on alternate days followed by the treatment irrigated at 5 days interval. Lowest uptake was recorded by absolute control followed by application of kaolin and atrazine. Seed priming with NaCl and polythene mulching were statistically on par with each other and resulted in a significantly higher P uptake compared to other treatments. Among antitranspirants, lime water spray recorded a better P uptake compared to kaolin and atrazine.

Potassium (K) uptake by the crop was also significantly influenced by various treatments and showed the same trend as that of P uptake. Highest K uptake was observed in farmers practice and the lowest in absolute control. Among the water stress mitigation treatments, polythene mulching recorded the highest K uptake (261% higher than that of absolute control) and it was on par with seed priming with NaCl. Among antitranspirants, lime water spray recorded a significantly higher P uptake compared to kaolin and atrazine.

4.2.5.2. Secondary nutrients

Calcium (Ca) uptake by the crop was significantly influenced by the treatments. Highest calcium uptake was noticed in farmers practice followed by the treatment irrigated at 5 days interval and the lowest in absolute control. Among water stress mitigation treatments polythene mulching recorded the highest Ca uptake (6 kg/ha) and it was found to be on par with irrigation at 5 days interval and lime water spray. Seed priming either with $CaCl_2$ or with NaCl was found to be better than that with KH_2PO_4.

Magnesium (Mg) uptake by the crop was significantly influenced by various treatments. The highest Mg uptake was recorded by farmers practice followed by the treatment irrigated at 5 days interval and the lowest by absolute control. Among water stress mitigation treatments, polythene mulching recorded the highest Mg uptake and it was statistically on par with irrigation at 5 days interval, plant residue mulching and seed priming with NaCl. Among antitranspirants, lime water spray recorded the highest Mg uptake compared to others.

Sulphur (S) uptake by the crop was significantly influenced by various treatments. The highest S uptake was recorded by farmers practice followed by the treatment irrigated at 5 days interval and the lowest uptake by absolute control. Polythene mulching was found to be significantly superior to all other water stress mitigation treatments, followed by seed priming with NaCl. Among antitranspirants, lime water spray recorded significantly higher S uptake compared to kaolin and atrazine.

Table 19. Effect of seed primers, mulches and antitranspirants on primary and secondary nutrient uptake by the crop

Tr. No.	Treatments	Nutrient uptake (kg/ha)					
		N	P	K	Ca	Mg	S
1	$CaCl_2$	12.58	2.02	22.09	5.23	2.10	0.59
2	NaCl	22.39	3.13	26.81	5.11	2.69	0.97
3	KH_2PO_4	11.11	1.49	20.41	3.97	1.67	0.49
4	PM	16.81	2.86	30.03	6.00	3.05	1.32
5	PRM	14.72	2.43	25.16	4.80	2.72	0.59
6	Kaolin	8.82	1.14	12.12	1.86	1.15	0.29
7	LWS	12.02	1.73	19.92	5.72	1.93	0.48
8	Atrazine	8.53	1.27	12.09	2.14	1.22	0.22
9	Control	24.25	4.04	34.44	6.34	3.47	1.50
10	FP	41.22	7.29	68.46	14.73	6.10	2.73
11	Abs. control	5.25	0.57	8.33	1.37	0.79	0.12
	CD(0.05)	3.67	0.49	4.38	1.006	0.43	0.16
	SEd	1.75	0.23	2.09	0.51	0.21	0.07

4.2.5.3. Micro nutrients

Various water stress mitigation treatments significantly influenced the iron (Fe) uptake by the crop. Farmers practice was found to be significantly superior to all other treatments and it was followed by irrigation at 5 days interval. The next best treatments were polythene mulching, seed priming with NaCl and plant residue mulching which were on par with each other. Foliar spray of lime water as antitranspirant was found to be significantly superior to kaolin and atrazine. The lowest Fe uptake was observed in absolute control which was found to be on par with kaolin spray.

Manganese (Mn) uptake was highest in farmers' practice which was irrigated on alternate days. Polythene mulching recorded the highest Mn uptake among water stress mitigation treatments and it was on par with the treatment irrigated at 5 days interval followed by the treatments, seed priming with NaCl, plant residue mulching and seed priming with $CaCl_2$ where as the lowest was noticed in absolute control. Lime water spray was significantly superior to kaolin and atrazine with regard to Mn uptake.

Table 20. Effect of seed primers, mulches and antitranspirants on micro nutrient uptake by the crop

Tr. No.	Treatments	Nutrient uptake (kg/ha)			
		Fe	Mn	Zn	B
1	**$CaCl_2$**	0.78	0.98	0.03	0.01
2	**NaCl**	0.99	1.19	0.05	0.02
3	**KH_2PO_4**	0.76	0.94	0.03	0.01
4	**PM**	1.01	1.44	0.05	0.01
5	**PRM**	0.92	1.01	0.03	0.01
6	**Kaolin**	0.30	0.49	0.02	0.01
7	**LWS**	0.77	0.92	0.03	0.01
8	**Atrazine**	0.41	0.52	0.02	0.01
9	**Control**	1.24	1.51	0.08	0.02
10	**FP**	2.24	3.24	0.16	0.03
11	**Abs. control**	0.17	0.41	0.01	0.01
	CD(0.05)	0.175	0.23	0.009	0.004
	SEd	0.08	0.11	0.004	0.001

Zinc (Zn) uptake showed the same trend as that of iron uptake by the crop and was significantly influenced by various treatments. Highest zinc uptake was recorded by farmers practice followed by the treatment irrigated at 5 days interval and the lowest by absolute control. Among seed primers, NaCl was significantly superior to $CaCl_2$ and KH_2PO_4 and it was on par with polythene mulching. A higher Zn uptake was observed in lime water spray compared to other antitranspirants.

Boron (B) uptake by the cowpea crop was significantly varied among the treatments. The highest boron uptake was recorded by farmers practice followed by irrigation at 5 days interval and the lowest by absolute control. Seed priming with NaCl resulted in a boron uptake on par with irrigation at 5 days interval, polythene/plant residue mulching and seed priming with calcium chloride. Among antitranspirants, lime water spray was found better compared to kaolin and atrazine.

4.2.6. Soil characters

Soil samples collected from each treatment after the final harvest of the crop were analysed for pH, organic carbon, primary, secondary and micro nutrients and the data are presented in Table 21 and 22.

4.2.6.1. Soil pH

Soil pH in various treatments after the experiment (5.2-5.9) did not show much variation compared to that before the experiment (5.4). However a slight increase in soil pH was noticed in farmers' practice, treatment irrigated at 5 days interval, lime water spray, kaolin spray, absolute control and seed priming with $CaCl_2$.

4.2.6.2. Soil organic carbon

Organic carbon status of soil after the experiment did not show much variation among various treatments and it ranged from 1.2 to 1.3 per cent compared to that of 1.2 per cent before the experiment.

4.2.6.3. Primary nutrients

Available nitrogen content in the soil before the experiment was 156.1 kg/ha and it got reduced to the extent of 123 to 143 kg/ha after the experiment and was not varied significantly among treatments. However, numerically higher soil N content was observed in seed priming with NaCl.

Available phosphorus content in soil before the experiment was 21.9 kg/ha which showed a reduction to the tune of 10.7 to 18.8 kg/ha after the experiment. Significantly highest P content was noticed in treatment irrigated at 5 days interval followed by seed priming with KH_2PO_4 and atrazine spray where as the lowest by absolute control.

Available potassium content in the soil before the experiment was 378.8 kg/ha and it ranged from 331-395 kg/ha after the experiment. However, the available K content after the experiment varied significantly among treatments. Highest K content was recorded by farmers practice followed by plant residue mulching, atrazine and lime water as antitranspirant where as the lowest by absolute control and seed priming with KH_2PO_4.

4.2.6.4. Secondary nutrients

Water stress mitigation treatments significantly influenced the Ca, Mg and S content in soil after the experiment.

Available calcium content in soil before the experiment was 179.5 mg/kg. After the experiment, soil calcium content ranged from 158 to 189 mg/kg soil. Highest Ca content was recorded by plant residue mulching which was on par with irrigation at 5 days interval and polythene mulching whereas the lowest was by atrazine spray.

Available magnesium content before the experiment was 99.1mg/kg soil and it showed a range of 98 - 117 mg/kg after the experiment. Seed priming with KH_2PO_4 or NaCl were on par with each other, in having highest Mg content where as the lowest was in lime water spray as antitranspirant and plant residue mulching.

Available sulphur content in soil before the experiment was 2.14 mg/kg and it showed an increase after the experiment (2.6-3.2 mg/kg soil). Soil S content after the experiment was highest in absolute control followed by the treatment irrigated at 5 days interval whereas the lowest was recorded in atrazine spray.

Table 21. Effect of seed primers, mulches and antitranspirants on primary and secondary nutrient content in soil

Tr. No.	Treatments	pH	Org. C (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)
1	**$CaCl_2$**	5.6	1.20	131.41	16.37	342.43	163.03	111.81	2.79
2	**NaCl**	5.2	1.24	143.73	13.44	363.55	171.28	115.01	2.87
3	**KH_2PO_4**	5.2	1.21	135.52	17.05	339.02	167.33	117.36	2.70
4	**PM**	5.3	1.22	123.20	14.57	344.85	177.38	108.76	2.87
5	**PRM**	5.4	1.24	127.30	13.21	384.78	189.20	98.60	2.95
6	**Kaolin**	5.8	1.24	135.52	12.99	362.23	163.65	104.90	3.04
7	**LWS**	5.9	1.24	131.41	13.89	373.78	171.00	98.05	2.70
8	**Atrazine**	5.5	1.30	127.30	17.05	377.77	158.68	104.05	2.63
9	**Control**	5.7	1.24	127.30	18.85	343.45	183.58	110.30	3.12
10	**FP**	5.9	1.23	135.52	14.57	395.81	173.68	107.30	2.79
11	**Abs. control**	5.6	1.26	135.52	10.73	331.24	160.03	112.15	3.20
	CD(0.05)	0.34	NS	NS	0.005	22.91	12.15	3.83	0.005
	SEd	0.16	-	-	0.002	10.9	5.81	1.83	0.002

4.2.6.5. Micronutrients

Soil micronutrient status after the experiment also varied significantly among treatments.

Available iron content in the soil after the experiment showed a range of 4.8 to 7.8 mg/kg compared to its content before the experiment (7.5mg/kg). Farmers practice recorded significantly higher iron content followed by kaolin spray and the treatment irrigated at 5 days interval whereas the lowest was noticed in seed priming either with NaCl or KH_2PO_4 and polythene mulching.

Available manganese content before the experiment was 57.7mg/kg which showed a reduction to the range of 36 to 49.9 mg/kg after the experiment. Significantly highest Mn content was observed in lime water spray and all other treatments (except farmers' practice, seed priming with KH_2PO_4 and absolute control) were on par with lime water spray.

Available zinc content in soil before the experiment was 1.82mg/kg. After the experiment it ranged from 1.0 to 1.7mg/kg. Among treatments, atrazine spray recorded significantly highest zinc content and the lowest was recorded by seed priming with NaCl and farmers practice.

Available copper content in the soil before the experiment was 5.52mg/kg. Copper content to the tune of 4.7 to 8.7 mg/kg was noticed after the experiment. Significantly highest copper content after the experiment was noticed in farmers practice. Seed priming either with NaCl or KH_2PO_4 and polythene mulching were on par with irrigation at 5 days interval, where as the lowest in kaolin spray.

Available boron content in soil before the experiment was 0.53mg/kg which showed a range of 0.26 - 0.67 mg/kg after the experiment. Highest boron content was observed in irrigation at 5 days interval followed by farmers practice and atrazine spray whereas the lowest was noticed in lime water spray, seed priming with $CaCl_2$ or NaCl.

Table 22. Effect of seed primers, mulches and antitranspirants on micro nutrient content in soil

Tr. No.	Treatments	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)
1	**$CaCl_2$**	5.92	46.53	1.53	5.66	0.26
2	**NaCl**	4.87	45.73	1.08	6.96	0.26
3	**KH_2PO_4**	4.96	36.34	1.21	6.91	0.34
4	**PM**	4.95	49.06	1.48	6.44	0.36
5	**PRM**	5.77	48.29	1.28	5.59	0.30
6	**Kaolin**	7.06	49.65	1.45	4.73	0.30
7	**LWS**	6.17	49.94	1.27	5.44	0.26
8	**Atrazine**	5.71	48.78	1.72	5.28	0.55
9	**Control**	6.66	44.95	1.55	6.81	0.67
10	**FP**	7.80	42.64	1.02	8.76	0.63
11	**Abs. control**	6.15	36.19	1.43	5.56	0.36
	CD(0.05)	0.484	5.61	0.08	0.85	0.03
	SEd	0.23	2.67	0.03	0.41	0.01

4.2.7. Soil moisture content

Soil samples were collected from a depth of 20cm at sowing and subsequently at 15 days interval till last harvest to estimate the soil moisture content (SMC) and the data are presented in Table 23.

Soil moisture content in the field at sowing of cowpea seeds was 8.7 per cent. After sowing, uniform irrigation was given up to 5 days irrespective of treatments for germination and establishment of the crop. After 5 days, farmers practice was irrigated on alternate days and irrigated control at 5 days interval. Absolute control and spraying antitranspirants were irrigated at 5 days interval with imposition of water stress from 15 to 40 DAS. Seed priming and mulching treatments were irrigated at 10 days interval.

In general, moisture status in the soil was very low during the entire crop period especially in treatments sprayed with antitranspirants and in absolute control. A gradual decline in soil moisture was observed in these treatments up to 30 DAS whereas mulching and seed priming treatments showed an increase at 30

DAS due to the receipt of irrigation at 25 DAS. However at 45 DAS, water stress release from treatments sprayed with antitranspirants and absolute control resulted in a slight increase in soil moisture content which again showed a slight progressive decline from 60 DAS onwards.

Soil moisture status at all stages of observation (15, 30, 45, 60 DAS and at final harvest) was significantly influenced by various treatments and the highest soil moisture content was observed in farmers practice (except at final harvest).

At 15 DAS among the water stress mitigation treatments, significantly higher soil moisture content was recorded by the treatments mulched either with polythene or plant residues and they were found significantly superior to the treatment irrigated at 5 days interval whereas a lower moisture status was noticed in seed priming treatments.

At 30 DAS (15 days after withholding irrigation), the highest the soil moisture content was observed in farmers practice followed by those irrigated at 5 days interval whereas the lowest in absolute control. Among the water stress mitigation treatments, mulching either with polythene or plant residues recorded significantly higher soil moisture content to the tune of 70 to 75 per cent compared to absolute control. Seed priming treatments recorded a higher soil moisture content compared to antitranspirants and absolute control.

At 45 DAS also highest the soil moisture content was observed in farmers practice followed by those irrigated at 5 days interval. Among water stress mitigation treatments, polythene mulching recorded significantly higher moisture content and it was on par with plant residue mulching, treatments sprayed with antitranspirants and seed priming with KH_2PO_4. In general, lower soil moisture content was noted in seed priming treatments.

At 60 DAS and at final harvest the superiority of farmers practice, irrigation at 5 days interval and mulching treatments was maintained. Soil moisture status in treatments sprayed with antitranspirants during the water stress imposed period was significantly inferior to irrigation at 5 days interval at 60 DAS whereas it was on par with the same at final harvest.

Table 23. Effect of seed primers, mulches and antitranspirants on soil moisture content

Tr. No.	Treatments	Soil moisture content (%)				
		15DAS	30DAS	45DAS	60DAS	At final harvest
1	**$CaCl_2$**	8.47	9.77	8.17	8.97	6.37
2	**NaCl**	8.90	9.37	8.03	8.47	5.97
3	**KH_2PO_4**	8.97	9.70	8.97	8.20	6.43
4	**PM**	11.20	10.76	9.47	9.37	8.77
5	**PRM**	10.57	11.00	9.23	9.90	8.50
6	**Kaolin**	9.73	7.73	9.43	8.33	6.67
7	**LWS**	9.67	7.50	9.20	8.27	6.80
8	**Atrazine**	9.90	7.40	9.33	8.30	6.90
9	**Control**	9.57	11.53	10.47	9.37	6.57
10	**FP**	12.33	13.57	12.50	10.77	7.83
11	**Abs. control**	9.37	6.30	8.90	8.50	6.03
	CD(0.05)	0.54	0.46	0.55	0.51	0.45
	SEd	0.25	0.22	0.26	0.24	0.21

4.3. Effect of nutrient management in mitigating water stress

The experiment was conducted to evaluate the effect of various nutrient management practices in mitigating water stress in vegetable cowpea.

4.3.1. Growth characters

Effect of various nutrient management practices on growth characters of vegetable cowpea are presented in Table 24. General growth of the crop was less than normal due to the extreme dry condition prevailed during the entire crop growth period (Appendix I & II).

4.3.1.1. Plant height

Severity of water stress decreased the plant height to the range of 10.9 to 13.9cm (at 60 DAS), though the variety can attain a height of 50-60cm under normal conditions. None of the treatments (application of farm yard manure (FYM), or biofertilizers (PGPR mix I + rhizobium and pseudomonas) or mineral nutrients (diammonium phosphate (DAP), potassium chloride (KCl), zinc sulphate ($ZnSO_4$) and boric acid (H_3BO_3) or its combination as foliar spray) could bring about any significant influence on height of cowpea plants at any stage of growth. However at 60 DAS, the treatments which received FYM or biofertilizers or spraying of mineral nutrients resulted in an increasing trend of plant height from 8 to 18 per cent compared to that which received no treatment during the crop period. Among the nutrient management practices, seed treatment with PGPR mix I + rhizobium recorded numerically higher plant height (12.9 cm) followed by foliar spray of $ZnSO_4$ (12.7cm).

4.3.1.2. Number of leaves

Number of leaves of cowpea plants was not significantly influenced by any of the treatments at 15, 30 and 60 DAS. However, at 45 DAS, plants irrigated on alternate days (farmer's practice) recorded the highest leaf number of 10.2 which was on par with those irrigated at 5 days interval (9.3). Among nutrient management practices, PGPR mix I + rhizobium as seed treatment and foliar spray of $ZnSO_4$ during the water stress imposed period recorded the highest number of leaves per plant (20-22 per cent higher than absolute control) and it was on par with the treatment irrigated at 5 days interval. At 60 DAS, there was a decline in the number of leaves per plant in farmers practice and irrigation at 5 days interval due to attainment of early maturity whereas the treatments which received various nutrient management practices resulted an increasing trend in number of leaves from 21 to 42 per cent compared to that which received no treatment during the period.

Table 24. Effect of nutrient management practices on plant biometry

Treatments	Plant height (cm)				No. of leaves				No. of branches			Leaf area index (LAI)			Root length (cm)	Root Shoot ratio	Days to flowering
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	20 DAS	40 DAS	60 DAS			
1. FYM alone	5.20	5.60	6.23	11.83	3.00	4.20	6.33	8.40	0.00	0.06	1.66	0.06	0.17	0.19	14.43	0.20	49.66
2. PGPR mix+Rhizobium	5.66	6.20	6.83	12.90	3.06	5.36	7.26	9.46	0.00	0.20	2.93	0.06	0.18	0.19	15.43	0.30	49.66
3. Pseudomonas	5.50	5.93	6.50	12.33	3.06	4.36	5.90	8.33	0.00	0.20	2.20	0.05	0.14	0.15	13.73	0.20	49.66
4. DAP	5.40	5.96	6.43	11.83	3.00	4.60	6.13	8.50	0.00	0.06	1.86	0.06	0.14	0.16	14.20	0.20	48.33
5. KCl	5.50	5.96	6.36	11.90	3.00	5.23	6.60	8.16	0.00	0.20	2.76	0.06	0.14	0.17	14.36	0.30	49.66
6. DAP+KCl	5.86	6.26	6.40	12.10	3.06	4.46	6.63	8.63	0.00	0.06	2.40	0.06	0.15	0.17	14.50	0.30	49.66
7. $ZnSO_4$	5.90	6.10	6.86	12.70	3.00	5.06	7.13	9.53	0.00	0.20	2.90	0.07	0.17	0.28	15.33	0.30	46.66
8. H_3BO_3	5.76	6.13	6.43	11.86	3.00	5.13	5.96	8.46	0.00	0.06	1.36	0.06	0.13	0.15	14.43	0.20	49.66
9.Combination*	5.86	6.10	6.66	12.00	3.00	4.20	6.16	8.50	0.00	0.06	1.70	0.05	0.13	0.15	14.20	0.20	50.33
10. Control	5.90	6.36	7.06	13.66	3.06	5.43	9.30	8.10	0.00	0.46	3.20	0.06	0.28	0.15	15.16	0.30	45.66
11. FP	6.00	6.50	7.23	13.93	3.06	5.56	10.23	7.43	0.06	1.06	3.73	0.07	0.38	0.26	16.73	0.30	45.00
12. Abs. control	5.73	5.93	6.13	10.90	3.00	4.06	5.90	6.73	0.00	0.06	1.40	0.05	0.15	0.16	14.10	0.23	50.33
CD(0.05)	NS	NS	NS	NS	NS	NS	2.37	NS	NS	NS	0.85	0.01	0.01	0.012	NS	0.028	2.22
SEd	-	-	-	-	-	-	1.14	-	-	-	0.41	0.004	0.004	0.005	-	0.01	1.07

4.3.1.3. Number of branches

No branches were observed at 15 DAS. At 30 DAS, branches were noted only in farmers practice. At 45 DAS, higher number of branches was observed in farmer's practice and in treatment irrigated at 5 days interval. Among nutrient management practices, seed treatment with PGPR mix I + rhizobium, soil drenching and foliar spray of pseudomonas, foliar spray of KCl and $ZnSO_4$ recorded numerically higher number of branches (198 per cent higher than absolute control). At 60 DAS, the same trend as that at 45 DAS was observed with significantly highest number of branches in farmer's practice. However, it was on par with treatment irrigated at 5 days interval, seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. Lowest number of branches was observed in foliar spray of boric acid followed by absolute control. Over all, the treatments which received various nutrient management practices (except boric acid) resulted in an increasing trend of number of branches from 14 to 107 per cent compared to that which received no treatment during the crop period.

4.3.1.4. Leaf area index

Leaf area index (LAI) of cowpea plants increased progressively up to 60 DAS in all treatments except in farmers practice and irrigation at 5 days interval. The decline in leaf area index in plots irrigated on alternate days and at 5 days interval at 60 DAS was due to the leaf fall as a result of attainment of early maturity. In general, various treatments significantly influenced the leaf area index of cowpea plants at all of stages of observation. Leaf area index at 20 DAS did not show much variation among treatments. However at 40 DAS, leaf area index was highest in farmers practice followed by the treatment irrigated at 5 days interval. Among nutrient practices, PGPR mix I + rhizobium, $ZnSO_4$ and FYM alone recorded higher leaf area index on par with each other whereas the lowest was noticed in boric acid spray. At 60 DAS, foliar spray of $ZnSO_4$ recorded significantly highest leaf area index and it was followed by farmers practice.

PGPR mix I + rhizobium and FYM alone were on par with each other and were found superior to other treatments with a 27-29 per cent increase in LAI compared to pseudomonas, which recorded the lowest LAI.

4.3.1.5. Root length

None of the nutrient management practices could bring about any significant influence on root length of vegetable cowpea under water stress. However, all the treatments (except pseudomonas) recorded an increasing trend in root length compared to absolute control.

4.3.1.6. Root:shoot ratio

Root shoot ratio of cowpea plants was significantly influenced by various treatments and the highest was recorded by farmers practice, irrigation at 5 days interval, foliar spray of either $ZnSO_4$, or KCl, or DAP+KCl and seed treatment with PGPR mix I + rhizobium. Application of FYM alone, pseudomonas, DAP, boric acid and combination of all nutrient management practices were found inferior to absolute control.

4.3.1.7. Days to flowering

Comparatively early flowering (45 DAS) was noted in farmer's practice and in treatment that received irrigation at 5 days interval. All treatments which received various nutrient management practices with imposed water stress showed a slight delay of one to five days (46 to 50 DAS) in attaining 50 per cent flowering compared to those received irrigation on alternate days (farmer's practice) and at 5 days interval. Among nutrient management practices, application of $ZnSO_4$ as foliar spray resulted in 50 per cent flowering at 46 DAS and it was on par with the irrigated control where as in combination of all nutrient management practices and in absolute control 50 per cent flowering occurred at 50 DAS.

4.3.2. Physiological parameters

Observations on physiological parameters were recorded during the water stress imposed period (10 days after the foliar spray of nutrients). Effect of treatments on various physiological parameters of cowpea plants are presented in Table 25 and the data showed that they were significantly influenced by different nutrient management practices.

4.3.2.1. Stomatal conductance

Highest stomatal conductance was observed in $ZnSO_4$ spray followed by the treatment irrigated at 5 days interval and the lowest in DAP+KCl spray.

4.3.2.2. Transpiration rate

Highest transpiration rate was also observed in $ZnSO_4$ spray which was on par with the treatment irrigated at 5 days interval and the lowest in DAP+KCl spray.

4.3.2.3. Photosynthetic rate

Photosynthetic rate also showed the same trend as that of stomatal conductance and transpiration rate and the highest photosynthetic rate was observed in $ZnSO_4$ spray followed by the treatment irrigated at 5 days interval and the lowest in DAP+KCl spray.

4.3.2.4. Chlorophyll content

Highest chlorophyll content was recorded by farmers practice and the lowest by absolute control. Application of various nutrient management measures could increase the chlorophyll content to the tune of 48 to 206 per cent compared to no treatment during the period. Seed treatment with PGPR mix I + rhizobium recorded the highest chlorophyll content and it was on par with farmers practice and irrigation at 5 days interval.

4.3.2.5. Relative leaf water content

Various nutrient management practices significantly influenced the relative leaf water content of cowpea plant under water stress. Highest relative leaf water content was recorded by farmers practice and the lowest by absolute control. Application of either FYM or biofertilizers or foliar spray of nutrients increased the relative leaf water content to the range of 20 to 138 per cent compared to no treatment during the crop period. Among foliar spray of nutrients, KCl, DAP and their combination were recorded higher relative leaf water content and they were on par with the treatment irrigated at 5 days interval.

Table 25. Effect of nutrient management practices on physiological parameters of crop

Tr. No.	Treatments	RLWC# (%)	Total Chlorophyll (mg/g plant)	Photosynthetic rate (μ mol CO_2 /m^2 /sec)	Transpiration rate (m mol H_2O/ m^2/ sec)	Stomatal conductance (mol H_2O / m^2/ sec)
1	**FYM alone**	20.93	0.21	15.92	2.43	0.27
2	**PGPR mix+ Rhizobium**	23.57	0.27	12.21	1.35	0.16
3	**Pseudomonas**	14.80	0.17	16.77	2.59	0.24
4	**DAP**	28.03	0.23	13.94	2.19	0.22
5	**KCl**	29.36	0.22	17.65	2.85	0.27
6	**DAP+KCl**	26.70	0.22	10.70	1.02	0.12
7	**$ZnSO_4$**	24.00	0.21	20.13	3.08	0.29
8	**H_3BO_3**	22.56	0.13	17.35	2.76	0.26
9	**Combination***	17.76	0.17	17.75	2.86	0.27
10	**Control**	32.66	0.27	19.85	3.06	0.29
11	**FP**	39.40	0.29	13.87	2.18	0.22
12	**Abs.control**	12.36	0.09	15.59	2.47	0.26
	CD(0.05)	6.194	0.059	0.138	0.023	0.004
	SEd	2.99	0.02	0.06	0.01	0.001

#Relative leaf water content, * PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.3.3. Yield attributes and yield

Effect of nutrient management practices on yield and yield attributes of vegetable cowpea grown under water stress is presented in Table 26. General yield of the crop was low due to the effect of extreme dry condition prevailed during the crop period (Appendix I & II) combined with aphid attack on vegetative growth, flowering and yield attributes.

4.3.3.1. Number of pods per plant

Number of pods per plant was significantly influenced by various nutrient management practices. Highest number of pods per plant was recorded by

Table 26. Effect of nutrient management practices on yield attributes and yield of crop

Treatments	Pod No. /plant	Pod length (cm)	Seeds /pod	Pod weight (g)	No. of harvest	Pod yield /plant (g)	Pod yield /plot (g)	Pod yield (kg/ha)	Stover yield (kg/ha)	DMP(at harvest) (kg/ha)
1. FYM alone	2.30	25.16	11.50	6.96	1.33	14.86	133.80	1651.85	2253.90	759.25
2. PGPR mix+Rhizobium	2.66	27.20	12.86	8.66	1.66	16.46	148.20	1829.63	3271.60	1012.34
3. Pseudomonas	2.33	23.90	10.16	6.76	1.33	14.96	134.70	1662.96	3004.93	926.87
4. DAP	2.00	23.30	10.83	6.20	1.33	14.46	130.20	1607.40	2545.67	816.62
5. KCl	2.73	24.66	10.90	6.56	1.33	14.80	133.20	1644.44	2776.54	872.42
6. DAP+KCl	3.00	27.70	12.96	8.86	1.66	16.66	150.00	1851.85	3574.48	1083.12
7. $ZnSO_4$	2.33	26.33	12.00	8.66	1.66	15.73	141.60	1748.14	3151.85	972.42
8. H_3BO_3	2.00	24.40	10.83	6.36	1.00	12.40	111.60	1377.77	2392.59	745.67
9. Combination*	2.00	24.36	11.50	6.76	1.00	10.93	98.40	1214.81	1575.72	537.03
10. Control	4.30	26.73	12.63	8.63	3.00	28.00	252.00	3111.11	4141.56	1409.63
11. FP	7.367	25.33	12.96	6.50	4.00	30.76	276.90	3418.51	4822.22	1608.23
12. Abs. control	1.03	21.10	10.50	6.00	1.00	10.56	95.10	1174.07	1460.49	532.51
CD(0.05)	0.62	1.95	NS	1.23	0.775	0.965	8.68	107.18	453.258	102.4
SEd	0.29	0.94	-	0.59	0.37	0.46	4.19	51.7	218.9	49.5

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) +DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

farmers' practice which was irrigated on alternate days followed by the treatment irrigated at 5 days interval and the lowest by absolute control. Among various treatments, foliar spray of DAP+KCl recorded the highest pod number per plant (191% over absolute control) and it was on par with foliar spray of KCl and seed treatment with PGPR mix I + rhizobium.

4.3.3.2. Pod length

The pod length recorded by various treatments in the experiment ranged from 21.1 to 27.7cm. The results showed that pod length of cowpea plants was significantly influenced by various treatments. Significantly longest pods were noticed in foliar spray of DAP+KCl and it was on par with seed treatment with PGPR mix I + rhizobium, irrigation at 5 days interval and foliar spray of $ZnSO_4$ whereas shortest in absolute control.

4.3.3.3. Number of seeds per pod

None of the treatments could influence the number of seeds per pod of cowpea plants. However, the numerically higher number of seeds per pod was recorded by farmers' practice and DAP+KCl and the lowest by pseudomonas. All nutrient management practices except pseudomonas showed an increasing trend in the number of seeds per pod of cowpea plants compared to absolute control.

4.3.3.4. Pod weight

Pod weight of cowpea plants was significantly influenced by application of FYM, biofertilizers and nutrients. All water stress mitigating nutrient management practices showed an increasing trend in pod weight ranging from 3 to 47 per cent compared to absolute control. Among them, foliar spray of DAP+KCl, seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$ recorded significantly higher pod weight and were on par with the treatment irrigated at 5 days interval.

4.3.3.5. Pod yield (per plant, per plot and per hectare)

Pod yield per plant was significantly influenced by various nutrient management practices. Highest pod yield per plant was recorded by farmers' practice which received irrigation on alternate days followed by the treatment irrigated at 5 days interval. Foliar spray of DAP+KCl, $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded significantly higher pod yield per plant than other treatments. Combined application of biofertilizers and elemental nutrients was found ineffective in mitigating water stress as it was on par with absolute control.

Pod yield per plot also showed the same trend as that of pod yield per plant. Highest pod yield per plot was obtained from farmers' practice followed by the treatment irrigated at 5 days interval. Among various nutrient management treatments, foliar spray of DAP+KCl recorded highest pod yield per plot and it was on par with seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. The lowest pod yield was recorded by absolute control and it was on par with combined application of biofertilizers and elemental nutrients.

The pod yield per hectare also showed the same trend as that of pod yield per plant and per plot. The highest pod yield was recorded by farmers' practice which was only 3418 kg/ha due to the reasons as mentioned above. Among nutrient management practices, foliar spray of DAP+KCl recorded the highest pod yield of 1851 kg/ha and it was on par with seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. The lowest pod yield was recorded by absolute control (1174kg/ha). Combined application of DAP and KCl was found much effective in increasing the pod yield of cowpea than its separate application. Similarly foliar spray of $ZnSO_4$ has a favourable effect than boric acid in water stress mitigation.

4.3.3.6. Stover yield (per plot and per hectare)

In general, the crop recorded a lower stover yield due to less vegetative growth as a result of exposure of plants to unfavourable weather condition prevailed during the crop season combined with aphid attack. However, the stover yield of the crop was significantly influenced by various treatments and the trend was same for both per plot and per hectare stover yield. The highest stover yield was recorded by farmers practice (4822 kg/ha) followed by the treatment which received irrigation at 5 days interval (4141 kg/ha) and the lowest by absolute control. Among nutrient management practices, foliar spray of DAP+KCl recorded the highest stover yield (144 percent higher than that obtained from absolute control) and it was on par with seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$.

4.3.3.7. Dry matter accumulation

Dry matter accumulation in cowpea plants during the cropping period was significantly influenced by various treatments. Farmers practice recorded a significantly higher dry matter accumulation (1608 kg/ha) compared to all other treatments where as absolute control recorded the lowest (532 kg/ha). All nutrient management treatments could bring about 1 to 103 per cent increase in total dry matter production compared to no treatment during the crop period. Among various treatments, foliar spray of DAP+KCl recorded the highest dry matter accumulation and it was on par with seed treatment with PGPR mix I + rhizobium followed by foliar spray of $ZnSO_4$. Combined application of nutrients and biofertilizers could not bring any favourable influence on dry matter accumulation as it was on par with absolute control.

4.3.3.8. Number of harvests

In general, the number of harvests was low due to low pod yield as a result of exposure of plants to unfavourable weather conditions during the entire crop period combined with infestation of aphids. The data showed that various treatments significantly influenced the number of harvests of the crop. The highest number of harvests (4 harvests) was done in farmers practice followed by the treatment which was irrigated at 5 days interval (3 harvests) and the lowest of one harvest was in absolute control, boric acid spray and combined application of biofertilizers and elemental nutrients. However, foliar spray of $ZnSO_4$, DAP+KCl and seed treatment with PGPR mix I + rhizobium could bring about a numerically higher number of harvests compared to other treatments.

4.3.3.9. Duration of the crop

It was observed that the plants in treatments which received irrigation on alternate days and at 5 days interval attained final maturity earlier (65 days) than the remaining treatments. Application of either FYM alone or biofertilizers or foliar spray of nutrients extended the duration of the crop by one week (72 days) without any variation among them.

4.3.4. Quality parameters

Effect of various nutrient management practices on quality parameters of vegetable cowpea grown under water stress are presented in Table 27.

4.3.4.1. Protein content in pod

Protein content in cowpea pods was significantly influenced by various treatments. Higher protein content in pod to the tune of 31 to 43 per cent was recorded by farmers practice, foliar spray of DAP+KCl, irrigation at 5 days interval, foliar spray of $ZnSO_4$, seed treatment with PGPR mix I + rhizobium, soil drenching and foliar spray of pseudomonas and foliar spray of boric acid compared to absolute control whereas the lowest was recorded by absolute control and foliar spray of DAP.

4.3.4.2. Protein content in stover

Protein content in stover also varied significantly among treatments. Higher stover protein content was noticed in seed treatment with PGPR mix I + rhizobium, foliar spray of DAP+KCl and farmers practice. The lowest was recorded by foliar spray of $ZnSO_4$.

Table 27. Effect of nutrient management practices on protein content of crop

Tr. No.	Treatments	Pod (%)	Stover (%)
1	**FYM alone**	16.88	4.63
2	**PGPR mix+ Rhizobium**	23.13	5.48
3	**Pseudomonas**	22.71	4.38
4	**DAP**	14.36	4.44
5	**KCl**	20.42	4.81
6	**DAP+KCl**	24.17	5.38
7	**$ZnSO_4$**	23.33	4.33
8	**H_3BO_3**	22.29	4.63
9	**Combination***	20.42	4.69
10	**Control**	23.96	4.67
11	**FP**	24.38	5.29
12	**Abs.control**	13.54	4.75
	CD(0.05)	2.39	0.32
	SEd	1.15	0.15

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.3.5. Nutrient uptake by the crop

Analysis of plant and pod samples from each treatment plots at final harvest was done to estimate primary (N, P, K), secondary (Ca, Mg, S), micro (Fe, Mn, Zn, Cu, B) and beneficial (Na) nutrient contents (Appendix V) and their uptake by the crop was calculated. Among these, content of sodium and copper in cowpea plants in all treatments were found to be below detectable level. Effect of application of various nutrient management practices on elemental uptake by vegetable cowpea is shown in Table 28 and 29.

4.3.5.1. Primary nutrients

In general, unfavourable weather especially extreme dry condition led to a reduced uptake of all nutrients by the crop and thereby a lower growth and yield. However, the uptake of primary nutrients [nitrogen (N), phosphorus (P) and potassium (K)] was significantly influenced by various treatments. Significantly higher nitrogen uptake by the crop was noted in farmers' practice (30.5 kg/ha) which was irrigated on alternate days followed by the treatment irrigated at 5 days interval and the lowest in absolute control. Among nutrient management practices, foliar spray of DAP+KCl and seed treatment with PGPR mix I with rhizobium recorded significantly higher nitrogen uptake compared to other treatments (178 and 164 per cent higher than absolute control respectively) and it was followed by foliar spray of $ZnSO_4$.

Highest phosphorus (P) uptake of 5.1 kg/ha was recorded by farmers practice followed by the treatment irrigated at 5 days interval. Lowest uptake was recorded by absolute control followed by combined application of biofertilizers and elemental nutrients. Similar to N uptake, foliar spray of DAP+KCl recorded significantly highest P uptake among nutrient management practices. Seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$ were statistically on par with each other and resulted in a significantly higher P uptake compared to other treatments.

Potassium (K) uptake showed the same trend as that of P uptake and farmers practice recorded significantly highest potassium uptake among various treatments. Among the nutrient management treatments, foliar spray of DAP+KCl recorded the highest K uptake (316% higher than that of absolute control) and it was on par with seed treatment with PGPR mix I + rhizobium.

Lower K uptake was noticed in absolute control followed by combined application of biofertilizers and elemental nutrients.

4.3.5.2. Secondary nutrients

Uptake of secondary nutrients by the crop was significantly influenced by the treatments. Highest calcium (Ca) uptake was noticed in farmers practice followed by the treatment irrigated at 5 days interval and the lowest in absolute control. Among nutrient management practices, foliar spray of DAP+KCl, foliar spray of $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded higher Ca uptake compared to other treatments.

Magnesium (Mg) uptake by the crop showed the same trend as that of N uptake. The highest Mg uptake was recorded by farmers practice followed by the treatment irrigated at 5 days interval. Among nutrient management treatments, foliar spray of DAP+KCl recorded the highest Mg uptake on par with seed treatment with PGPR mix I + rhizobium and it was followed by foliar spray of $ZnSO_4$. A lower uptake was recorded by absolute control followed by combined application of biofertilizers and elemental nutrients.

The highest sulphur (S) uptake was recorded by farmers practice followed by seed treatment with PGPR mix I + rhizobium whereas the lowest uptake was noticed in absolute control. Foliar spray of $ZnSO_4$ was the next best treatment in S uptake and it was statistically on par with the above treatment and irrigation at 5 days interval. Foliar spray of DAP+KCl recorded a significantly higher S uptake compared to the remaining treatments.

Table 28. Effect of nutrient management practices on primary and secondary nutrient uptake by crop

	Treatments	Nutrient uptake (kg/ha)					
		N	P	K	Ca	Mg	S
1	**FYM alone**	10.69	1.31	19.02	4.49	1.58	0.65
2	**PGPR mix+Rhizobium**	17.29	1.97	30.13	6.43	2.38	1.09
3	**Pseudomonas**	14.09	1.51	27.45	5.93	1.97	0.61
4	**DAP**	9.87	1.26	21.36	4.81	1.82	0.79
5	**KCl**	13.16	1.47	22.63	5.56	2.03	0.69
6	**DAP+KCl**	18.11	2.25	30.49	7.16	2.46	0.89
7	**$ZnSO_4$**	15.16	1.99	24.59	6.46	2.07	1.01
8	**H_3BO_3**	11.67	1.02	14.06	4.52	1.64	0.43
9	**Combination***	8.78	0.74	9.49	3.14	1.19	0.36
10	**Control**	25.64	3.63	38.80	8.04	2.98	0.99
11	**FP**	30.56	5.15	41.93	9.73	3.79	1.29
12	**Abs.control**	6.55	0.47	7.39	3.02	1.17	0.23
	CD(0.05)	1.03	0.163	2.72	0.84	0.257	0.088
	SEd	0.49	0.07	1.31	0.41	0.12	0.04

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.3.5.3. Micro nutrients

Various treatments significantly influenced the iron (Fe) uptake by the crop and it showed the same trend as that of N and Mg. Among all treatments, farmers practice recorded significantly highest Fe uptake and it was followed by the treatment irrigated at 5 days interval. Among nutrient management practices, seed treatment with PGPR mix I + rhizobium, foliar spray of $ZnSO_4$, soil drenching and foliar spray of pseudomonas and foliar spray of DAP+KCl recorded higher Fe uptake compared to other treatments. The lowest Fe uptake was observed in absolute control and it was on par with combined application of biofertilizers and elemental nutrients and KCl spray.

Manganese (Mn) uptake was highest in farmers' practice which was irrigated on alternate days. Foliar spray of DAP+KCl recorded the highest Mn uptake among nutrient management treatments which was on par with the treatment irrigated at 5 days interval and it was followed by foliar spray of $ZnSO_4$

and seed treatment with PGPR mix I + rhizobium where as the lowest was noticed in absolute control. Zinc (Zn) uptake was significantly influenced by various treatments. Highest zinc uptake was recorded by farmers practice and it was on par with foliar spray of $ZnSO_4$ and the lowest by absolute control. Combined foliar spray of DAP+KCl and KCl alone were found to be on par with each other and it was followed by irrigation at 5 days interval and seed treatment with PGPR mix I + rhizobium.

Boron (B) uptake by the cowpea crop was significantly varied among treatments. The highest boron uptake was recorded by foliar spray of boric acid and the lowest by absolute control. Among nutrient management treatments, foliar spray of DAP+KCl recorded the highest boron uptake and it was on par with farmers practice and irrigation at 5 days interval. Boron uptake by seed treatment with PGPR mix I + rhizobium was found to be on par with foliar spray of DAP+KCl, $ZnSO_4$, soil drenching and foliar spray of pseudomonas and foliar spray of KCl alone.

Table 29. Effect of nutrient management practices on micro nutrient uptake by crop

Tr. No.	Treatments	Nutrient uptake (kg/ha)			
		Fe	Mn	Zn	B
1	**FYM alone**	0.69	0.87	0.04	0.01
2	**PGPR mix+ Rhizobium**	1.07	1.28	0.06	0.02
3	**Pseudomonas**	0.98	1.08	0.05	0.01
4	**DAP**	0.78	0.81	0.05	0.01
5	**KCl**	0.51	1.15	0.07	0.01
6	**DAP+KCl**	0.95	1.43	0.08	0.02
7	**$ZnSO_4$**	1.05	1.30	0.09	0.01
8	**H_3BO_3**	0.60	0.65	0.04	0.09
9	**Combination***	0.48	0.55	0.04	0.01
10	**Control**	1.23	1.56	0.06	0.02
11	**FP**	1.49	1.86	0.10	0.02
12	**Abs.control**	0.43	0.54	0.03	0.01
	CD(0.05)	0.128	0.16	0.008	0.004
	SEd	0.06	0.07	0.003	0.001

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) +DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.3.6. Soil characters

Soil samples collected from each treatment after the final harvest of the crop were analysed for pH, organic carbon, primary, secondary and micro nutrients and the data are presented in Table 30 and 31.

4.3.6.1. Soil pH

Soil pH in various treatments after the experiment (5.1-5.9) did not show much variation compared to that before the experiment (5.4). However a slight increase in soil pH was noticed in PGPR mix I + rhizobium, DAP, DAP+KCl, $ZnSO_4$, boric acid, farmers practice and the treatment irrigated at 5 days interval.

4.3.6.2. Soil organic carbon

Organic carbon status of soil after the experiment did not show much variation among various treatments and it ranged from 1.04 to 1.2 per cent compared to that of 1.2 per cent before the experiment.

4.3.6.3. Primary nutrients

Available nitrogen content in the soil was 156.1 kg/ha before the experiment and it got reduced to the extent of 119 to 139 kg/ha after the experiment and was not varied significantly among treatments. However, numerically higher soil N content was observed in foliar spray of 2% DAP alone.

Available phosphorus content in soil before the experiment was 21.9 kg/ha and it showed a reduction to the tune of 11.9 to 18.2 kg/ha after the experiment. Significantly highest P content was noticed in foliar spray of KCl and it was followed by combined application of biofertilizers and elemental nutrients where as the lowest in soil drenching and foliar spray of pseudomonas.

Available potassium content in the soil before the experiment was 378.8 kg/ha and it showed a slight reduction after the experiment (239-313 kg/ha). However, the available K content after the experiment varied significantly among treatments. Highest K content was recorded by foliar spray of DAP+KCl. All other treatments except foliar spray of KCl and farmers practice were on par with DAP+KCl in the case of soil K content.

4.3.6.4. Secondary nutrients

Different treatments significantly influenced the Ca, Mg and S content in soil after the experiment.

Available calcium content in soil before the experiment was 179.5 mg/kg. Calcium content to the range of 150 to 187 mg/kg was noticed after the experiment. However, higher Ca content was recorded by combined application of biofertilizers and elemental nutrients and it was on par with foliar spray of DAP alone and the lowest content by seed treatment with PGPR mix I + rhizobium.

Available magnesium content before the experiment was 99.1mg/kg soil and it ranged from 84.9 - 118 mg/kg after the experiment. Highest Mg content was observed in FYM alone followed by farmers practice and combined application of biofertilizers and elemental nutrients where as the lowest content was foliar spray of DAP+KCl.

Available sulphur in soil was 2.14 mg/kg before the experiment and it showed a drastic increment after the experiment (2.5-3.1 mg/kg soil). Soil S content after the experiment was highest in treatment irrigated at 5 days interval followed by foliar spray of DAP+KCl. The lowest was recorded by foliar spray of DAP alone.

4.3.6.5. Micronutrients

Soil micronutrient status after the experiment also varied significantly among treatments.

Available iron content in soil after the experiment showed a range of 4.7 to 8.7 mg/kg compared to its content before the experiment (7.5mg/kg). However, highest Fe content in soil after the experiment was observed in foliar spray of DAP+KCl followed by farmers practice and soil drenching and foliar spray of pseudomonas whereas the lowest was in foliar spray of KCl alone.

Available manganese content before the experiment was 57.7mg/kg which showed a reduction to the range of 32.9 to 51.4 mg/kg after the experiment. Highest Mn content after the experiment was recorded by farmers practice and it was followed by seed treatment with PGPR mix I + rhizobium where as the lowest content by absolute control and the treatment irrigated at 5 days interval.

Available zinc content in soil was 1.82mg/kg before the experiment. After the experiment it ranged from 1.1 to 1.8 mg/kg. The treatment irrigated at 5 days interval recorded a significantly higher zinc content followed by foliar spray of $ZnSO_4$, boric acid, combined application of biofertilizers and elemental nutrients and foliar spray of DAP alone whereas a lower content was recorded by seed treatment with PGPR mix I + rhizobium.

Available copper content in the soil before the experiment was 5.52mg/kg. A copper content to the tune of 3.9 to 6.0 mg/kg was noticed after the experiment. Seed treatment with PGPR mix I + rhizobium showed significantly highest copper content after the experiment followed by combined application of biofertilizers and elemental nutrients, foliar spray of $ZnSO_4$ and FYM alone whereas the lowest was in farmers practice.

Available boron content in soil before the experiment was 0.53mg/kg. After the experiment it showed a range of 0.37 - 0.76 mg/kg and a significantly higher value was noticed in combined application of biofertilizers and elemental nutrients, which was on par with the treatment irrigated at 5 days interval and the lowest was in foliar spray of $ZnSO_4$.

Table 30. Effect of nutrient management practices on primary and secondary nutrient content in soil

Tr. No	Treatments	pH	Org. C (%)	N	P	K	Ca	Mg	S
				(kg/ha)			(mg/kg)		
1	**FYM alone**	5.26	1.11	135.52	12.85	309.39	167.88	118.00	2.86
2	**PGPR mix+Rhizobium**	5.76	1.27	131.41	15.56	306.75	150.38	90.60	2.61
3	**Pseudomonas**	5.43	1.21	119.09	11.95	305.54	172.38	98.45	2.78
4	**DAP**	5.86	1.11	139.62	12.63	288.60	179.38	91.70	2.53
5	**KCl**	5.06	1.29	131.41	18.26	246.69	166.68	103.51	2.61
6	**DAP+KCl**	5.86	1.27	123.20	14.21	313.90	159.58	84.96	3.03
7	**$ZnSO_4$**	5.76	1.08	123.20	15.33	303.23	164.53	103.76	2.78
8	**H_3BO_3**	5.60	1.29	131.41	12.85	273.75	175.73	99.66	2.95
9	**Combination***	5.43	1.04	135.52	16.68	300.37	187.08	111.56	2.61
10	**Control**	5.96	1.13	135.52	14.88	306.42	168.43	89.01	3.11
11	**FP**	5.96	1.21	127.30	16.01	239.98	155.33	116.31	2.70
12	**Abs.control**	5.36	1.26	135.52	13.53	300.15	174.78	108.86	2.78
	CD(0.05)	0.305	0.102	NS	0.003	44.09	9.96	8.61	0.005
	SEd	0.14	0.05	-	0.001	21.2	4.81	4.15	0.002

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

Table 31. Effect of nutrient management practices on micro nutrient content in soil

Tr. No.	Treatments	Fe	Mn	Zn	Cu	B
		(mg/kg)				
1	**FYM alone**	6.07	45.22	1.17	5.40	0.41
2	**PGPR mix+Rhizobium**	5.57	49.89	1.13	6.05	0.41
3	**Pseudomonas**	6.35	43.84	1.15	4.58	0.49
4	**DAP**	6.21	37.73	1.55	4.40	0.51
5	**KCl**	4.71	42.80	1.23	4.63	0.45
6	**DAP+KCl**	8.71	35.42	1.26	4.99	0.41
7	**$ZnSO_4$**	6.18	47.35	1.65	5.49	0.37
8	**H_3BO_3**	6.27	46.60	1.57	4.64	0.64
9	**Combination***	5.30	35.91	1.57	5.57	0.76
10	**Control**	4.93	33.08	1.84	4.96	0.72
11	**FP**	6.36	51.41	1.13	3.96	0.45
12	**Abs.control**	5.54	32.97	1.27	4.78	0.41
	CD(0.05)	0.078	1.128	0.129	0.67	0.109
	SEd	0.03	0.54	0.06	0.32	0.05

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.3.7. Soil moisture content

Soil samples were collected from a depth of 20cm at sowing and subsequently at 15 days interval till last harvest to estimate the soil moisture content (SMC) and the data are presented in Table 32.

Soil moisture content in the field at sowing of cowpea seeds was 8.7 per cent. After sowing, uniform irrigation was given up to 5 days irrespective of treatments for germination and establishment of the crop. After 5 days, irrigation was given at 5 days interval till 15 DAS in all treatments except farmer’s practice and the irrigated control, which was irrigated on alternate days and at 5 days interval respectively. Further, irrigation was withheld up to 40 DAS for imposing water stress in absolute control and in treatments which were treated with different nutrient management practices. From 40 DAS, irrigation was restarted in the above treatments at 5 days interval.

In general, moisture status in the soil was very low during the entire crop period. A gradual decline in soil moisture was observed in all nutrient management treatments up to 30 DAS. However at 45 DAS, water stress release from these treatments resulted in a slight increase in soil moisture content and again from 60 DAS onwards it showed a slight progressive decline. Soil moisture status at all stages (15, 30, 45 and 60 DAS) was significantly influenced by various treatments and the highest soil moisture content was observed in farmers practice.

At 15 DAS, since the crop was irrigated uniformly, soil moisture content ranged from 10.1 to 10.8 per cent among the treatments except in farmers practice which received irrigation on alternate days. At 30 DAS (15 days after withholding irrigation), the soil moisture content in the nutrient management treatments was 54 to 72 per cent less than that in farmers practice. At 45 DAS, as the irrigation was restarted, soil moisture content increased to the range of 9.1 to 9.5 per cent from 7.1 to7.9 per cent at 30 DAS in nutrient management treatments. At 60 DAS, application of FYM alone, seed treatment with PGPR mix I+ rhizobium and soil drenching and foliar spray of pseudomonas resulted in higher soil moisture content comparable to farmers practice and irrigation at 5 days interval. At final harvest of the crop, a still reduction in soil moisture content was noticed in all treatments compared to that at 60 DAS and it ranged from 6.3 to 7.8 per cent.

Table 32. Effect of nutrient management practices on soil moisture content

Tr. No.	Treatments	Soil moisture content (%)				
		15DAS	30DAS	45DAS	60DAS	At final harvest
1	**FYM alone**	10.76	7.43	9.57	10.13	7.33
2	**PGPR mix+Rhizobium**	10.40	7.33	9.23	9.43	7.43
3	**Pseudomonas**	10.20	7.90	9.10	9.10	6.67
4	**DAP**	10.13	7.50	9.37	8.47	6.80
5	**KCl**	10.66	7.20	9.10	8.87	7.83
6	**DAP+KCl**	10.70	7.90	9.37	8.20	6.37
7	**$ZnSO_4$**	10.83	7.50	9.57	8.67	7.23
8	**H_3BO_3**	10.67	7.70	9.47	8.10	6.80
9	**Combination***	10.83	7.10	9.23	8.10	7.33
10	**Control**	10.20	9.47	9.67	9.43	7.40
11	**FP**	14.53	12.27	13.43	10.47	7.77
12	**Abs.control**	10.47	7.20	9.37	8.90	7.33
	CD(0.05)	0.356	0.43	0.503	0.398	0.394
	SEd	0.17	0.21	0.24	0.19	0.19

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) + DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

4.4. Second year experiment

The best treatments from each of the three experiments conducted in the first year were selected and their individual and possible combinations were evaluated in an experiment during the subsequent year.

The best treatments, salicylic acid 2% and water spray from the first experiment, seed priming with NaCl 0.5%, plant residue mulching and lime water spray (2% $Ca(OH)_2$) as antitranspirant from the second experiment, seed treatment with PGPR mix I + rhizobium, foliar spray of 2% DAP+1% KCl and foliar spray of 0.5% zinc sulphate from third experiment were selected, their individual and possible combinations were tried for confirmation of the results of first year experiments and to develop an agronomic package for mitigating water stress in vegetable cowpea.

4.4.1. Growth characters

Effect of various promising water stress mitigation treatments from the first year experiments, alone and their combinations on various growth characters of vegetable cowpea are presented in Table 33. General growth of the crop was better than that in first year experiments due to the effect of treatments and the rainfall received towards the later stage of the crop. (Appendix I &II).

4.4.1.1. Plant height

Various drought mitigation treatments alone and their combinations could bring about significant influence on height of cowpea plants at all stages of growth. There was a progressive increase in plant height and it varied from 10.4 - 24.8 cm at 60 DAS among various treatments.

At 15 DAS, all treatments in which mulching was done with plant residues recorded higher plant height and were found to be on par with farmers' practice which was irrigated on alternate days. The tallest plants were observed in the treatment combination NaCl+PRM+(PGPR mix I+ rhizobium) followed by farmers practice whereas the shortest were noticed in absolute control.

At 30 DAS also, all the mulched treatments resulted in a better plant height compared to most of the non mulched treatments and were found to be on par with farmers practice. The treatment combination NaCl+PRM+(PGPR mix I+ rhizobium) recorded significantly tallest plants and absolute control recorded the shortest. Among the non mulched treatments, PGPR mix I+ rhizobium and water spray were on par with farmers practice.

At 45 DAS, all treatment combinations involving mulching (except NaCl+PRM+ (PGPR mix I+ rhizobium) + water spray) recorded a higher plant height and were on par with farmers practice. The tallest plants were noticed in

Table 33. Effect of treatments on plant biometry

Treatments	Plant height (cm)				No. of leaves				No. of branches		Leaf area index (LAI)			Root length (cm)	Root Shoot ratio	Days to flowering
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	45 DAS	60 DAS	20 DAS	40 DAS	60 DAS			
1. NaCl	6.13	7.33	7.90	12.00	4.07	9.67	17.13	18.77	0.00	0.50	0.06	0.17	0.43	9.57	0.17	53.00
2. PRM	6.97	8.50	12.63	16.73	4.80	10.00	23.13	32.33	0.17	2.20	0.07	0.24	0.81	12.10	0.23	52.33
3. PGPR	6.83	8.70	9.90	12.27	4.67	10.30	17.10	23.00	0.33	2.17	0.06	0.16	0.47	12.13	0.18	52.67
4. WS	6.30	7.70	7.87	11.40	3.87	9.27	13.23	17.87	0.00	0.13	0.06	0.15	0.41	8.40	0.16	52.67
5. SA	6.27	7.67	8.30	12.73	4.57	9.90	17.20	18.17	0.00	1.00	0.06	0.18	0.47	9.70	0.17	54.33
6. DAP+KCl	6.40	7.47	9.77	11.57	4.03	9.97	17.63	18.40	0.00	0.70	0.06	0.18	0.42	8.93	0.17	53.67
7. $ZnSO_4$	6.27	7.33	8.03	11.90	4.07	9.90	16.87	17.40	0.00	0.53	0.07	0.16	0.46	9.70	0.20	54.00
8. LWS	6.57	7.33	7.87	11.43	4.00	9.73	16.33	17.20	0.00	0.20	0.06	0.15	0.42	9.23	0.17	56.33
9. NaCl+PRM	7.23	8.07	16.97	20.63	5.70	10.47	26.27	29.77	0.10	2.23	0.09	0.25	0.54	11.40	0.20	52.33
10.NaCl+PRM+ PGPR	9.90	10.43	14.37	14.70	4.87	12.00	20.23	30.57	0.33	1.07	0.07	0.24	0.54	12.70	0.25	51.33
11.NaCl+PRM+ PGPR+WS	7.43	8.20	10.83	15.57	5.23	11.33	18.17	23.23	0.00	0.97	0.08	0.22	0.51	11.53	0.23	52.33
12.NaCl+PRM+ PGPR+SA	7.13	8.93	16.37	24.83	4.93	14.33	28.60	34.90	0.00	1.77	0.11	0.31	0.54	11.30	0.30	52.00
13.NaCl+PRM+ PGPR+DAP+KCl	7.73	8.60	14.30	17.07	4.87	10.70	22.13	27.03	0.47	1.18	0.07	0.24	0.52	13.10	0.30	51.00
14.NaCl+PRM+ PGPR+$ZnSO_4$	7.23	8.63	14.47	18.50	4.67	11.90	26.57	30.17	0.30	2.33	0.09	0.27	0.75	12.60	0.23	51.67
15.NaCl+PRM+ PGPR+LWS	7.37	8.40	14.10	15.50	5.57	10.67	25.30	26.13	0.53	2.10	0.09	0.27	0.52	10.93	0.30	50.00
16. Absolute control	5.93	6.87	7.67	10.43	3.20	9.50	16.30	16.83	0.00	0.20	0.06	0.10	0.23	8.40	0.16	55.00
17. Control	7.53	8.50	11.30	13.07	5.43	11.13	23.67	20.57	0.33	0.60	0.07	0.32	0.28	12.33	0.20	52.33
18. FP	7.93	8.83	14.17	15.30	5.83	12.37	34.33	24.17	0.47	1.33	0.08	0.52	0.52	10.70	0.23	49.67
CD(0.05)	1.33	1.25	2.26	2.86	1.35	2.29	4.15	4.28	NS	1.51	0.008	0.07	0.14	1.94	NS	2.69
SEd	0.65	0.61	1.11	1.41	0.66	1.12	2.04	2.11	-	0.74	0.003	0.03	0.06	0.95	-	1.32

NaCl+PRM and NaCl+PRM+ (PGPR mix I+ rhizobium) + salicylic acid. Among the non mulched treatments, seed treatment with PGPR mix I+ rhizobium and foliar spray of (DAP+KCl) were on par with the treatment irrigated at 5 days interval. Moreover they recorded 27.6 to 30 per cent increase in plant height compared to absolute control.

At 60 DAS also the positive effect of mulching was observed which resulted in 15.7 to 95 per cent increase in plant height compared to non mulched ones. The treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid resulted in significantly highest plant height followed by NaCl+PRM and NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate, which in turn were on par with each other. Individual application of treatments resulted in 9.6 to 22 per cent increase in plant height compared to absolute control.

4.4.1.2. Number of leaves

Number of leaves of cowpea plants was significantly influenced by various treatments at all stages of the crop. Farmers practice recorded the highest number of leaves at 15 and 45 DAS. In general, there was a progressive increase in number of leaves up to 60 DAS. However, at 60 DAS, there was a decline in the number of leaves per plant in farmers practice and irrigation at 5 days interval due to attainment of early maturity as in the case of first year experiments.

At 15 DAS, all treatment combinations involving mulching with plant residues recorded higher number of leaves on par with farmers practice and the treatment irrigated at 5 days interval. Among the treatment combinations, NaCl+PRM and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray recorded the highest number of leaves per plant. Among the non mulched treatments, PGPR mix I+ rhizobium and salicylic acid 2% spray were on par with farmers practice.

At 30 DAS, the treatment combination, NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid recorded significantly highest number of leaves per plant and all mulched treatments resulted in higher number of leaves compared to non mulched treatments and were on par with farmers practice, except PRM alone. Among non mulched treatments, seed treatment with PGPR mix I+ rhizobium maintained its superiority and it was on par with farmers practice. However, all other treatments without mulching recorded a lesser number of leaves on par with absolute control.

At 45 DAS, the superiority of mulching in resulting more number of leaves per plant was evident from the data. Among the treatment combinations NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid recorded the highest number of leaves per plant and it was on par with NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate, NaCl+PRM and NaCl+PRM+ (PGPR mix I+ rhizobium)+lime water spray. Among the treatments without mulching, foliar spray of (DAP+KCl) recorded the highest number of leaves whereas the lowest was recorded by water spray.

At 60 DAS also the favourable influence of mulching either alone or in combination with other treatments resulted in more number of leaves per plant compared to non mulched treatments. Among the mulched treatments, NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid and PRM alone recorded the highest number of leaves per plant. Among the non mulched treatments, PGPR mix I+ rhizobium was found superior to others in maintaining more number of leaves.

4.4.1.3. Number of branches

In general, branching was noticed from 45 DAS only. At 45 DAS, branches were noticed in plots irrigated on alternate days (farmers practice) and at 5 days interval, PRM alone, seed treatment with PGPR mix I + rhizobium and all combination treatments involving mulching except NaCl+PRM+ (PGPR mix I+ rhizobium)+water spray and NaCl+PRM+ (PGPR mix I+ rhizobium)+salicylic acid. However, none of the treatments could bring about any significant influence on number of branches of cowpea plants at 45 DAS. At 60 DAS, all mulched treatments recorded significantly higher number of branches on par with farmers practice. Among non mulched treatments, seed treatment with PGPR mix I+ rhizobium and foliar spray of salicylic acid 2% resulted in more number of branches per plant and were on par with farmers practice.

4.4.1.4. Leaf area index

In general, a progressive increase in leaf area index was noticed up to 60 DAS in all treatments except in farmers practice and irrigation at 5 days interval. The decline in leaf area index in plots irrigated on alternate days (farmers practice) and at 5 days interval at 60 DAS was due to the leaf fall as a result of attainment of early maturity.

At 20 DAS, the treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium)+salicylic acid recorded the highest leaf area index followed by NaCl+PRM and NaCl+PRM+ (PGPR mix I+ rhizobium)+lime water spray which were found to be superior to farmers practice. All mulched treatments recorded higher leaf area index compared to non mulched ones. Among the individual application of treatments, foliar spray of zinc sulphate and lime water recorded higher leaf area index on par with the treatment irrigated at 5 days interval. Lowest leaf area index was observed in absolute control.

At 40 DAS, leaf area index varied significantly among the treatments and it was highest in farmers practice followed by the treatment irrigated at 5 days interval whereas the lowest was in absolute control. Mulching with plant residues either alone or in combination with other treatments resulted in a better leaf area index compared to no mulching. Among treatment combinations, NaCl+PRM+

(PGPR mix I+ rhizobium)+salicylic acid, NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate and NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray recorded significantly higher leaf area index which were on par with the treatment irrigated at 5 days interval. Among non mulched treatments, foliar spray of salicylic acid 2 % and (DAP+KCl) were found better in maintaining higher leaf area index.

At 60 DAS also, all mulched treatments recorded a comparatively higher leaf area index than non mulched ones (7.8 to 72.6 per cent). Moreover, PRM alone and NaCl+PRM+(PGPR mix I+ rhizobium)+zinc sulphate recorded significantly higher leaf area index compared to all other treatments including farmers practice whereas the lowest was in absolute control.

4.4.1.5. Root length

In general, mulching with plant residues either alone or in combination or seed treatment with PGPR mix I + rhizobium resulted in an improvement in root length of cowpea plants (29.7 to 60 per cent) grown under water stress. Highest root length was observed in NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl) whereas the lowest was in water spray.

4.4.1.6. Root:shoot ratio

The favourable influence of mulching alone or in combination with other treatments was reflected in root shoot ratio also even though there was no significant difference among treatments.

4.4.1.7. Days to flowering

Under favorable condition the test variety flowers in 40-45 DAS. Among the treatments, comparatively early flowering (49 DAS) was noted in farmer’s practice. Mulching alone or in combination with other treatments was on par with farmers' practice which attained 50 per cent flowering at 50-52 DAS. On the other hand, individual application of treatments without mulching resulted in a delay of four to seven days (53 to 56 DAS) in attaining 50 per cent flowering compared to farmers' practice.

4.4.2. Physiological and biochemical parameters

Observations on physiological and biochemical parameters were recorded at 15 days interval (except stomatal conductance, transpiration rate and photosynthetic rate at 45 DAS) during the crop period up to 60 DAS. In general, stomatal conductance, transpiration rate, photosynthetic rate, total chlorophyll content, relative leaf water content, proline content, nitrate reductase activity and chlorophyll stability index of cowpea plants were significantly influenced by various treatments. Effect of different treatments on various physiological and biochemical parameters of cowpea plants are presented in Table 34, 35 & 36.

4.4.2.1. Stomatal conductance

Stomatal conductance of cowpea plants was significantly influenced by various water stress mitigation treatments at all stages of crop growth except at 30 DAS.

At 15 DAS, highest stomatal conductance was observed in seed treatment with PGPR mix I + rhizobium and it was on par with farmers practice, irrigation at 5 days interval, NaCl+PRM+(PGPR mix I+ rhizobium)+water spray, foliar spray of (DAP+KCl), lime water spray and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray whereas the lowest was in NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid.

Table 34. Effect of treatments on stomatal conductance, transpiration rate and photosynthetic rate of crop

Treatments	Stomatal conductance (mol H_2O / m^2/ sec)				Transpiration rate (m mol H_2O/ m^2/ sec)				Photosynthetic rate (µ mol CO_2 /m^2 /sec)			
	15 DAS	30 DAS	40 DAS	60 DAS	15 DAS	30 DAS	40 DAS	60 DAS	15 DAS	30 DAS	40 DAS	60 DAS
1. NaCl	0.06	0.27	0.13	0.13	1.58	3.42	2.06	2.12	9.91	7.74	7.38	10.30
2. PRM	0.07	0.09	0.20	0.71	1.60	2.08	3.04	5.69	13.57	8.45	7.75	13.52
3. PGPR	0.14	0.25	0.16	0.50	1.44	3.12	2.19	5.28	8.98	9.49	7.92	10.79
4. WS	0.05	0.19	0.09	0.77	1.92	1.74	1.72	6.39	7.07	10.78	8.21	14.19
5. SA	0.06	0.11	0.19	0.31	1.70	1.98	2.13	4.23	8.82	11.11	8.98	16.01
6. DAP+KCl	0.11	0.17	0.07	0.38	2.30	2.88	1.14	3.66	9.80	12.37	8.99	10.09
7. $ZnSO_4$	0.08	0.24	0.10	0.09	2.68	3.33	1.86	1.99	7.91	10.79	7.34	13.13
8. LWS	0.11	0.26	0.19	0.40	2.64	3.43	2.77	4.43	6.92	14.63	9.33	16.93
9. NaCl+PRM	0.01	0.12	0.16	0.34	1.80	2.09	2.67	4.17	6.89	12.69	9.59	14.74
10.NaCl+PRM+ PGPR	0.01	0.20	0.14	0.11	2.13	3.05	2.01	1.84	7.60	11.30	4.92	11.59
11.NaCl+PRM+ PGPR+WS	0.13	0.20	0.35	0.46	2.99	2.89	4.32	4.67	7.07	7.72	8.19	8.45
12.NaCl+PRM+ PGPR+SA	0.04	0.19	0.11	0.19	2.23	3.01	1.47	3.12	8.14	7.92	7.02	11.64
13.NaCl+PRM+ PGPR+DAP+KCl	0.05	0.16	0.12	0.26	1.80	2.73	1.53	3.99	6.61	7.46	10.32	13.89
14.NaCl+PRM+ PGPR+$ZnSO_4$	0.06	0.18	0.17	0.18	1.56	2.29	1.72	2.73	7.35	8.64	7.82	20.13
15.NaCl+PRM+ PGPR+LWS	0.09	0.20	0.29	0.63	2.02	3.31	3.26	5.58	6.78	11.49	8.39	16.27
16. Absolute control	0.07	0.19	0.13	0.18	1.98	3.03	1.94	2.87	5.88	9.60	8.83	10.63
17. Control	0.11	0.20	0.11	0.86	2.29	3.95	2.01	6.92	7.25	12.07	7.03	10.22
18. FP	0.09	0.23	0.11	0.23	2.30	2.91	2.54	4.26	7.87	12.84	7.67	11.09
CD(0.05)	0.057	NS	0.10	0.24	0.58	NS	0.96	1.35	1.19	NS	2.19	5.74
SEd	0.02	-	0.04	0.12	0.28	-	0.47	0.66	0.58	-	1.07	2.82

Seed priming with NaCl and foliar spray of lime water recorded a numerically higher stomatal conductance, at 30 DAS even though there was no significant difference among treatments.

At 40 DAS, before restarting irrigation, most of the mulched treatments recorded a higher stomatal conductance compared to non mulched ones, of which, NaCl+PRM+(PGPR mix I+ rhizobium)+water spray was significantly superior to all other treatments except NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray whereas foliar spray of (DAP+KCl) recorded the lowest.

At 60 DAS, highest stomatal conductance was noticed in treatment irrigated at 5 days interval on par with water spray, PRM alone and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray. The lowest was recorded by foliar spray of zinc sulphate.

4.4.2.2. Transpiration rate

At 15 DAS, highest transpiration rate was observed in NaCl+PRM+(PGPR mix I+ rhizobium)+water spray which was on par with foliar spray of zinc sulphate and lime water, whereas the lowest was in seed treatment with PGPR mix I + rhizobium.

At 30 DAS, none of the treatments showed any significant influence on transpiration rate of cowpea plants.

At 40 DAS, before restarting irrigation, the influence of treatments on transpiration rate showed a similar trend as that on stomatal conductance and significantly highest transpiration rate was noticed in NaCl+PRM+(PGPR mix I+ rhizobium)+water spray whereas foliar spray of (DAP+KCl) recorded the lowest.

At 60 DAS also, the effect of treatments on transpiration rate showed almost the same trend as that on stomatal conductance. Highest transpiration rate was noticed in treatment irrigated at 5 days interval on par with water spray, PRM alone and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray. The lowest was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium).

4.4.2.3. Photosynthetic rate

Various water stress mitigation treatments significantly influenced photosynthetic rate at all stages of crop growth except at 30 DAS. At 15 DAS, significantly highest photosynthetic rate was recorded by PRM alone followed by seed priming with NaCl, foliar spray of (DAP+KCl), seed treatment with PGPR mix I + rhizobium and foliar spray of salicylic acid. Lowest photosynthetic rate was observed in absolute control.

At 30 DAS, photosynthetic rate of cowpea plants was not significantly influenced by any of the treatments.

At 40 DAS, before restarting irrigation, NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl) recorded highest photosynthetic rate and the remaining treatments except NaCl+PRM+(PGPR mix I+ rhizobium) were on par with farmers practice.

At 60 DAS, the treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium) +zinc sulphate recorded the highest photosynthetic rate. Among individual application of treatments, foliar spray of lime water and salicylic acid was on par with the above treatment, and the lowest was in NaCl+PRM+(PGPR mix I+ rhizobium)+water spray.

4.4.2.4. Chlorophyll content

Chlorophyll content of cowpea plants was significantly influenced by various water stress mitigation treatments at all stages except at 30 DAS. All water stress mitigation treatments recorded a significantly higher chlorophyll content compared to absolute control at 40, 45 and 60 DAS.

At 15 DAS, among the treatments, NaCl+PRM resulted in highest chlorophyll content and it was on par with all treatments except PRM alone, NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl), foliar spray of zinc sulphate, farmers practice and absolute control.

None of the treatments could bring any significant influence on chlorophyll content at 30 DAS. However, a numerically higher value was recorded by lime water spray and NaCl+PRM+(PGPR mix I+ rhizobium)+water spray.

At 40 DAS, seed priming with NaCl recorded the highest chlorophyll content followed by PRM alone, NaCl+PRM and they were on par with each other.

At 45 DAS, among non mulched and mulched treatments, foliar spray of zinc sulphate and NaCl+PRM, resulted in highest chlorophyll content respectively and they were on par with farmers practice and the treatment irrigated at 5 days interval.

At 60 DAS, seed treatment with PGPR mix I+ rhizobium recorded significantly highest chlorophyll content followed by foliar spray of zinc sulphate, NaCl+PRM, and NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid and were on par with irrigation at 5 days interval.

Table 35. Effect of treatments on total chlorophyll, chlorophyll stability index and relative leaf water content of crop

Treatments	Total chlorophyll (mg/g plant)					Chlorophyll Stability Index (CSI) (%)					Relative Leaf Water Content (%)				
	15 DAS	30 DAS	40 DAS	45 DAS	60 DAS	15 DAS	30 DAS	40 DAS	45 DAS	60 DAS	15 DAS	30 DAS	40 DAS	45 DAS	60 DAS
1. NaCl	1.94	2.74	3.01	1.72	1.71	61.44	78.26	77.39	79.30	63.79	65.23	60.57	51.23	70.67	59.63
2. PRM	1.65	2.17	2.93	1.66	1.59	61.31	89.48	94.04	82.02	68.95	73.63	74.47	54.87	83.00	73.70
3. PGPR	2.05	2.59	2.56	1.83	2.81	59.35	88.98	84.33	79.39	51.14	63.03	62.47	54.03	74.27	76.03
4. WS	2.02	2.43	2.53	1.79	1.69	63.53	77.25	75.98	85.82	57.28	61.63	65.20	46.27	79.30	67.30
5. SA	1.76	2.26	2.53	1.86	1.88	57.05	86.05	92.27	79.55	66.45	64.60	67.67	53.83	77.03	73.18
6. DAP+KCl	1.93	2.49	2.63	1.71	1.51	66.20	78.79	94.47	86.05	66.10	66.43	64.87	53.03	80.40	61.10
7. $ZnSO_4$	1.65	2.60	2.81	2.44	2.33	63.26	85.05	93.91	87.77	73.03	66.67	67.40	52.53	81.17	76.97
8. LWS	1.89	2.84	2.47	2.05	1.83	65.58	83.68	85.79	89.16	66.72	61.63	67.80	54.37	79.00	71.10
9. NaCl+PRM	2.11	2.33	2.89	2.16	2.29	63.80	87.40	92.38	83.00	68.31	66.30	73.40	55.30	85.57	74.00
10.NaCl+PRM+ PGPR	1.83	2.58	2.79	1.76	2.17	65.71	87.86	98.02	85.77	80.99	75.30	73.23	56.80	87.13	79.50
11.NaCl+PRM+ PGPR+WS	1.93	2.77	2.79	1.43	1.90	59.45	78.23	97.92	80.82	81.17	76.67	67.87	57.27	85.43	74.07
12.NaCl+PRM+ PGPR+SA	1.92	2.38	2.12	1.86	2.19	64.05	87.79	96.52	83.12	75.21	72.53	74.67	56.67	85.73	73.13
13.NaCl+PRM+ PGPR+DAP+KCl	1.65	2.68	2.40	1.65	1.89	61.13	83.65	94.58	81.74	83.31	70.40	74.70	55.30	80.60	78.67
14.NaCl+PRM+ PGPR+$ZnSO_4$	1.79	2.43	2.78	1.89	1.80	64.26	88.73	96.52	89.68	82.80	71.53	74.40	57.97	83.63	71.27
15.NaCl+PRM+ PGPR+LWS	1.93	2.49	2.73	1.71	1.69	77.49	86.10	96.30	88.28	69.63	66.33	68.43	55.50	87.27	74.13
16. Absolute control	1.68	2.48	1.67	1.12	1.48	60.97	65.60	77.72	75.92	50.32	59.00	55.67	43.33	64.97	55.20
17. Control	2.03	2.48	2.54	2.24	2.29	70.73	88.75	97.05	94.97	96.81	74.97	74.33	64.90	82.37	66.74
18. FP	1.32	2.46	2.56	2.40	1.83	100.00	100.00	100.00	100.00	100.00	79.63	75.67	73.00	87.10	70.83
CD(0.05)	0.37	NS	0.15	0.27	0.15	5.087	8.383	2.436	2.865	7.098	7.799	6.473	4.874	3.79	4.644
SEd	0.18	-	0.07	0.13	0.07	2.50	4.12	1.19	1.41	3.49	3.84	3.18	2.40	1.86	2.28

4.4.2.5. Relative leaf water content (RLWC)

Relative leaf water content was significantly varied among treatments irrespective of stages of the crop and farmers practice was found to be the superior treatment at 15, 30 and 40 DAS.

At 15 DAS, most of the mulched treatments resulted in a better RLWC compared to non mulched ones and among them NaCl+PRM+(PGPR mix I+ rhizobium)+water spray, NaCl+PRM+(PGPR mix I+ rhizobium), irrigation at 5 days interval, PRM alone and NaCl+PRM+(PGPR mix I+ rhizobium)+salicylic acid were on par with each other and farmers practice. Foliar spray of zinc sulphate and (DAP+KCl) recorded a higher relative water content than the remaining individually applied treatments and absolute control.

At 30 DAS, all treatments except seed priming with NaCl were significantly superior to absolute control and all mulched treatments except NaCl+PRM+(PGPR mix I+ rhizobium)+water spray and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray were on par with farmers practice. An increase in RLWC to the tune of 8.8 to 34 per cent was recorded by water stress mitigation treatments compared to absolute control.

At 40 DAS, before the restart of irrigation, all treatments except water spray were significantly superior to absolute control and among mulched ones, NaCl+PRM+(PGPR mix I+ rhizobium)+zinc sulphate recorded higher RLWC and was on par with all other mulched treatments. Among individual application of treatments, foliar spray of lime water, salicylic acid and seed treatment with PGPR mix I+ rhizobium recorded a higher RLWC which was on par with mulched treatments.

At 45 DAS also, all treatments were significantly superior to absolute control and all mulched treatments except PRM alone and

NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl) were on par with farmers practice. Among them NaCl+PRM+(PGPR mix I+ rhizobium)+ lime water spray resulted in higher RLWC than other mulched treatments. Among individual application of treatments, foliar spray of zinc sulphate recorded a higher RLWC compared to others.

At 60 DAS, all treatments except seed priming with NaCl were significantly superior to absolute control as at 30 DAS. The treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium) recorded the highest RLWC which was on par with NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl), foliar spray of zinc sulphate and seed treatment with PGPR mix I+rhizobium.

4.4.2.6. Chlorophyll stability index (CSI)

Chlorophyll stability index of cowpea plants was significantly influenced by various water stress mitigation treatments at all stages of crop growth. Among treatments, farmers practice recorded the highest chlorophyll stability index irrespective of stages.

At 15 DAS, the treatment combination, NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray recorded the highest chlorophyll stability index followed by the treatment irrigated at 5 days interval which in turn was on par with foliar spray of (DAP+KCl) and NaCl+PRM+(PGPR mix I+ rhizobium) whereas the lowest was in foliar spray of salicylic acid.

At 30 DAS, all water stress mitigation treatments recorded a significantly higher chlorophyll stability index compared to absolute control. Highest chlorophyll stability index was observed in PRM alone and it was on par with all mulched treatments except NaCl+PRM+(PGPR mix I+ rhizobium)+

water spray, seed treatment with PGPR mix I + rhizobium, foliar spray of salicylic acid, zinc sulphate and lime water.

At 40 DAS, significantly highest chlorophyll stability index was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium) and NaCl+PRM+(PGPR mix I+ rhizobium)+ water spray which were on par with each other. They were on par with all other mulched treatments except NaCl+PRM+ (PGPR mix I+ rhizobium)+ (DAP+KCl), PRM alone and NaCl+PRM. Foliar spray of (DAP+KCl) was found better in higher chlorophyll stability index than other individually applied treatments.

At 45 DAS, the treatment irrigated at 5 days interval recorded the highest chlorophyll stability index followed by NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate, foliar spray of lime water, NaCl+PRM+(PGPR mix I+ rhizobium)+ lime water spray and foliar spray of zinc sulphate. The lowest chlorophyll stability index was noticed in absolute control.

At 60 DAS also, irrigation at 5 days interval recorded the highest chlorophyll stability index on par with farmers practice, followed by NaCl+PRM+(PGPR mix I+ rhizobium)+ (DAP+KCl), NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate, NaCl+PRM+ (PGPR mix I+ rhizobium)+ water spray and NaCl+PRM+ (PGPR mix I+ rhizobium), whereas the lowest was in absolute control. All treatments except water spray and seed treatment with PGPR mix I + rhizobium recorded significantly higher chlorophyll stability than absolute control. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest chlorophyll stability index and it was on par with most of the mulched treatments.

4.4.2.7. Nitrate reductase (NRase) activity

Nitrate reductase activity of cowpea plants was significantly influenced by various treatments. Among treatments, farmers practice recorded the highest nitrate reductase activity at all stages except at 60 DAS. Moreover, most of the mulched treatments showed a higher nitrate reductase activity compared to non mulched ones at all stages of crop growth.

At 15 DAS, among treatments, significantly highest nitrate reductase activity was noticed in NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl) whereas the lowest was in foliar spray of salicylic acid. Among individual application of treatments water spray was found superior in nitrate reductase activity.

At 30 DAS, all water stress mitigation treatments either individually or in combination, recorded a significantly higher NRase activity compared to absolute control. The treatment combinations, NaCl+PRM+(PGPR mix I+ rhizobium), NaCl+PRM+(PGPR mix I+ rhizobium)+ lime water spray and NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate were on par with each other and with irrigation at 5 days interval. Among individual application of treatments, seed priming with NaCl resulted in higher nitrate reductase activity.

At 40 DAS also, all treatments recorded a significantly higher NRase activity compared to absolute control and the treatment combination, NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate maintained its superiority in keeping highest NRase activity and it was on par with irrigation at 5 days interval. Among individual application of treatments, foliar spray of zinc sulphate and salicylic acid resulted in higher NRase activity compared to others.

At 45 DAS, all treatments recorded significantly higher NRase activity compared to absolute control. Farmers practice and irrigation at 5 days interval

Table 36. Effect of treatments on nitrate reductase activity and proline content of the crop

Treatments	Nitrate Reductase (NRase) activity (µg NO_2/g/hr)					Proline content (mg/g plant)				
	15 DAS	30 DAS	40 DAS	45 DAS	60 DAS	15 DAS	30 DAS	40 DAS	45 DAS	60 DAS
1. NaCl	35.14	40.49	51.83	52.61	48.67	6.87	74.43	149.28	110.08	41.19
2. PRM	39.19	46.77	54.32	53.93	49.09	4.07	74.66	69.63	71.62	30.54
3. PGPR	37.06	30.47	38.81	44.76	44.78	4.91	88.40	152.87	106.24	38.77
4. WS	38.29	30.01	38.28	44.57	47.26	4.35	88.76	98.23	83.53	39.09
5. SA	33.68	36.15	58.02	62.82	37.27	3.23	103.33	177.18	126.75	35.70
6. DAP+KCl	35.48	33.57	46.20	46.63	37.06	5.75	73.80	139.53	112.56	38.28
7. $ZnSO_4$	36.83	40.21	59.12	57.59	45.40	5.47	136.33	154.92	123.43	47.89
8. LWS	34.35	35.82	50.26	48.81	33.37	5.27	122.00	135.48	117.26	29.08
9. NaCl+PRM	41.34	41.27	59.49	61.45	48.77	5.83	87.50	112.50	94.44	38.93
10.NaCl+PRM+ PGPR	35.71	50.62	67.99	63.09	35.06	6.01	72.83	87.82	82.64	36.53
11.NaCl+PRM+ PGPR+WS	41.22	45.67	48.41	62.51	46.80	5.74	65.46	86.85	63.92	50.01
12.NaCl+PRM+ PGPR+SA	42.24	46.22	61.49	67.72	37.00	9.30	74.70	77.30	67.00	36.69
13.NaCl+PRM+ PGPR+DAP+KCl	43.59	44.30	64.81	63.18	45.47	7.61	78.10	88.92	67.17	37.66
14.NaCl+PRM+ PGPR+$ZnSO_4$	38.52	48.24	72.57	68.30	48.46	6.49	98.56	100.50	66.23	29.75
15.NaCl+PRM+ PGPR+LWS	35.71	48.33	62.96	66.08	48.74	5.91	115.00	117.37	74.07	35.16
16. Absolute control	34.35	20.39	22.71	33.38	36.90	4.54	53.16	120.11	51.87	32.42
17. Control	42.58	52.54	74.31	79.58	30.04	6.19	21.90	20.69	22.20	20.03
18. FP	44.94	56.02	80.69	82.96	20.12	5.73	15.40	12.42	13.89	9.53
CD(0.05)	0.005	4.572	3.725	4.785	7.149	1.25	10.08	7.47	7.96	4.16
SEd	0.002	2.25	1.83	2.35	3.52	0.61	4.96	3.67	3.92	2.04

recorded significantly higher NRase activity and they were on par with each other. NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate, NaCl+PRM+(PGPR mix I+ rhizobium)+ salicylic acid and NaCl+PRM+(PGPR mix I+ rhizobium)+ lime water spray, maintained their superiority in recording higher NRase activity. Foliar spray of salicylic acid recorded a significantly higher NRase activity than all other individual application of treatments and absolute control.

At 60 DAS, all mulched treatments except NaCl+PRM+(PGPR mix I+ rhizobium)+ salicylic acid and NaCl+PRM+(PGPR mix I+ rhizobium) recorded higher NRase activity and they were on par with each other. Among individual application of treatments, seed priming with NaCl, foliar spray of water, zinc sulphate and seed treatment with PGPR mix I+ rhizobium resulted in significantly higher nitrate reductase activity and they were on par with most of the mulched treatments. The lowest nitrate reductase activity was recorded by farmers practice.

4.4.2.8. Proline content

Various water stress mitigating treatments significantly influenced the proline content of cowpea plants all stages of growth. Moreover, most of the mulched treatments recorded a lower proline content compared to non mulched ones.

At 15 DAS, the highest proline content was noticed in NaCl+PRM+(PGPR mix I+ rhizobium)+ salicylic acid followed by NaCl+PRM+(PGPR mix I+ rhizobium)+ (DAP+KCl), seed priming with NaCl and NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate whereas the lowest was in foliar spray of salicylic acid.

At 30 DAS, significantly highest proline content was observed in foliar spray of zinc sulphate followed by lime water spray and NaCl+PRM+(PGPR mix I+ rhizobium)+lime water spray. All treatments recorded significantly higher proline content compared to absolute control. Farmers practice recorded significantly lowest proline content and it was on par with the treatment irrigated at 5 days interval.

At 40 DAS, significantly higher proline content was noticed in foliar spray of salicylic acid followed by zinc sulphate spray, seed treatment with PGPR mix I+rhizobium and seed priming with NaCl. All mulched treatments recorded lower proline content compared to non mulched ones and farmers practice recorded significantly lowest proline content.

At 45 DAS also, all mulched treatments recorded lower proline content compared to non mulched ones. Significantly higher proline content was noticed in all treatments compared to absolute control and the highest content was in foliar spray of salicylic acid which was on par with zinc sulphate spray, whereas the lowest was in farmers practice.

At 60 DAS, among treatments, NaCl+PRM+(PGPR mix I+ rhizobium)+ water spray and foliar spray of zinc sulphate recorded significantly higher proline content, and farmers practice the lowest. Here also most of the individual application of treatments resulted in higher proline content compared to mulched ones.

4.4.3. Yield attributes and yield

Effect of various water stress mitigation treatments either alone or in combination on the yield and yield attributes of cowpea plants are presented in Table 37. General yield of the crop was low due to the exposure of plants to dry weather conditions prevailed during major part of crop growing period. However, the crop showed a better performance than that in first year experiments due to the receipt of rainfall towards the later stages of crop growth (Appendix I &II/Fig. 28).

4.4.3.1. Number of pods per plant

Number of pods per plant was significantly influenced by various water stress mitigation treatments. All treatments which involve mulching except NaCl+PRM, farmers practice and irrigation at 5 days interval recorded significantly higher number of pods per plant compared to non mulched plots. The highest number of pods per plant was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate and it was on par with PRM alone where as the lowest by absolute control. Individual application of treatments increased the number of pods per plant to the tune of 8 to 56 per cent compared to absolute control. Moreover, foliar spray of zinc sulphate, seed treatment with PGPR mix I+ rhizobium, foliar spray of salicylic acid and foliar spray of (DAP+KCl) resulted in significantly higher number of pods per plant compared to the remaining individual application of treatments and absolute control.

4.4.3.2. Pod length

Various water stress mitigation treatments significantly influenced the length of pod also. Positive influence of mulching either alone or in combination with other treatments on pod length was evident from the data. Longest pods were observed in PRM alone and it was on par with all other treatments involving mulching and also with farmers practice. Among the individual application of treatments, seed treatment with PGPR mix I+ rhizobium, foliar spray of salicylic acid and foliar spray of (DAP+KCl) were significantly superior to absolute control.

4.4.3.3. Number of seeds per pod

Significant influence of various water stress mitigation treatments was noticed on number of seeds per pod also. Favourable influence of mulching was reflected in number of seeds per pod also as in number of pods per plant and pod length. Highest number of seeds per pod was noticed in NaCl+PRM+(PGPR

Table 37. Effect of treatments on yield attributes and yield of crop

Treatments	Pod No. /plant	Pod length (cm)	Seeds /pod	Pod weight (g)	No. of harvest	Pod yield /plant (g)	Pod yield /plot (kg)	Pod yield (kg/ha)	Stover yield (kg/ha)	DMP (at harvest) (kg/ha)
1. NaCl	5.13	25.43	11.07	7.10	4.00	40.33	4.03	4481.48	5518.52	1931.11
2. PRM	8.67	30.53	13.27	8.47	4.67	64.77	6.48	7196.29	8333.33	2984.74
3. PGPR	6.47	26.27	11.00	7.47	4.33	44.33	4.43	4925.93	5962.96	2100.00
4. WS	4.47	24.37	10.53	6.33	3.33	23.67	2.37	2629.63	4333.33	1374.07
5. SA	6.27	26.23	11.37	7.17	4.33	45.67	4.57	5074.07	5666.67	2058.52
6. DAP+KCl	6.13	26.17	11.50	7.20	4.33	43.33	4.33	4814.82	5518.52	1984.44
7. $ZnSO_4$	6.47	25.87	11.43	7.57	3.67	46.67	4.67	5185.19	6074.07	2165.93
8. LWS	5.57	24.10	11.37	7.17	3.00	35.00	3.50	3888.88	5000.00	1722.22
9. NaCl+PRM	6.47	28.73	12.00	8.20	4.33	59.00	5.90	6555.56	7740.74	2751.85
10.NaCl+PRM+ PGPR	7.40	27.43	12.10	8.20	4.33	63.67	6.37	7074.07	7851.85	2859.25
11.NaCl+PRM+ PGPR+WS	8.10	29.53	14.20	8.43	4.00	60.00	6.00	6666.67	7703.70	2761.48
12.NaCl+PRM+ PGPR+SA	7.90	28.57	13.10	8.27	3.67	61.33	6.13	6814.82	8851.85	3037.78
13.NaCl+PRM+ PGPR+DAP+KCl	8.23	27.80	12.77	8.20	4.67	63.00	6.30	7000.00	7814.82	2839.26
14.NaCl+PRM+ PGPR+$ZnSO_4$	8.87	29.23	12.37	8.43	4.33	69.00	6.90	7666.67	8222.22	3035.56
15.NaCl+PRM+ PGPR+LWS	8.40	27.77	13.57	8.47	4.67	59.27	5.93	6585.19	8074.07	2829.93
16. Absolute control	4.13	22.93	10.47	5.70	3.67	20.33	2.03	2259.25	3555.56	1143.70
17. Control	6.87	27.20	12.10	7.57	4.00	53.33	5.33	5925.93	6370.37	2349.63
18. FP	7.53	27.43	12.27	8.03	4.33	56.33	5.63	6259.25	6740.74	2484.44
CD (0.05)	0.37	3.13	2.04	1.13	NS	10.76	1.08	1195.95	1332.81	411.17
SEd	0.18	1.54	1.00	0.55	-	5.30	0.53	589.13	656.55	202.54

mix I+ rhizobium)+water spray and it was on par with farmers practice and most of the treatments which involve mulching. The lowest number of seeds per pod was observed in absolute control.

4.4.3.4. Pod weight

Weight of individual pods was significantly influenced by various treatments. All water stress mitigation treatments except water spray could bring about a significant increase in pod weight compared to absolute control. All treatments with mulching recorded higher pod weight compared to non mulched ones. Among them, PRM alone, NaCl+PRM+ (PGPR mix I+ rhizobium)+lime water spray, NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate, NaCl+PRM+ (PGPR mix I+ rhizobium)+water spray were found to be better. Among individual application of treatments, foliar spray of zinc sulphate and seed treatment with PGPR mix I+ rhizobium recorded higher pod weight on par with farmers practice.

4.4.3.5. Pod yield (per plant, per plot and per hectare)

In general, the influence of various water stress mitigation treatments on pod yield per plant, pod yield per plot and pod yield per hectare followed the same trend. As in the case of yield attributes, all treatments which involve mulching recorded higher pod yield compared to those without mulching. Among them, NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate resulted in significantly highest pod yield (7666kg/ha) than that obtained from farmers practice, irrigation at 5 days interval, all individual application of treatments and absolute control even though it was on par with all other treatments in which mulching was included. Treatments which involve mulching could bring about an increase in pod yield ranging from 5 to 22 per cent compared to farmers' practice which was irrigated on alternate days. Among individual application of treatments, foliar spray of zinc sulphate and foliar spray of salicylic acid recorded higher pod yield on par with farmers practice. A yield increment to the tune of 16 to 129 was observed due to the individual application of treatments for mitigating water stress compared to absolute control.

4.4.3.6. Stover yield (per plot and per hectare)

Influence of various water stress mitigation treatments on stover yield per plot and per hectare followed the same trend. As observed in growth parameters, yield attributes and yield, the treatments with mulching either alone or in combination with other treatments resulted in higher stover yield compared to those without mulching. Moreover, the stover yield obtained from these treatments was found to be significantly higher than that from the treatment irrigated at 5 days interval, all individual application of treatments and absolute control. Highest stover yield was obtained from the treatments, NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid, PRM alone, NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate and NaCl+PRM+ (PGPR mix I+ rhizobium)+lime water spray . Stover yield obtained from treatments, foliar spray of zinc sulphate, seed treatment with PGPR mix I+ rhizobium, foliar spray of salicylic acid, foliar spray of (DAP+ KCl) and seed priming with NaCl were on par with farmers practice and irrigation at 5 days interval, and were significantly superior to absolute control.

4.4.3.7. Dry matter accumulation

Effect of various water stress mitigation treatments on dry matter production also showed the same trend as that on pod and stover yield, with mulched ones superior to non mulched treatments. Among various treatments, NaCl+PRM+ (PGPR mix I+ rhizobium)+salicylic acid, NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate and PRM alone recorded the highest dry matter accumulation significantly superior to farmers practice, irrigation at 5 days interval, individual application of treatments and absolute control. Among individual application of treatments, foliar spray of zinc sulphate and seed treatment with PGPR mix I+ rhizobium were found to be on par with farmers practice, irrigation at 5 days interval and were significantly superior to water spray and absolute control.

4.4.3.8. Number of harvests

Number of harvests was not significantly influenced by various water stress mitigation treatments and it ranged from 3 to 5 pickings.

4.4.3.9. Duration of the crop

It was observed that the plants in treatments which received irrigation on alternate days (farmers practice) and at 5 days interval attained final maturity earlier (65 days) than the remaining treatments. However, plants in water stress mitigation treatments either alone or in combination exhibited resurgence of vegetative growth on receipt of rainfall during the later stage of growth, which resulted in an extension of crop duration by three weeks (85 days) without any variation among them.

4.4.4. Quality parameters

Effect of various treatments on protein content in pod and stover of vegetable cowpea are presented in Table 38.

4.4.4.1. Protein content in pod

Various water stress mitigation treatments significantly influenced the protein content in pod of cowpea. All treatments involving mulching recorded a better pod protein content compared to individual application of treatments and absolute control. Among various treatments, NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl) and farmers practice recorded significantly highest pod protein content compared to all other treatments whereas the lowest was in absolute control. Moreover, the pod protein content recorded by the remaining mulched treatments were on par with that by the treatment irrigated at 5 days interval. Individual application of treatments improved the pod protein content to the tune of 11.8 to 29.5 per cent compared to absolute control.

4.4.4.2. Protein content in stover

Stover protein content also varied significantly among treatments as in the case of pod protein content. Most of the mulching involved treatments recorded a better stover protein content compared to individual application of treatments and absolute control. Highest stover protein content was recorded by NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate which was on par with irrigation at 5 days interval and PRM alone whereas the lowest in absolute control. Among individual application of treatments, seed treatment with PGPR mix I+ rhizobium and foliar spray of (DAP+KCl) recorded the highest stover protein content on par with farmers practice. Moreover, all the individual application of treatments except lime water spray were superior to absolute control.

Table 38. Effect of treatments on protein content of crop

Tr. No.	Treatments	Pod (%)	Stover (%)
1	**NaCl**	10.39	2.73
2	**PRM**	13.13	6.02
3	**PGPR**	12.03	4.38
4	**WS**	10.94	2.73
5	**SA**	11.48	3.28
6	**DAP+KCl**	12.03	3.83
7	**$ZnSO_4$**	11.48	2.73
8	**LWS**	11.48	1.64
9	**NaCl+PRM**	13.67	4.38
10	**NaCl+PRM+PGPR**	12.58	3.83
11	**NaCl+PRM+PGPR+WS**	12.58	4.92
12	**NaCl+PRM+PGPR+SA**	13.67	4.38
13	**NaCl+PRM+PGPR+DAP+KCl**	15.86	5.47
14	**NaCl+PRM+PGPR+$ZnSO_4$**	13.67	6.56
15	**NaCl+PRM+PGPR+LWS**	13.13	4.92
16	**Absolute control**	9.29	1.09
17	**Control**	12.58	6.02
18	**FP**	15.86	3.83
	CD(0.05)	1.26	1.05
	SEd	0.62	0.51

4.4.5. Nutrient uptake by the crop

Analysis of plant and pod samples from each treatment plots at final harvest was done to estimate primary (N, P, K), secondary (Ca, Mg, S), micro (Fe, Mn, Zn, Cu, B) and beneficial (Na) nutrient contents (Appendix VI) and their uptake by the crop was calculated. Among these, content of sodium and copper in cowpea plants in all treatments were found to be below detectable level. Effect of application of various water stress mitigation treatments on elemental uptake by vegetable cowpea is shown in Table 39 and 40.

4.4.5.1. Primary nutrients

The uptake of primary nutrients [nitrogen (N), phosphorus (P) and potassium (K)] was significantly influenced by various treatments. All treatments with mulching recorded higher primary nutrient uptake compared to non mulched ones.

Highest N uptake was recorded by NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate and it was on par with NaCl+PRM+(PGPR mix I+ rhizobium)+(DAP+KCl) and PRM alone whereas the lowest was in absolute control. Individual application of treatments except water spray was significantly superior to absolute control and among them, seed treatment with PGPR mix I+ rhizobium, foliar spray of (DAP+KCl), salicylic acid and zinc sulphate were found better than others in N uptake.

Farmers practice recorded significantly highest P uptake followed by NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid and PRM alone. Individual application of treatments resulted in an increase in P uptake ranging from 1.5 to 162 per cent compared to absolute control. Among them, seed treatment with PGPR mix I + rhizobium, foliar spray of (DAP+KCl) and seed priming with NaCl were found to be superior to other treatments.

All mulched treatments resulted in an increase in K uptake to the tune of 2.3 to 46.7 per cent compared to farmers practice. Moreover, among treatments, NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate recorded the highest K uptake which was on par with PRM alone and NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray. Among individual application of treatments, seed treatment with PGPR mix I + rhizobium, foliar spray of salicylic acid, seed priming with NaCl and foliar spray of (DAP+KCl) were on par with farmers practice.

4.4.5.2. Secondary nutrients

Uptake of secondary nutrients by the crop was significantly influenced by various treatments. In general, all treatments involving mulching recorded higher uptake of calcium (Ca), magnesium (Mg) and sulphur (S) than farmers practice, irrigation at 5 days interval, individual application of treatments and absolute control.

Highest Ca uptake was noticed in NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid and it was on par with all mulched treatments either alone or in combination whereas the lowest was in absolute control. Individual application of treatments except water spray was better than absolute control which resulted in an increment in Ca uptake ranging from 27 to 82 per cent.

The treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate recorded significantly highest Mg uptake and it was on par with NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray, NaCl+PRM+ (PGPR mix I+ rhizobium)+ water spray and NaCl+PRM. Among individual application of treatments, foliar spray of zinc sulphate was found to be superior and it was on par with farmers practice and irrigation at 5 days interval. The lowest Mg uptake was observed in absolute control.

Among mulched treatments, NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray resulted in highest S uptake on par with NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl) and the lowest in absolute control. Among individual application of treatments, foliar spray of (DAP+KCl) and lime water spray were on par with farmers practice and irrigation at 5 days interval.

4.4.5.3. Micro nutrients

Similar to primary and secondary nutrients, uptake of micro nutrients by the crop was also significantly influenced by various treatments and all treatments involving mulching recorded higher micro nutrient uptake [iron (Fe), manganese (Mn) zinc (Zn) and boron (B)] than most of the individual application of treatments and absolute control.

All water stress mitigation treatments recorded significantly higher iron uptake than absolute control. The treatment, PRM alone recorded highest Fe uptake and all treatments with mulching were on par with farmers practice. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest Fe uptake which was on par with all mulched treatments, farmers practice, irrigation at 5 days interval and seed treatment with PGPR mix I+ rhizobium but significantly superior to other individual application of treatments and absolute control.

Influence of various treatments on Mn uptake showed the same trend as that on N, K and Mg uptake. The treatment combination, NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate recorded the highest Mn uptake on par with PRM alone, NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl), NaCl+PRM+ (PGPR mix I+ rhizobium) and NaCl+PRM. Among individual application of treatments, foliar spray of zinc sulphate resulted in highest Mn uptake on par with farmers practice and was significantly superior to absolute control.

All water stress mitigation treatments except water spray resulted significantly higher zinc uptake compared to absolute control. Among them, PRM alone recorded the highest zinc uptake and it was on par with NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate and NaCl+PRM. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest Zn uptake which was on par with farmers practice, seed treatment with PGPR mix I+ rhizobium and seed priming with NaCl but significantly superior to the remaining treatments and absolute control.

Among various treatments, highest B uptake was observed in NaCl+PRM+PGPR+ salicylic acid on par with NaCl+PRM+(PGPR mix I+ rhizobium), NaCl+PRM+ (PGPR mix I+ rhizobium)+lime water spray and NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl). Among individual application of treatments, seed treatment with PGPR mix I + rhizobium recorded the highest B uptake which was on par with farmers practice but significantly superior to absolute control.

Table 39. Effect of treatments on primary and secondary nutrient uptake of crop

Tr. No.	Treatments	Nutrient Uptake (kg/ha)					
		N	P	K	Ca	Mg	S
1	NaCl	17.23	7.53	45.88	11.71	6.50	4.11
2	PRM	41.83	12.46	66.93	16.87	9.53	6.24
3	PGPR	24.36	8.79	50.87	12.43	6.97	3.85
4	WS	11.53	3.42	32.21	9.01	4.88	3.30
5	SA	21.46	5.99	48.49	12.01	6.39	4.49
6	DAP+KCl	22.27	7.68	45.03	11.07	6.99	5.84
7	$ZnSO_4$	21.09	5.79	40.90	13.06	7.69	4.03
8	LWS	14.32	4.75	37.93	10.86	6.34	5.46
9	NaCl+PRM	34.87	9.02	51.55	16.84	10.06	4.79
10	NaCl+PRM+PGPR	33.36	10.19	60.22	16.70	9.62	4.85
11	NaCl+PRM+PGPR+WS	34.81	9.03	59.36	16.68	10.07	5.47
12	NaCl+PRM+PGPR+SA	37.48	13.19	56.01	18.72	9.59	4.95
13	NaCl+PRM+PGPR+DAP+KCl	43.46	8.24	55.14	16.68	9.73	6.72
14	NaCl+PRM+PGPR+$ZnSO_4$	45.83	11.47	73.86	17.89	11.32	6.11
15	NaCl+PRM+PGPR+LWS	36.11	9.18	66.35	16.35	10.12	7.42
16	Absolute control	6.75	3.37	23.83	7.18	4.14	2.74
17	Control	32.57	11.32	46.11	13.07	8.58	6.33
18	FP	34.49	14.93	50.31	13.72	8.62	5.35
	CD(0.05)	5.37	1.49	8.51	2.69	1.46	0.97
	SEd	2.64	0.73	4.19	1.32	0.71	0.47

Table 40. Effect of treatments on micronutrient uptake of crop

Tr. No.	Treatments	Nutrient Uptake (kg/ha)			
		Fe	Mn	Zn	B
1	NaCl	1.53	2.29	0.21	0.09
2	PRM	2.39	4.15	0.35	0.13
3	PGPR	1.99	2.57	0.22	0.12
4	WS	1.45	2.21	0.15	0.06
5	SA	1.46	1.95	0.19	0.09
6	DAP+KCl	1.54	2.38	0.18	0.08
7	$ZnSO_4$	2.09	2.80	0.25	0.11
8	LWS	1.59	2.41	0.18	0.09
9	NaCl+PRM	2.05	4.02	0.31	0.13
10	NaCl+PRM+PGPR	2.26	3.74	0.26	0.16
11	NaCl+PRM+PGPR+WS	1.87	3.22	0.27	0.12
12	NaCl+PRM+PGPR+SA	2.24	3.29	0.28	0.17
13	NaCl+PRM+PGPR+DAP+KCl	2.25	4.07	0.29	0.15
14	NaCl+PRM+PGPR+$ZnSO_4$	2.19	4.23	0.33	0.12
15	NaCl+PRM+PGPR+LWS	2.06	2.65	0.25	0.16
16	Absolute control	0.80	1.58	0.10	0.06
17	Control	2.03	3.28	0.29	0.12
18	FP	2.19	2.82	0.27	0.12
	CD(0.05)	0.36	0.61	0.04	0.034
	SEd	0.17	0.30	0.01	0.01

4.4.6. Soil characters

Soil samples collected from each treatment after the final harvest of the crop were analysed for pH, organic carbon, primary, secondary and micro nutrients and the data are presented in Table 41 and 42.

4.4.6.1. Soil pH

Soil pH in various treatments after the experiment showed a reduction (5.06-5.46) compared to that before the experiment (5.6). However, there was not much variation in soil pH value among treatments.

4.4.6.2. Soil organic carbon

Organic carbon status of soil after the experiment did not show much variation among various treatments and it ranged from 1.1 to 1.4 per cent compared to that of 1.4 per cent before the experiment.

4.4.6.3. Primary nutrients

Soil primary nutrient status after the experiment varied significantly among treatments. Available nitrogen content in the soil was 262.8 kg/ha before the experiment and it got reduced to the range of 154 to 197 kg/ha after the experiment. Farmers practice recorded the highest soil N content followed by foliar spray of zinc sulphate, irrigation at 5 days interval and seed treatment with PGPR mix I+ rhizhobium whereas the lowest was in seed priming with NaCl.

Available phosphorus content in soil before the experiment was 17.6 kg/ha and it ranged to the tune of 10.8 to 16.3 kg/ha after the experiment. Highest soil P content was noticed in NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid and the lowest was in seed treatment with PGPR mix I+ rhizhobium.

Available potassium content in the soil before the experiment was 315.3 kg/ha and it ranged from 234-331.1 kg/ha after the experiment. All treatments recorded a significantly higher soil K content compared to absolute control. Highest K content was recorded by farmers practice followed by the treatment irrigated at 5 days interval and NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray.

4.4.6.4. Secondary nutrients

Different treatments significantly influenced the Ca, Mg and S content in soil after the experiment.

Available calcium content in soil before the experiment was 218.7 mg/kg. After the experiment, soil calcium content reduced to the tune of 175.8 to 206.5 mg/kg. However, higher Ca content was recorded by foliar spray of zinc sulphate followed by NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate and the lowest content by NaCl+PRM.

Available magnesium content in the soil before the experiment was 131.6 mg/kg and it showed the range of 120.5-137.3 mg/kg after the experiment. Highest Mg content was observed in foliar spray of zinc sulphate whereas the lowest content was in NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray.

Available sulphur in soil was 3.32 mg/kg before the experiment and it ranged from 1.4 - 6.1 mg/kg after the experiment. Soil S content after the experiment was highest in farmers practice followed by the treatment irrigated at 5 days interval and NaCl+PRM+ (PGPR mix I+ rhizobium). The lowest was recorded by NaCl+PRM and seed treatment with PGPR mix I+ rhizhobium.

Table 41. Effect of treatments on primary and secondary nutrient content in soil

Tr. No.	Treatments	pH	Org. C (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)
1	**NaCl**	5.4	1.33	153.70	11.90	292.73	197.16	128.86	2.53
2	**PRM**	5.3	1.46	166.02	11.65	309.06	182.31	124.66	3.20
3	**PGPR**	5.3	1.30	190.66	10.83	282.10	191.46	135.86	1.43
4	**WS**	5.3	1.30	178.34	13.06	264.00	185.86	123.45	2.10
5	**SA**	5.1	1.26	172.18	15.80	300.90	197.66	127.13	2.10
6	**DAP+KCl**	5.4	1.30	172.18	14.93	259.84	194.56	133.43	3.20
7	**$ZnSO_4$**	5.4	1.26	190.66	13.90	259.14	206.46	137.29	2.10
8	**LWS**	5.4	1.46	166.02	11.90	267.71	184.98	129.24	2.33
9	**NaCl+PRM**	5.1	1.43	178.34	11.16	296.06	175.86	127.24	1.43
10	**NaCl+PRM+PGPR**	5.5	1.36	159.86	11.81	309.76	181.88	134.93	3.63
11	**NaCl+PRM+PGPR+WS**	5.1	1.46	166.02	14.93	289.09	189.17	130.56	3.20
12	**NaCl+PRM+PGPR+SA**	5.2	1.33	178.34	16.26	291.04	193.98	134.45	2.56
13	**NaCl+PRM+PGPR+DAP+KCl**	5.4	1.13	178.34	11.91	302.88	193.51	131.36	2.76
14	**NaCl+PRM+PGPR+$ZnSO_4$**	5.2	1.40	178.34	13.90	289.75	198.56	131.73	2.10
15	**NaCl+PRM+PGPR+LWS**	5.2	1.40	166.02	13.20	312.89	188.06	120.56	3.20
16	**Absolute control**	5.2	1.46	178.34	12.62	234.20	182.96	133.63	3.13
17	**Control**	5.3	1.33	190.66	11.54	322.09	191.86	127.46	4.10
18	**FP**	5.4	1.43	196.82	12.97	331.08	184.86	124.46	6.10
	CD(0.05)	0.22	0.107	14.96	3.32	18.70	0.03	0.046	0.897
	SEd	0.11	0.05	7.36	1.63	9.21	0.01	0.02	0.44

4.4.6.5. Micro nutrients

Soil micronutrient status after the experiment also varied significantly among treatments.

Available iron content in soil after the experiment ranged to the tune of 5 to 6.7 mg/kg compared to its content before the experiment (6.01mg/kg). Highest Fe content in soil after the experiment was observed in foliar spray of (DAP+KCl) followed by farmers practice whereas the lowest was in NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray. Available manganese content before the experiment was 48.1mg/kg which ranged from 36.3 to 53.9 mg/kg after the experiment. Highest Mn content after the experiment was recorded by

NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray where as the lowest content by foliar spray of salicylic acid.

Available zinc content in soil was 2.1 mg/kg before the experiment. After the experiment it ranged from 1.8 to 3.7 mg/kg. NaCl+PRM recorded significantly highest zinc content whereas the lowest content was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray.

Available copper content in soil before the experiment was 5.67mg/kg. An increase in copper content to the tune of 5.6 to 7.5 mg/kg was noticed after the experiment. NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl) showed significantly highest copper content in soil after the experiment whereas the lowest was in NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray. Available boron content in soil before the experiment was 0.53mg/kg. After the experiment it ranged from 0.19 - 0.61 mg/kg and the highest value was noticed in water spray, which was on par with foliar spray of lime water and farmers practice. The lowest boron content was observed in absolute control.

Table 42. Effect of treatments on micro nutrient content in soil

Tr. No.	Treatments	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)
1	**NaCl**	6.30	42.76	2.63	5.66	0.40
2	**PRM**	5.60	46.11	2.46	6.73	0.49
3	**PGPR**	5.20	47.16	3.23	6.86	0.45
4	**WS**	5.70	47.02	3.03	7.46	0.61
5	**SA**	5.60	36.26	2.06	6.66	0.26
6	**DAP+KCl**	6.70	43.71	2.56	6.20	0.36
7	**$ZnSO_4$**	6.00	45.85	2.73	6.80	0.33
8	**LWS**	5.60	45.06	2.40	5.73	0.54
9	**NaCl+PRM**	6.10	49.80	3.73	6.03	0.26
10	**NaCl+PRM+PGPR**	5.50	51.02	2.13	5.93	0.29
11	**NaCl+PRM+PGPR+WS**	5.10	36.91	2.05	6.43	0.33
12	**NaCl+PRM+PGPR+SA**	6.40	39.63	2.66	5.76	0.42
13	**NaCl+PRM+PGPR+DAP+KCl**	5.50	42.66	2.06	7.56	0.47
14	**NaCl+PRM+PGPR+$ZnSO_4$**	5.90	52.76	3.06	5.93	0.42
15	**NaCl+PRM+PGPR+LWS**	5.00	53.90	1.84	5.63	0.49
16	**Absolute control**	6.30	38.40	3.53	6.03	0.19
17	**Control**	5.96	45.40	2.46	6.23	0.49
18	**FP**	6.50	42.80	2.43	5.86	0.52
	CD(0.05)	0.023	0.095	0.05	0.05	0.09
	SEd	0.01	0.05	0.02	0.02	0.04

4.4.7. Soil moisture content

Soil samples were collected from a depth of 20cm at sowing and subsequently at 15 days interval till last harvest with an additional sampling at 69 DAS due to the receipt of rainfall on previous day, to estimate the soil moisture content (SMC) and the data are presented in Table 43.

Soil moisture content in the field at sowing of cowpea seeds was 8.5 per cent. After sowing, uniform irrigation was given up to 5 days irrespective of treatments for germination and establishment of the crop. After 5 days, irrigation was given at 5 days interval till 15 DAS in all treatments except farmer's practice and the irrigated control, which were irrigated on alternate days and at 5 days interval respectively. Further, irrigation was withheld up to 40 DAS for imposing water stress in absolute control and in various treatments with and without mulching. From 40 DAS, irrigation was restarted in the above treatments at 5 days interval.

In general, moisture status in the soil was higher in mulched treatments compared to non mulched ones in addition to farmers practice and irrigation at 5 days interval. A gradual decline in soil moisture was observed in all treatments (except in farmers practice and irrigation at 5 days interval) up to 30 DAS. However at 45 DAS, water stress release from these treatments resulted in an increase in soil moisture content and maintained more or less the same level at 60 DAS. A progressive increase in SMC was observed at 69DAS due to the receipt of unexpected rainfall on the previous day, and it showed a slight decline at 75 DAS and at final harvest.

Soil moisture status at all stages of observation (15, 30, 45, 60, 69, 75 DAS and at final harvest) was significantly influenced by various treatments and the highest soil moisture content was observed in farmers practice followed by various mulched treatments either alone or in combination, irrespective of stages.

At 15 DAS among the water stress mitigation treatments, significantly higher soil moisture content was recorded by PRM alone and it was found to be on par with NaCl+PRM+ (PGPR mix I+ rhizobium)+ salicylic acid and NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate whereas the lowest moisture status was noticed in absolute control. All individual application of treatments was on par with the treatment irrigated at 5 days interval.

At 30 DAS (15 days after withholding irrigation), among the water stress mitigation treatments, the highest soil moisture content was observed in NaCl+PRM+ (PGPR mix I+ rhizobium) which was on par with all mulched treatments except NaCl+PRM and irrigation at 5 days interval. Mulching either alone or in combination recorded significantly higher soil moisture content to the tune of 31 to 39 per cent compared to absolute control. Among individual application of treatments, foliar spray of zinc sulphate was statistically on par with the remaining treatments except lime water spray.

At 45 DAS, among water stress mitigation treatments, highest soil moisture content was observed in NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate followed by NaCl+PRM+(PGPR mix I + rhizobium) and NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl). Among individual application of treatments, foliar spray of salicylic acid and zinc sulphate was on par with the treatment irrigated at 5 days interval and the lowest SMC was noticed in water spray and lime water spray.

At 60 DAS, the superiority of NaCl+PRM was observed and it was on par with all other mulched treatments except NaCl+PRM+ (PGPR mix I+ rhizobium)+ lime water spray. Soil moisture status in individual application of treatments was on par with the treatment irrigated at 5 days interval.

After unexpected rain at 68 DAS also, the mulched treatments maintained superiority in soil moisture status and the highest was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium) whereas all individual application of treatments recorded soil moisture content on par with absolute control.

At 75 DAS, among the mulched treatments, NaCl+PRM+ (PGPR mix I+ rhizobium) and NaCl+PRM were significantly superior to all other treatments except farmers practice whereas the soil moisture status in individual application of treatments was found to be on par with that in absolute control.

At final harvest also, NaCl+PRM+ (PGPR mix I+ rhizobium) and NaCl+PRM maintained its superiority among the mulched treatments, compared to all other treatments and a lower soil moisture status was observed in individual application of treatments with the lowest value in lime water spray and seed priming with NaCl.

Table 43. Effect of treatments on soil moisture content

Tr. No.	Treatments	Soil moisture content (%)						
		15 DAS	30 DAS	45 DAS	60 DAS	After rain	75 DAS	At final harvest
1	**NaCl**	9.40	7.7	9.56	9.73	11.47	10.27	9.57
2	**PRM**	11.63	9.53	10.76	10.77	12.50	11.30	10.57
3	**PGPR**	9.63	7.90	9.36	9.67	11.60	10.47	9.83
4	**WS**	9.30	7.53	9.10	9.37	11.80	10.57	9.90
5	**SA**	9.67	7.47	9.76	9.90	11.93	10.77	10.13
6	**DAP+KCl**	9.87	7.50	9.23	9.56	11.57	10.40	9.73
7	**$ZnSO_4$**	9.87	7.90	9.67	9.40	11.73	10.63	9.90
8	**LWS**	9.40	7.40	9.10	9.33	11.60	10.27	9.57
9	**NaCl+PRM**	10.13	9.37	10.77	11.16	13.10	12.47	11.70
10	**NaCl+PRM+PGPR**	10.77	9.90	11.13	11.03	13.33	12.63	11.97
11	**NaCl+PRM+PGPR+WS**	10.67	9.57	10.57	10.93	12.83	11.90	11.17
12	**NaCl+PRM+PGPR+SA**	11.20	9.83	10.77	10.77	12.67	11.43	10.77
13	**NaCl+PRM+PGPR+DAP+KCl**	10.10	9.50	11.07	11.13	12.90	11.57	10.77
14	**NaCl+PRM+PGPR+$ZnSO_4$**	10.93	9.73	11.23	10.77	12.83	11.87	11.10
15	**NaCl+PRM+PGPR+LWS**	10.73	9.57	10.46	10.60	12.47	11.43	10.70
16	**Absolute control**	8.87	7.10	9.23	9.37	11.57	10.37	9.67
17	**Control**	9.93	9.43	10.07	9.77	12.07	10.87	10.17
18	**FP**	12.63	12.17	12.27	11.93	14.80	14.53	13.77
	CD(0.05)	0.78	0.49	0.45	0.523	0.59	0.51	0.56
	SEd	0.38	0.24	0.22	0.25	0.29	0.25	0.27

4.4.8. Economics of crop production

Effect of various treatments on economics of crop production was given in Table 44. The general cost of cultivation of the crop except for treatment application was Rs.58,551/- and Rs.60,051/- in mulched and non mulched treatments (excluding cost of weeding in mulched ones). Among the treatments, the cost for farmers practice was the highest (Rs.79,051/-) and absolute control the lowest (Rs.60,051/-). Among treatment combinations, NaCl+PRM+ (PGPR mix

I+ rhizobium)+salicylic acid and among individual application of treatments, foliar spray of salicylic acid recorded the highest cost of cultivation.

All mulched treatments resulted in higher income compared to non mulched ones, the treatments irrigated on alternate days (farmers practice) and 5 days interval, of which, the treatment combination NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate recorded the highest income of Rs.2,68,334/-. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest income whereas absolute control, the lowest.

In general, net profit and B:C ratio were also higher from the treatments which involve mulching. The highest net profit of Rs. 2,03,389/- and B:C ratio of 4.1 were obtained from the treatment NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate followed by PRM alone and the lowest was from absolute control.

Table 44. Effect of treatments on economics of production

Tr. No.	Treatments	Cost of cultivation except treatment (Rs/ha)	Cost of treatment application (Rs/ha)	Total cost (Rs/ha)	Total Income (Rs/ha)	Net Profit (Rs/ha)	B:C
1	NaCl	60,051	9	60,060	1,56,852	96,792	2.6
2	PRM	58,551	3000	61,551	2,51,870	1,90,319	4.1
3	PGPR	60,051	705	60,756	1,72,408	1,11,652	2.8
4	WS	60,051	1000	61,051	92,037	30,986	1.5
5	SA	60,051	10,400	70,451	1,77,593	1,07,142	2.5
6	DAP+KCl	60,051	2630	62,681	1,68,519	1,05,838	2.6
7	$ZnSO_4$	60,051	2680	62,731	1,81,482	1,18,751	2.8
8	LWS	60,051	1042	61,093	1,36,111	75,018	2.2
9	NaCl+PRM	58,551	3009	61,560	2,29,445	1,67,885	3.7
10	NaCl+PRM+PGPR	58,551	3714	62,265	2,47,593	1,85,328	3.9
11	NaCl+PRM+PGPR+WS	58,551	4714	63,265	2,33,334	1,70,069	3.6
12	NaCl+PRM+PGPR+SA	58,551	14,114	72,665	2,38,519	1,65,854	3.3
13	NaCl+PRM+PGPR+DAP+KCl	58,551	6344	64,895	2,45,000	1,80,105	3.7
14	NaCl+PRM+PGPR+$ZnSO_4$	58,551	6394	64,945	2,68,334	2,03,389	4.1
15	NaCl+PRM+PGPR+LWS	58,551	4756	63,307	2,30,482	1,67,175	3.6
16	Absolute control	60,051	0	60,051	79,074	19,023	1.3
17	Control	61,451	0	61,451	2,07,408	1,45,957	3.4
18	FP	79,051	0	79,051	2,19,074	1,40,023	2.7

4.4.9. Field water use efficiency (FWUE)

Field water use efficiency of various treatments varied with yield and the total quantity of water applied during the crop season and the data are given in Table 45. The highest field water use efficiency was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate due to highest yield and the lowest by absolute control. A lower FWUE was recorded by farmers practice mainly due to more quantity of water applied.

Table 45. Effect of treatments on field water use efficiency (FWUE)

Tr. No.	Treatments	Quantity of water applied (mm) (at 2cm depth)	FWUE (kg/ha-mm)
1	NaCl	340	13.18
2	PRM	340	21.16
3	PGPR	340	14.48
4	WS	340	7.734
5	SA	340	14.92
6	DAP+KCl	340	14.16
7	$ZnSO_4$	340	15.25
8	LWS	340	11.43
9	NaCl+PRM	340	19.28
10	NaCl+PRM+PGPR	340	20.80
11	NaCl+PRM+PGPR+WS	340	19.60
12	NaCl+PRM+PGPR+SA	340	20.04
13	NaCl+PRM+PGPR+DAP+KCl	340	20.58
14	NaCl+PRM+PGPR+$ZnSO_4$	340	22.54
15	NaCl+PRM+PGPR+LWS	340	19.36
16	Absolute control	340	6.64
17	Control	320	18.52
18	FP	660	9.48

4.4.10. Incidence of pests and diseases

In general, aphid infestation was noticed in the experiment plots irrespective of treatments for which timely control measures were adopted. No specific disease was noticed in any of the treatments.

Table 46. Scoring of aphids

Tr. No.	Treatments	Scoring
1	NaCl	Moderate
2	PRM	Moderate
3	PGPR	Moderate
4	WS	Moderate
5	SA	Moderate
6	DAP+KCl	Moderate
7	$ZnSO_4$	Moderate
8	LWS	Moderate
9	NaCl+PRM	Mild
10	NaCl+PRM+PGPR	Moderate
11	NaCl+PRM+PGPR+WS	Mild
12	NaCl+PRM+PGPR+SA	Mild
13	NaCl+PRM+PGPR+DAP+KCl	Mild
14	NaCl+PRM+PGPR+$ZnSO_4$	Mild
15	NaCl+PRM+PGPR+LWS	Mild
16	Absolute control	Moderate
17	Control	Moderate
18	FP	Moderate

Plate 5. NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate

Plate 6. PRM alone

Plate 7. Foliar spray of 0.5% zinc sulphate

Plate 8. Absolute control

Plate 9. Farmers' practice

Plate 10. Irrigation at 5 days interval

DISCUSSION

DISCUSSION

Field experiments were conducted during the summer season of 2014 and 2015, at the Agronomy Research Farm to evaluate various agrotechniques for mitigating water stress in vegetable cowpea. There were three experiments during the first year each of which was dealt with (1) effect of exogenous application of plant growth regulators (PGRs), (2) effect of seed priming, antitranspirants and soil moisture conservation practices and (3) effect of nutrient management practices in mitigating water stress in vegetable cowpea. Better treatments from the first year experiments were selected and their individual and possible combinations were evaluated in an experiment during the subsequent year. The results of the experiments are discussed here under.

1.1. Effect of plant growth regulators in mitigating water stress

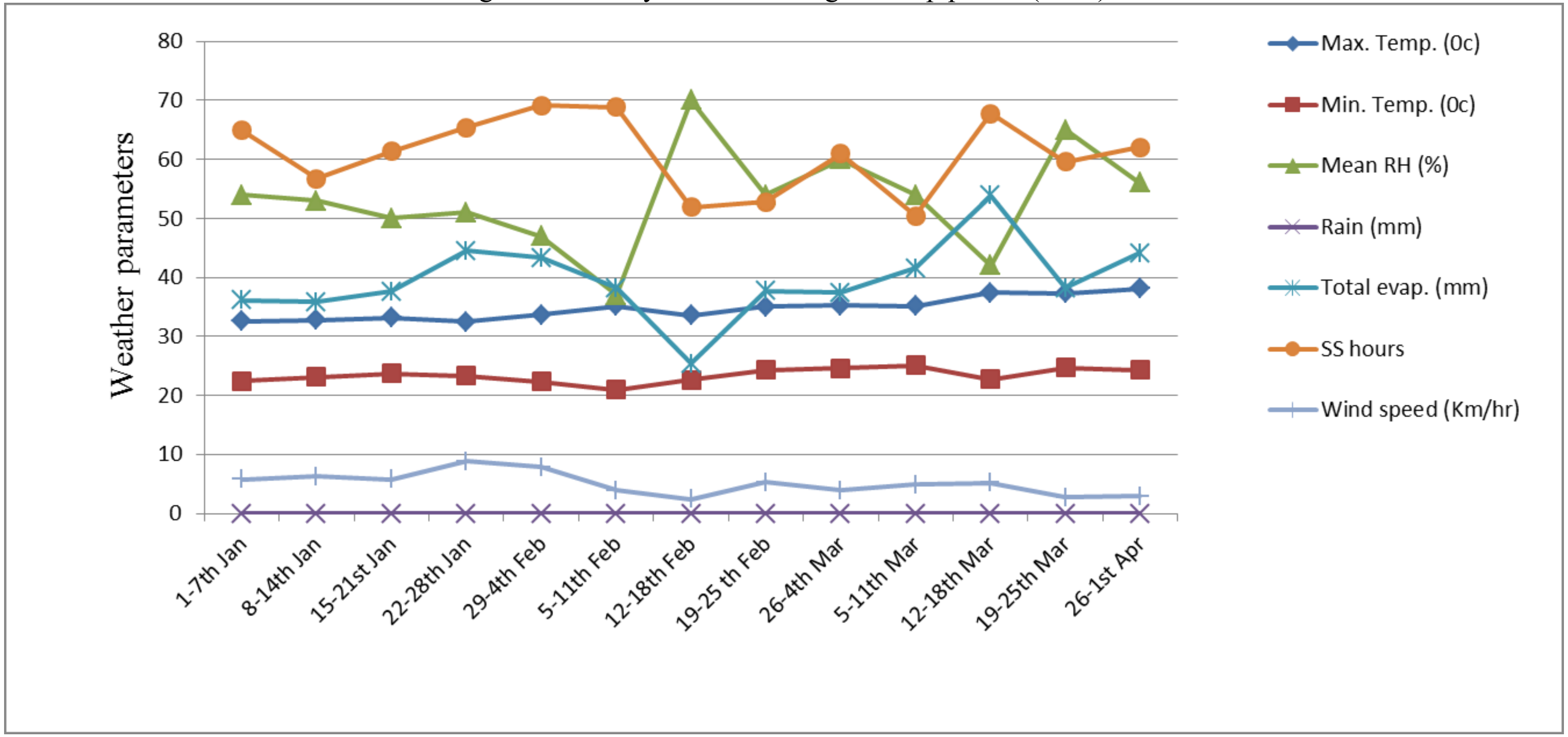
The experiment was conducted to evaluate the effect of exogenous application of plant growth regulators in mitigating water stress in vegetable cowpea.

1.1.1. Growth characters

The general growth of cowpea plants was poor due to the extreme dry condition prevailed during the crop season (Fig 5.) combined with aphid infestation. However, there was a progressive increase in various growth characters of vegetable cowpea such as plant height, number of leaves, number of branches and leaf area up to final harvest except that of number of leaves per plant and leaf area in treatments irrigated at 2 days and 5 days interval which recorded a lesser leaf number at 60 DAS compared to that at 45 DAS. This is due to the leaf fall from plants as a result of attainment of early final maturity consequent to comparatively lesser exposure to water stress in these treatments.

Among the growth characters, plant height was not significantly influenced by various treatments at any stage of observation, whereas number of leaves varied significantly among treatments at 45 and 60 DAS and number of branches at 45 DAS. In general, the treatments which received spraying of either PGRs or coconut water or water during water imposed period resulted in an

Figure 5. Weekly weather during the crop period (2014)



increasing trend of plant height from 1 to 25 per cent, number of leaves from 7 to 38 per cent and number of branches from 9.5 to 38 per cent compared to that which received no treatment during the period. This showed the favourable influence of the treatments on the growth of vegetable cowpea during the water stressed period. The lower growth characters in absolute control are due to the adverse effect of water deficit on cell division, cell enlargement and differentiation. Moreover, exposure of plants to water stress affects stomatal opening and closing which in turn reduce the transpiration rate thereby reducing the nutrient absorption and their efficient utilization by the crop. The higher number of leaves and leaf area index noticed in NAA 40ppm and salicylic acid 2% at 60 DAS can be due to their positive effect on source sink relationship (Upadhyay and Ranjan, 2015). The positive influence of salicylic acid on leaf area index of cowpea (Afshari *et al*., 2013), common bean (Sadeghipour and Aghaei, 2012) and that of NAA on plant height, number of leaves per plant, number of branches per plant and leaf area of soybean was reported by Deotale *et al.* (1998).

Plants acquire water from soil only through roots. So root length, its density and proliferation are important to overcome water stress. In general, the treatments which received irrigation on alternate days and at 5 days interval recorded higher root length and lowest in absolute control. Moisture stress inhibits the development of roots in cowpea during water stress (Hamidou *et al.*, 2007). However, the root shoot ratio of cowpea plants in these treatments were on par with water stress imposed ones as it recorded higher shoot growth also. Among the exogenously applied treatments, salicylic acid 2% recorded a higher root length on par with farmers' practice which showed the favourable influence of the treatment on root growth of cowpea plants under water stress situation. Increased root length in garlic with application of salicylic acid under water stress was also reported by Bideshki *et al.* (2013).

All water stress imposed treatments showed a slight delay in flowering (1- 4days) compared to those received irrigation on alternate days and at 5 days interval. This is due to the delay in attaining sufficient vegetative growth before flowering as a result of imposed water stress as reported by French (2012) in faba bean.

5.1.2. Physiological parameters

Highest stomatal conductance, transpiration rate and photosynthetic rate was observed in farmers practice followed by the treatment irrigated at 5 days interval due to lesser water stress experienced by the cowpea plants. Lower values of the above parameters in the water stress imposed treatments might be due to the stomatal closure and its consequence. Among PGRs, ascorbic acid 1 and 2 % recorded higher stomatal conductance, transpiration rate and photosynthetic rate. Favourable influence of exogenous application of ascorbic acid on the above physiological parameters was reported by Malik and Ashraf (2012) in wheat.

Highest chlorophyll content and relative leaf water content was recorded by farmers practice due to non exposure of cowpea plants to water stress whereas the lowest by absolute control as a result of the impact of extreme water stress experienced by the plants. The decrease in chlorophyll under drought stress is mainly the result of damage to chloroplasts caused by reactive oxygen species (Smirnoff, 1995). Effect of drought stress on reduction of total chlorophyll content in cowpea was reported by Singh and Raja Reddy (2011) and in mung bean by Thalooth *et al.* (2006). Exogenous application of either PGRs, or coconut water or water during the water stress imposed period could increase the chlorophyll content to the tune of 5 to 53 per cent and relative leaf water content to the range of 2 to 78 per cent compared to no treatment during the period. This showed the favourable influence of the treatments to mitigate the adverse effect of water stress on chlorophyll content and relative leaf water content of vegetable cowpea. Favourable influence of exogenous application of PGRs, on chlorophyll content and relative leaf water content of crop plants was reported by various workers; CCC on pigeon pea (Dayal *et al.,* 1993), salicylic acid on cowpea (Afshari *et al*., 2013), ascorbic acid on soybean (Amira and Qados, 2014), NAA on cowpea (Ganiger *et al.,* 2003) and brassinolide on wheat (Dhayal *et al*., 2012).

5.1.3. Yield and yield attributes

In general, pod yield obtained from the experiment was low due to lesser yield attributes resulted from the carryover effect of poor vegetative growth of plants on exposure to unfavourable weather condition prevailed during the crop season accompanied by aphid infestation. However, pod yield was significantly influenced by various treatments. Among treatments, significantly highest pod yield was recorded by farmers' practice due to non exposure of cowpea plants to water stress as evident from data on physiological parameters (Fig. 6). Among exogenously applied treatments, salicylic acid 2% recorded the highest pod yield (Fig 7) which was on par with farmers practice, irrigation at 5 days interval, NAA 40 ppm and water spray. This is due to the cumulative effect of comparatively higher yield attributes recorded by the above treatments (Fig. 8). The favourable influence of salicylic acid on pod formation in soybean was reported by Kumar *et al*. (1999) and on grain yield in corn by Yaghoubian *et al.* (2014). Positive effect of NAA application on yield and yield attributes was reported by Aslam *et al.* (2010) in chick pea, Singh and Sharma (1982) in groundnut, Bai *et al*. (1987) in green gram and Khanzada *et al.* (2002) in soybean. The lowest pod yield in brassinolide 1ppm and CCC 10 ppm due to lower yield attributes showed the ineffectiveness of these treatments for mitigating water stress in vegetable cowpea. Absolute control resulted in 153 per cent reduction in pod yield compared to farmers practice due to the impact of severe water stress on growth and yield attributes. Reduction in yield due to water stress was reported by Nilanthi *et al.* (2014) in black gram, Samarah *et al.* (2006) in soybean and Nam *et al.* (2001) in red gram.

In general, irrespective of treatments, the crop recorded a lower stover yield due to less vegetative growth as a result of exposure of plants to unfavourable weather condition prevailed during the crop season combined with aphid attack. However, the stover yield of the crop was significantly influenced by various treatments. The highest was recorded by farmers practice and the treatment which received irrigation at 5 days interval due to the impact of better

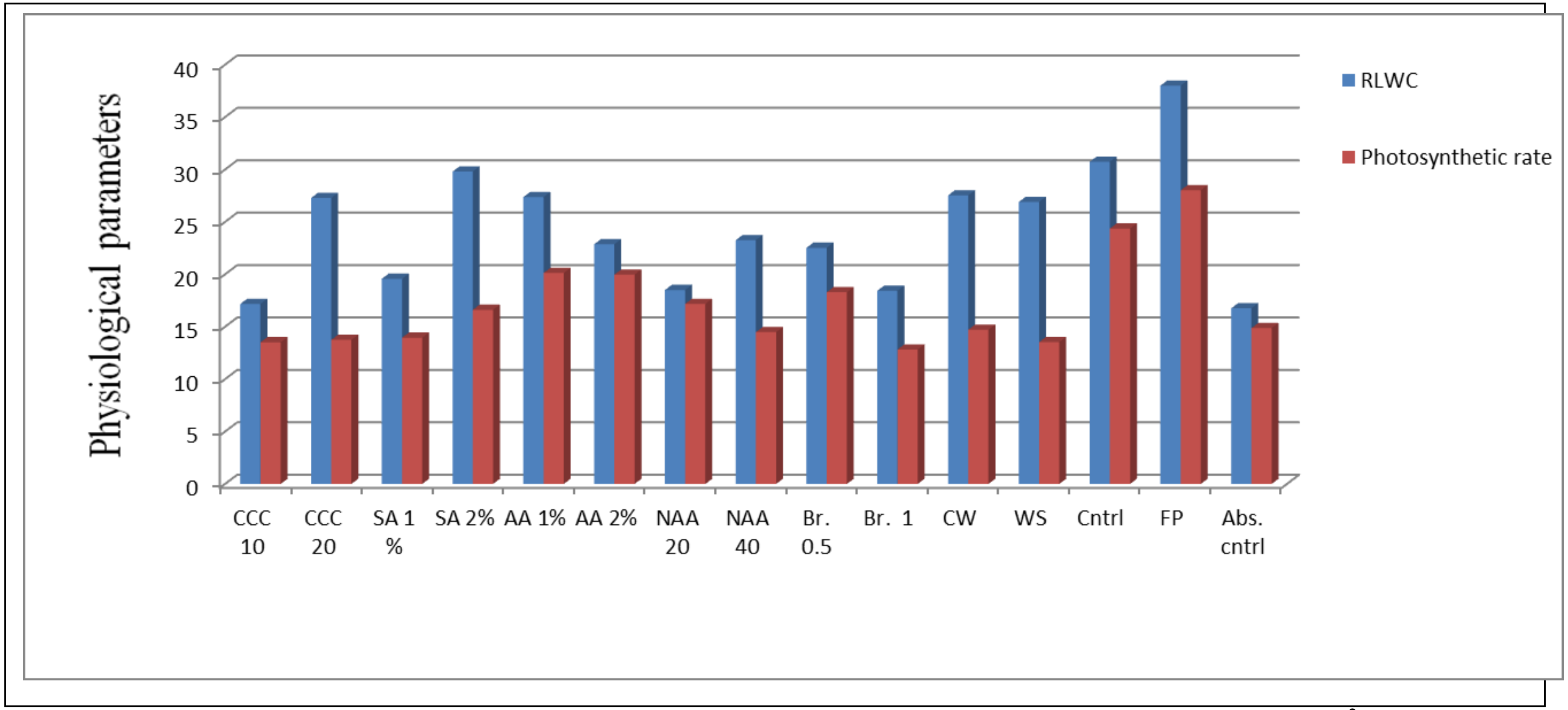


Figure 6. Effect of plant growth regulators on RLWC* (%) and photosynthetic rate (μ mol CO_2 /m^2 /sec)

Figure 7. Effect of plant growth regulators on yield of cowpea

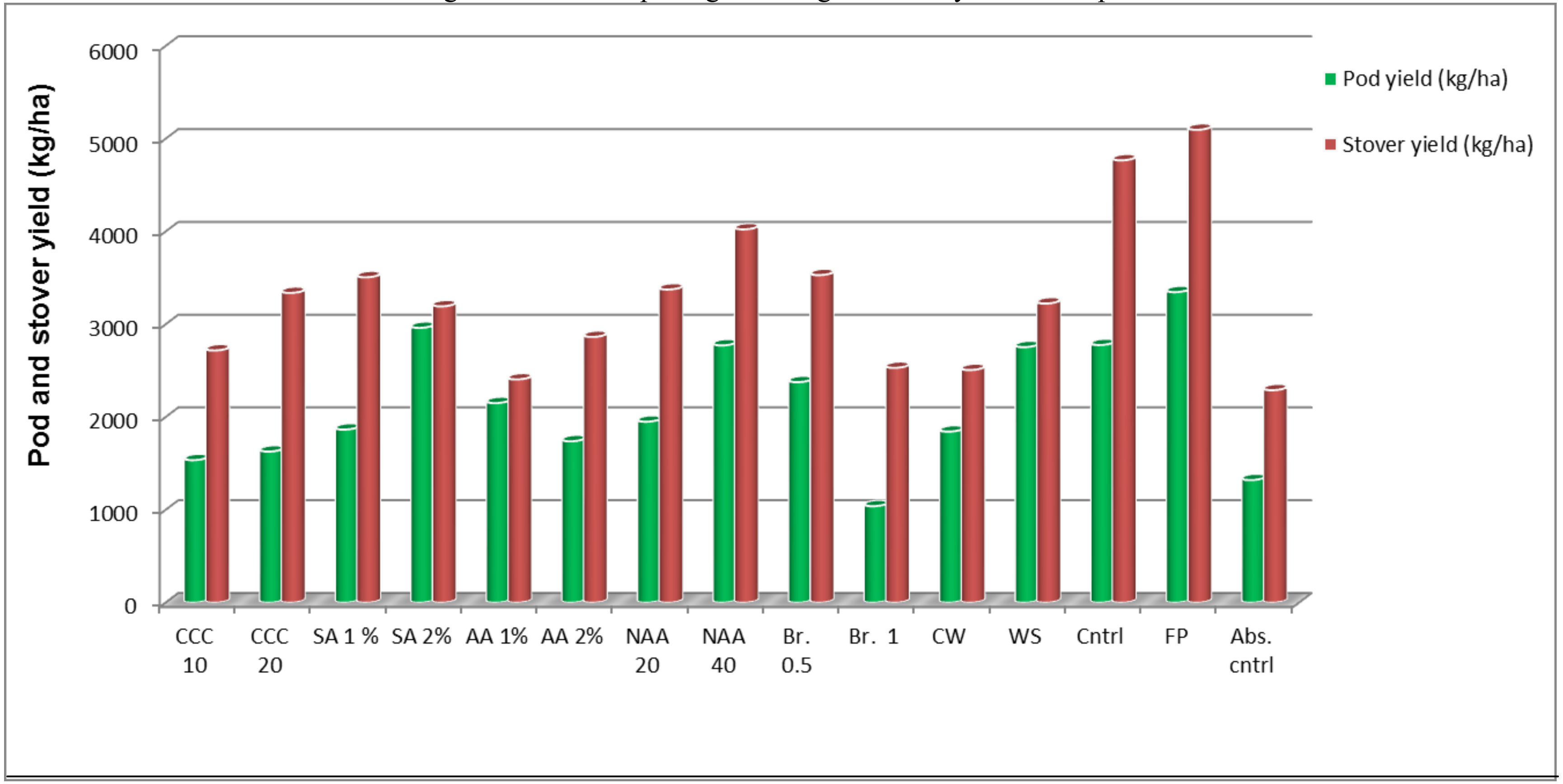
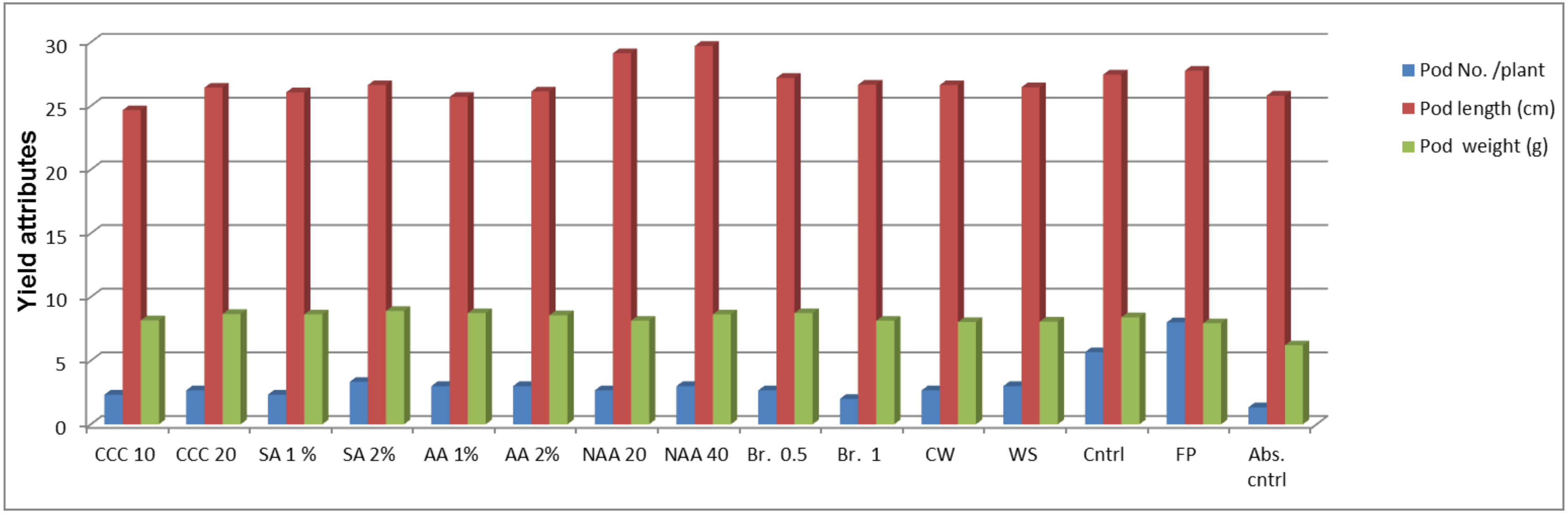


Figure 8. Effect of plant growth regulators on yield attributes of cowpea



water availability on growth (Fig. 9) and physiology (Fig. 6) of cowpea plants. Among PGRs, NAA 40 ppm recorded the highest stover yield as a result of its favourable influence on various growth parameters. Parmer *et al.* (2011) also reported the highest stover yield in green gram with foliar spray of NAA 40 ppm.

The impact of unfavourable weather conditions prevailed during the crop season on growth and yield of the crop was reflected on total dry matter accumulation also. However, it was significantly influenced by various treatments. Farmers practice recorded a significantly higher dry matter accumulation compared to all other treatments where as absolute control recorded the lowest and the reason for which is explained earlier. Biomass reduction in cowpea due to water deficit was reported by Anyia and Herzog (2004). All treatments which received spraying of either plant growth regulators or coconut water or water during the water stress imposed period could bring about 10 to 113 per cent increase in total dry matter production compared to no treatment during the crop period as a result of their favourable influence on either growth or yield or both. Among the PGRs, NAA 40 ppm recorded the highest dry matter accumulation due to its positive influence mainly on growth parameters and there by stover yield and it was on par with the treatment irrigated at 5 days interval. Aslam *et al.* (2010) reported that NAA application at 80 per cent water depletion could maintain the biological yield in chickpea.

Yield of the crop was reflected in number of harvests and it varied from one harvest in brassinolide 1ppm, CCC 10 ppm and absolute control to four harvests in farmers practice (Fig. 10). Duration of the crop was influenced by water availability and the plants in treatments which received irrigation on alternate days and at 5 days interval attained final maturity (65 days) earlier than the remaining treatments. Absolute control as well as exogenous application of either PGRs, or coconut water or water extended the duration of the crop by one week (72 days) without any variation among them. This can be due to the delay in attaining sufficient vegetative growth (physiological maturity) before flowering as a result of imposed water stress (Smith and Hamel, 2012).

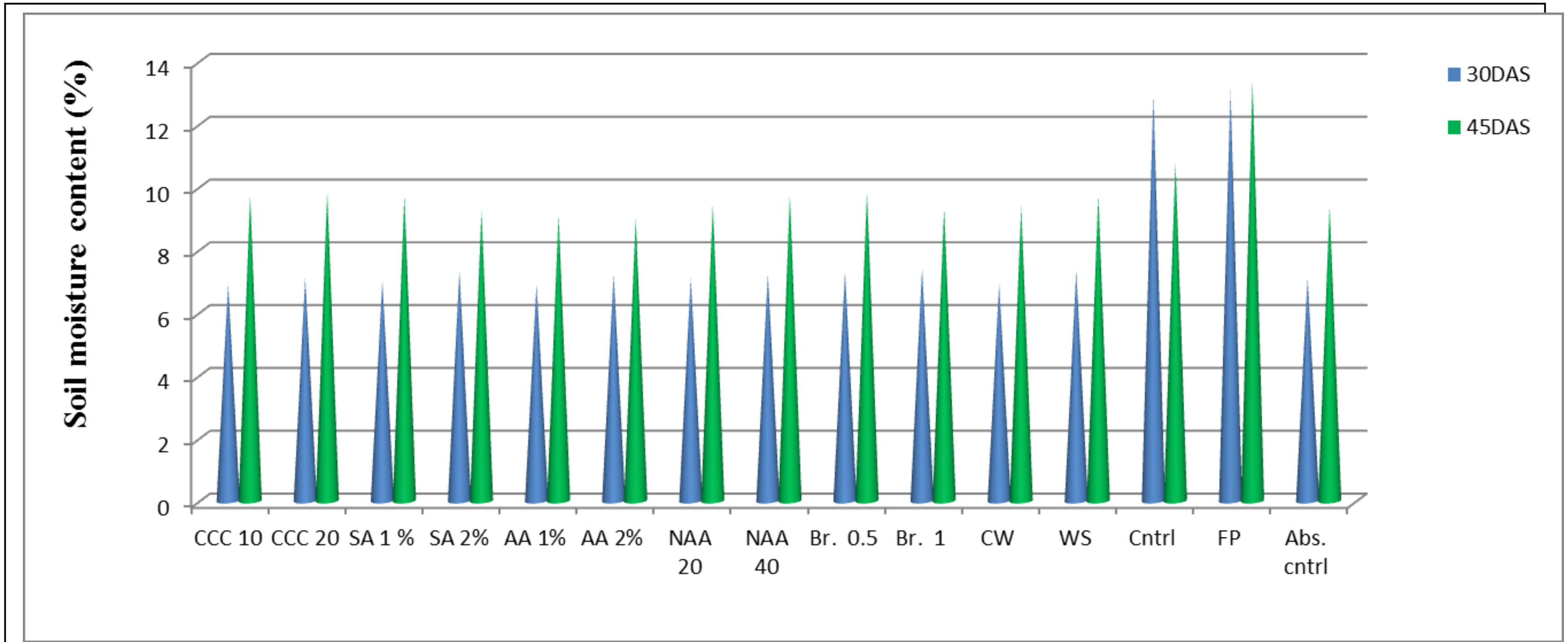


Figure 9. Effect of plant growth regulators on soil moisture content

5.1.4. Quality parameters

Protein content in cowpea pods and stover was significantly influenced by various treatments. Higher protein content both in pods and stover was recorded by farmers practice, irrigation at 5 days interval, NAA 40 ppm and salicylic acid 2%. This is due to more uptake of nitrogen by the plants and maintenance of comparatively better water balance inside the plants as evident from the data (Fig. 11 & 6). Increased nitrogen content in cucumber plants with salicylic acid application and in soybean by foliar spray of NAA 50 ppm was reported by Singh *et al.* (2010) and Kalarani *et al.* (2002) respectively.

5.1.5. Nutrient uptake by the crop

Uptake of nutrients (primary, secondary and micronutrients) by the crop was significantly influenced by various treatments. In general, irrigation on alternate days and at 5 days interval resulted in a higher uptake of nutrients due to more soil water availability (Fig. 9).

Among exogenous application of treatments, NAA 40 ppm recorded a comparatively higher uptake of all nutrients, whereas salicylic acid 2% improved the uptake of primary nutrients due to their favourable influence on root growth (Fig. 12) and nutrient content (Appendix III). Increased NPK uptake in green gram (Raman and Venkatrama, 2006) and in sweet pepper (Abou El-Yazeid, 2011) was reported by foliar application of NAA and salicylic acid respectively. Bera *et al*. (2008) also reported increased pod set and yield along with more N, P, K content in green gram with salicylic acid application.

Figure 10. Effect of plant growth regulators on number of harvest

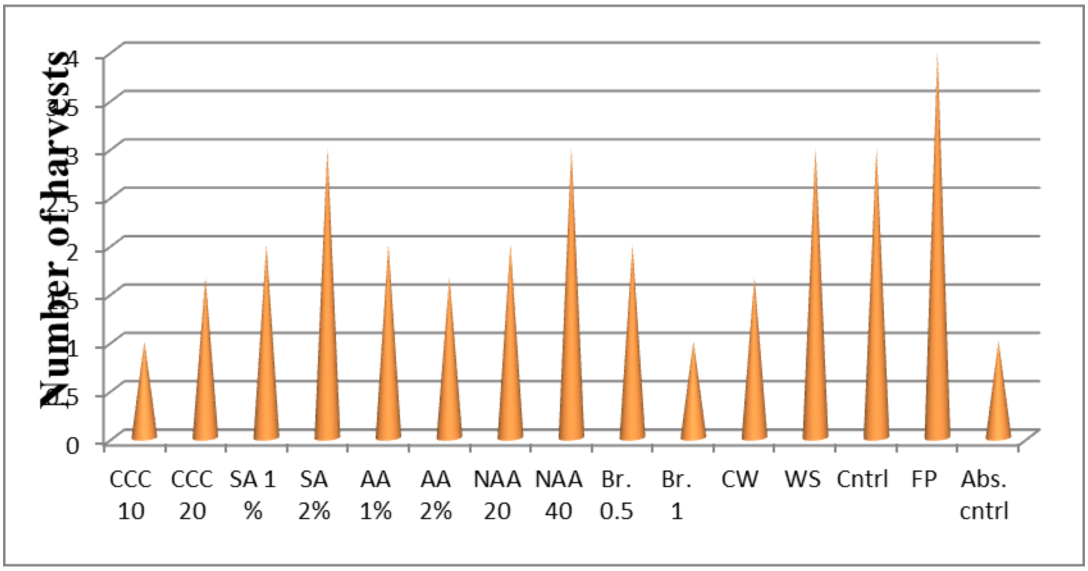


Figure 11. Effect of plant growth regulators on nitrogen uptake

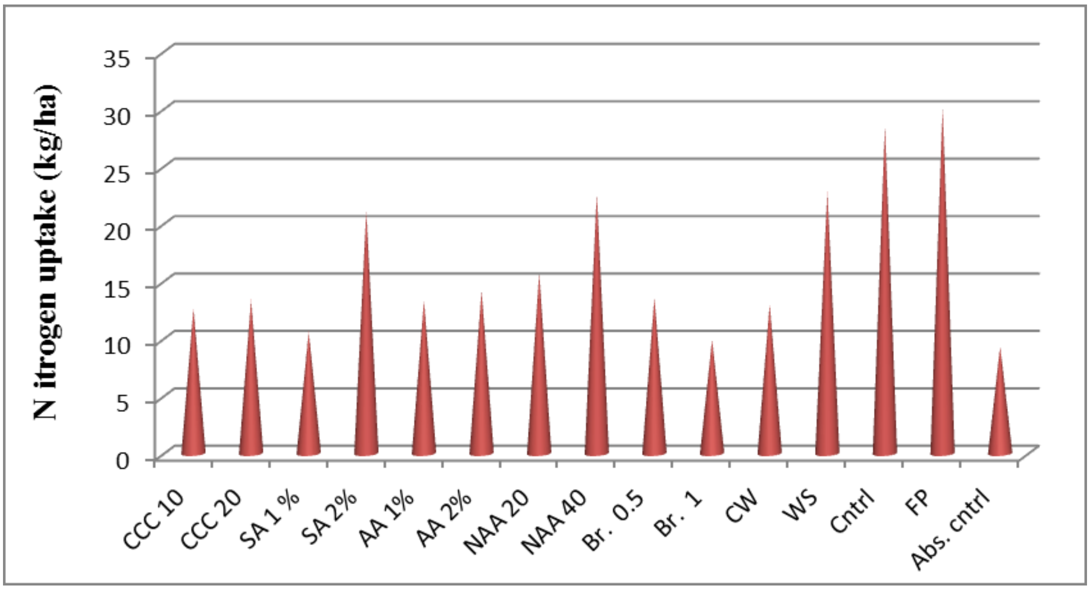
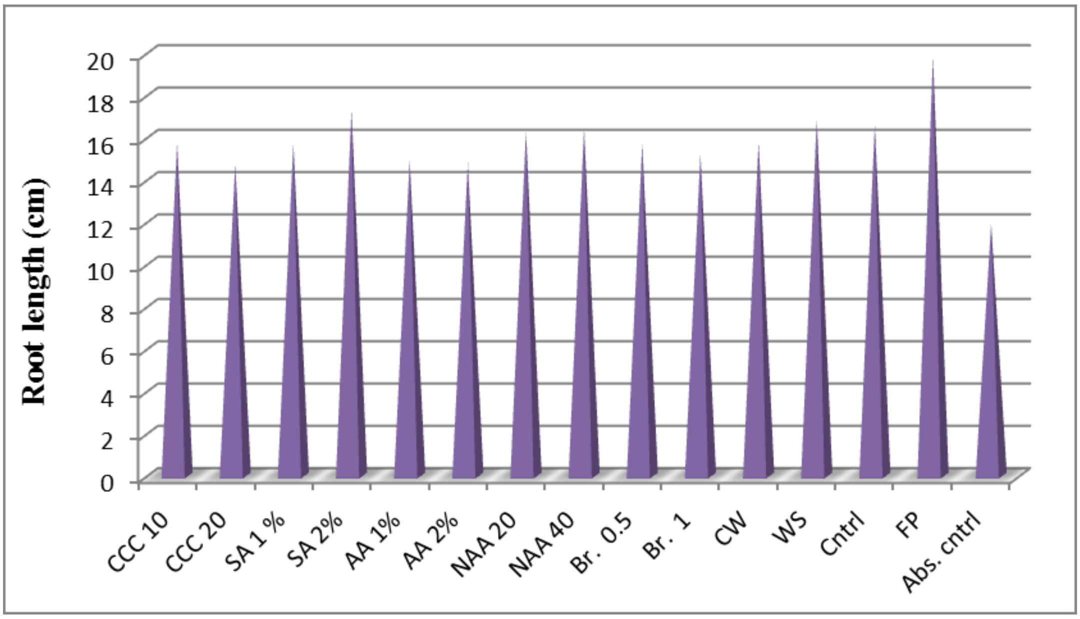


Figure 12. Effect of plant growth regulators on root growth



5.1.6. Soil characters

Soil pH and organic carbon content after the experiment did not show much variation compared to their values before the experiment. Soil pH ranged from 5.1 to 5.8 and organic carbon content from 0.9 to 1.4 per cent among treatments and the significant difference can be attributed to the minute variation in values among replications.

Application of different treatments significantly influenced the primary (except N) P and K), secondary (Ca, Mg and S) and micro (Fe, Mn, Zn, Cu and B) nutrient content in soil after the experiment. All elemental nutrients (except Mg, S, Zn, Cu and B) showed a reduction in their status compared to their content before the experiment due to their uptake and utilization by the crop. Among exogenously applied treatments, brassinolide 1 ppm was found superior in maintaining N, K, S and Mn status in the soil whereas NAA 20 ppm recorded higher Ca status. Foliar spray of water maintained higher P, Mg and Fe in the soil after the experiment. Higher Zn and B content were noticed in brassinolide 0.5 ppm whereas salicylic acid 2% recorded the higher soil copper status.

5.1.7. Soil moisture content

In general, soil moisture status in the field was very low during the entire crop period due to high evaporation caused by high wind speed and temperature (Fig. 5). A gradual decline in soil moisture content was observed from 15 DAS to 30 DAS in exogenously applied treatments due to the imposition of water stress (Fig. 9). However at 45 DAS, water stress release from these treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards due to the severity of high air temperature and faster evaporation from the soil. The very low values at final harvest can be attributed to the stoppage of irrigation in all treatments on attainment of full maturity of the crop.

5.2. Effect of seed priming, antitranspirants and moisture conservation practices in mitigating water stress

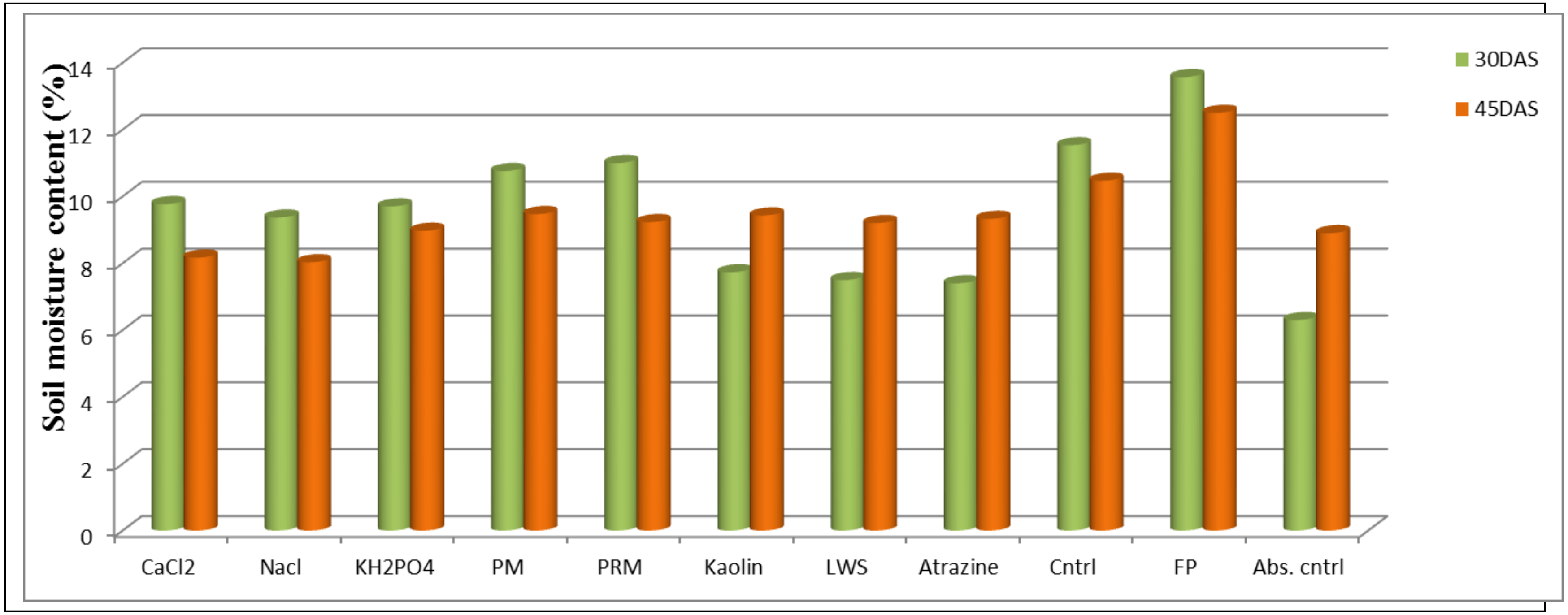
The experiment was conducted to evaluate the effect of seed priming, mulching and use of antitranspirants in mitigating water stress in vegetable cowpea.

5.2.1. Growth characters

The general growth of cowpea plants in the trial was low due to their exposure to adverse weather conditions and aphid infestation. However, there was a progressive increase in the growth of plants up to final harvest. All growth characters such as plant height, number of leaves and branches per plant were significantly influenced by various treatments especially at 45 DAS. Leaf area index at 40 and 60 DAS also showed significant variation among treatments.

In general, plant growth was significantly highest in farmers' practice which was irrigated on alternate days followed by the treatment irrigated at 5 days interval due to the lesser water stress experienced by the plants. The decrease in number of leaves and leaf area at 60 DAS in these treatments is due to the leaf fall consequent to the attainment of early maturity.

Figure 13. Effect of seed primers, mulches and antitranspirants on soil moisture content



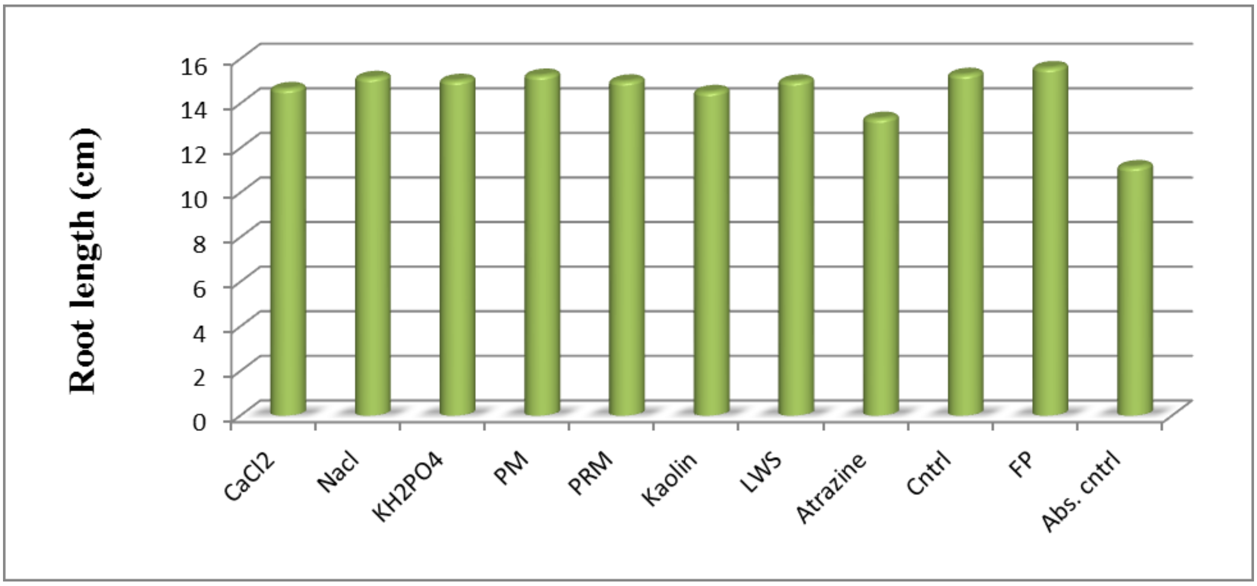
Among water stress mitigation treatments, mulching with polythene recorded better plant growth and it was on par with plant residue mulching. This can be attributed to the better soil moisture availability resulted from reduced evaporation as evident from the data (Fig. 13). Beneficial effect of mulching on improved soil water and reduced temperature regime was reported by Cook *et al.* (2006).

Among seed primers, seed hardening with 0.5% NaCl resulted in a better growth of cowpea plants compared to that with 2% $CaCl_2$ and 1% KH_2PO_4 which might be due to the comparatively better efficacy of sodium chloride in equipping the cowpea plants for drought tolerance. The increased tolerance of NaCl primed seedlings can be attributed to higher osmotic adjustment, as they have more Na^+ and Cl^- in roots and more sugars and organic acids in leaves than plants from non-primed seeds Cayuela *et al.* (1996). The increased accumulation of osmolytes in the seedlings raised from primed seeds could facilitate the increased uptake of water resulting in a turgor which ultimately promotes the expansion of cells. The germination percentage, root-shoot ratio, vigour index and thereby growth of pearl millet was improved by seed hardening with sodium chloride (Sundaram and Kannaiyan, 1989). This improvement can be attributed partially to osmotic adjustment, metabolic repair processes or due to the build up of metabolites necessary for germination (Haghpanah *et al.* 2009).

Among antitranspirants, foliar spray of lime water as 2% $Ca(OH)_2$ during the water stress imposed period resulted in better growth of cowpea plants due to formation of a white coating on the leaves which in turn increase albedo thus reducing transpiration, whereas kaolin 2% and atrazine 0.1kg/ha were ineffective and sometimes they were found more or less equivalent to absolute control.

Favourable influence of water mitigation treatments on root length was evident from the data (Fig. 14) and resulted in an increase in root length ranging from 20 to 37 per cent compared to absolute control. This is due to the effect of comparatively better water availability on root growth of cowpea plants during the extreme weather conditions in which the crop was grown. Beneficial effect of seed priming (Punithavathi and Palaniswamy, 2001), mulching (Chakraborty *et al.,* 2008) and antitranspirants (Thakuria *et al.,* 2004a) on root length can be due to the maintainence of cell turgidity, thereby higher relative leaf water content, improved soil moisture retention and increased reflection of solar radiation. Better root shoot ratio in mulching either with polythene or plant residues and seed priming with NaCl is due to the favourable influence of these treatments on the growth of both root as well as shoot. Mulching moderates soil temperature fluctuations (Palada *et al.,* 1992) and thereby improve root length, density and dry biomass in wheat (Chakraborty *et al.,* 2008). Increased the root shoot ratio of groundnut (Arjunan and Srinivasan, 1989) and pearl millet (Sundaram and Kannaiyan, 1989) was obtained by seed hardening with calcium chloride and sodium chloride respectively.

Fig. 14. Effect of seed primers, mulches and antitranspirants on root growth



Comparatively early flowering (45 DAS) was noted in treatments irrigated on alternate days and at 5 days interval due to early attainment of better vegetative growth as a result of lesser water stress experienced by the plants. The slight delay for attainment of 50% flowering especially in kaolin and atrazine sprayed treatments comparable to absolute control is due to the delay in attaining sufficient vegetative growth as a result of exposure of plants to imposed water stress combined with less efficiency of the treatments. Robins and Domingo (1956) reported a delayed flowering in dry beans under water stress. Costa *et al.* (1997) also reported a delayed flowering under water stress applied at the vegetative stage in cowpea.

5.2.2. Physiological parameters

Better stomatal conductance, transpiration rate and photosynthetic rate observed in farmers practice and mulching treatments can be attributed to better growth of plants due to higher soil moisture availability. Photosynthesis was higher in mulched pepper plants (Thakur *et al.,* 2002). The lowest values of the above physiological parameters in foliar spray of kaolin and lime water as antitranspirants due to the interference of the treatments on stomatal behaviour. Foliar application of antitranspirants limits CO_2 exchange due to reduced stomatal conductance which in turn regulates transpiration (Amor *et al*., 2010).

Highest chlorophyll content and relative water content were observed in farmers practice followed by irrigation at 5 days interval due to exposure of plants to lesser water stress (Fig. 13) and better uptake of nutrients by the plants (Table 46). Among water stress mitigation treatments, seed priming with NaCl, mulching either with polythene or plant residue and lime water spray as antitranspirant recorded a higher values of the above physiological parameters due to their effect on maintaining a favourable water balance inside the plants. Increased chlorophyll content due to maintenance of cell turgidity and inhibition of chlorophyll breakdown in green gram as a result of seed hardening with NaCl was reported by (Jisha and Puthur, 2014). Similarly, an increased chlorophyll content by wheat straw mulching in soybean (Sekhon *et al*. (2005) and black polyethylene mulching in cucumber (Kirnak and Demirtas, 2006) as a result of increased soil moisture retention, was also reported.

5.2.3. Yield and yield attributes

Influence of unfavourable weather and aphid infestation on vegetative growth and yield attributes resulted in a lower yield (pod and stover) of cowpea plants. However, pod yield was significantly influenced by various treatments. Significantly higher pod yield was recorded by farmers' practice due to lesser exposure of cowpea plants to water stress as evident from the data on soil moisture status (Fig. 13).

Among water stress mitigation treatments, comparatively higher pod yield was recorded by mulching either with polythene or plant residues (Fig. 15). This is due to the effect of mulching in making the availability of soil moisture for a comparatively longer period through soil moisture conservation and its consequent favourable influence on nutrient uptake (Table 47), vegetative growth (Fig. 16) and yield attributes (Fig. 17) of cowpea plants. Significant role of mulching on soil moisture conservation is well established. Sarolia and Bhardwaj (2012) have also reported that mulched plants grow and mature more uniformly than unmulched plants as mulching reduces evaporation, increases infiltration and thereby conserves soil moisture. (Kirnak and Demirtas, 2006) also observed the favourable influence of black polyethylene mulch on total leaf area, chlorophyll content, yield and plant dry matter of cucumber grown under water stress conditions.

Seed priming with NaCl was found superior to $CaCl_2$ and KH_2PO_4 to achieve a comparatively higher pod yield by inducing more number of pods per plant along with higher pod weight. This can be attributed to the positive influence of seed priming with NaCl in equipping the emerging cowpea plants to overcome the adverse effect of water stress by maintaining a favourable water balance inside the plants as evident from the data on relative leaf water content (Fig. 18). This in turn resulted in better vegetative growth; higher total chlorophyll content, better translocation of assimilates to the economic part and thereby higher yield attributes and yield. Halopriming with NaCl improved the drought stress

Table 47. Effect of seed primers, mulches and antitranspirants on macro and micro nutrient uptake by the crop

Treatments	Nutrient uptake (kg/ha)									
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B
$CaCl_2$	12.58	2.02	22.09	5.23	2.10	0.59	0.78	0.98	0.03	0.14
Nacl	22.39	3.13	26.81	5.11	2.69	0.97	0.99	1.19	0.05	0.16
KH_2PO_4	11.11	1.49	20.41	3.97	1.67	0.49	0.76	0.94	0.03	0.12
PM	16.81	2.86	30.03	6.00	3.05	1.32	1.01	1.44	0.05	0.15
PRM	14.72	2.43	25.16	4.80	2.72	0.59	0.92	1.01	0.03	0.13
Kaolin	8.82	1.14	12.12	1.86	1.15	0.29	0.30	0.49	0.02	0.07
LWS	12.02	1.73	19.92	5.72	1.93	0.48	0.77	0.92	0.03	0.11
Atrazine	8.53	1.27	12.09	2.14	1.22	0.22	0.41	0.52	0.02	0.07
Control	24.25	4.04	34.44	6.34	3.47	1.50	1.24	1.51	0.08	0.17
FP	41.22	7.29	68.46	14.73	6.10	2.73	2.24	3.24	0.16	0.29
Abs. control	5.25	0.57	8.33	1.37	0.79	0.12	0.17	0.41	0.01	0.05
CD(0.05)	3.67	0.49	4.38	1.006	0.43	0.16	0.175	0.23	0.009	0.025
SEd	1.75	0.23	2.09	0.47	0.21	0.07	0.08	0.11	0.004	0.01

Figure 15. Effect of seed primers, mulches and antitranspirants on yield of the crop

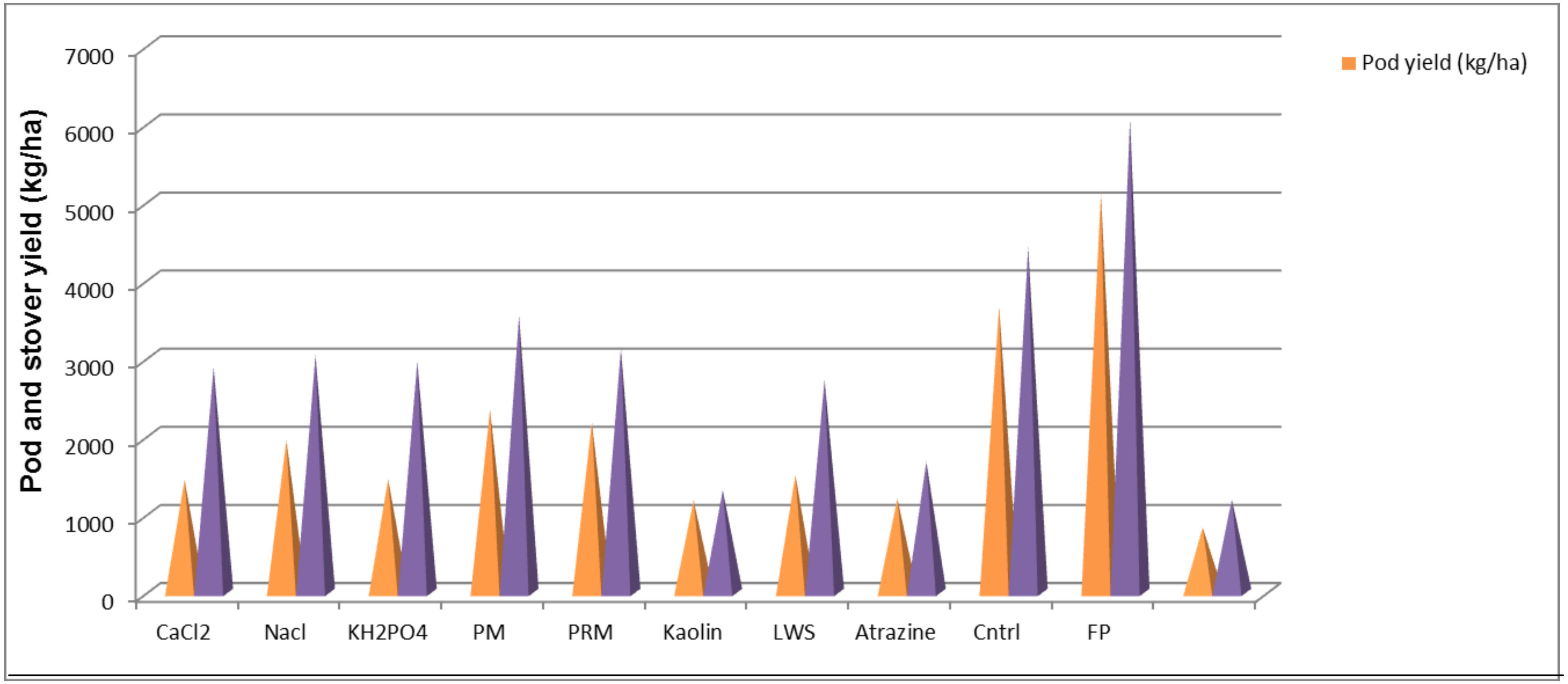


Figure 16. Effect of seed primers, mulches and antitranspirants on growth parameters of the crop

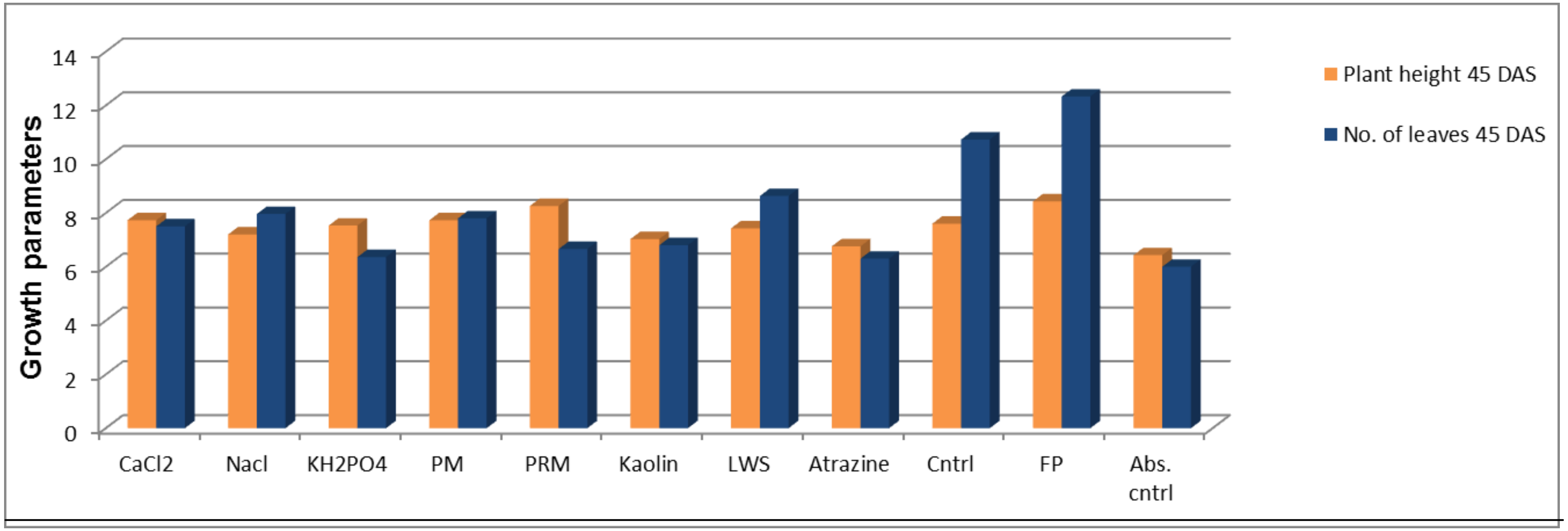
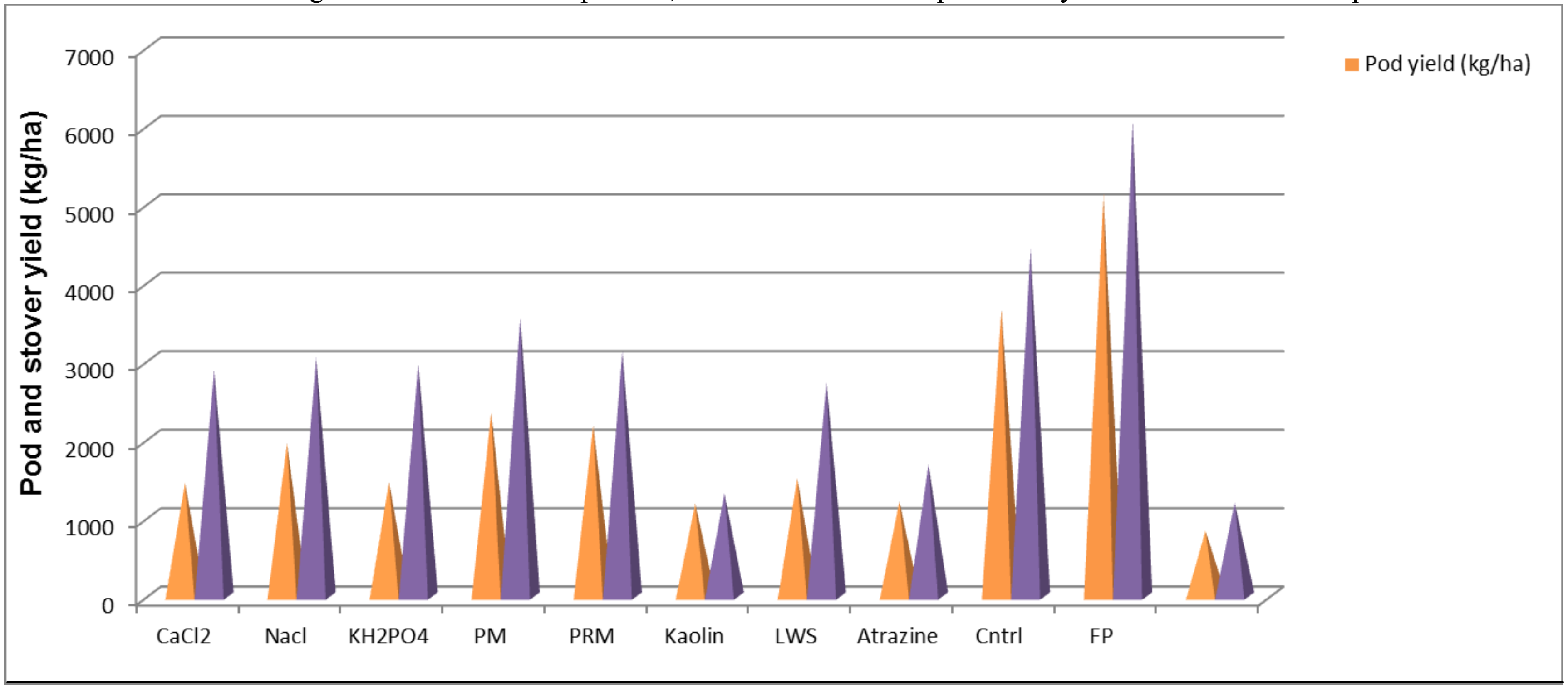


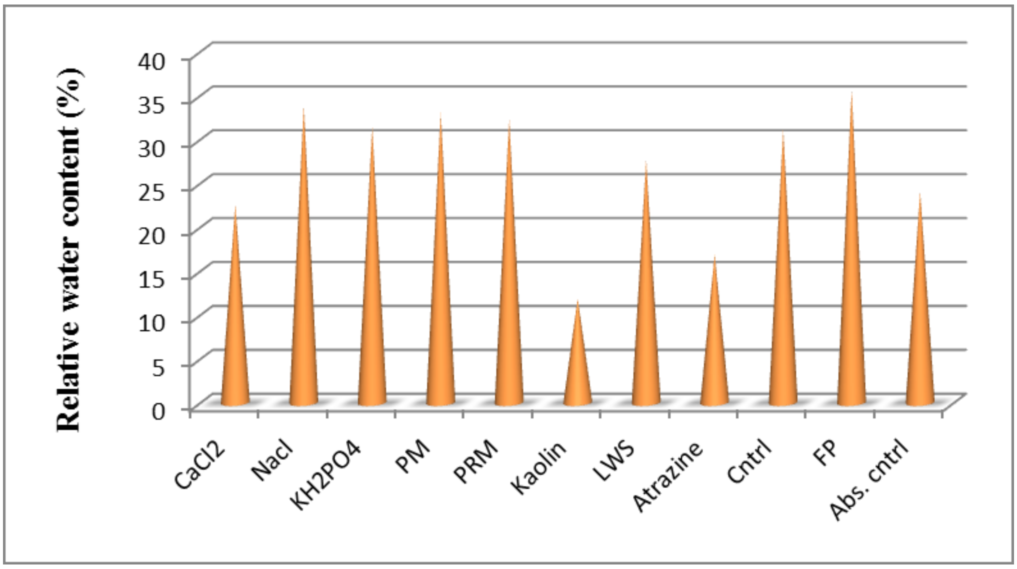
Figure 17. Effect of seed primers, mulches and antitranspirants on yield attributes of the crop



tolerance of *Vigna radiata* (Jisha and Puthur, 2014) and seedling establishment, yield and quality of hybrid sunflower (Hussain *et al*., 2006).

Foliar application of lime water as antitranspirant resulted in 25 and 27 per cent increase in pod yield compared to atrazine and kaolin respectively even though the effect was not significant. This can be attributed to the effect of lime water spray in increasing albedo thereby reducing leaf temperature and transpiration which favourably influenced the relative water content and total chlorophyll and resulted in better growth and yield attributes of cowpea plants grown under water stress situation. Reddy and Setty (1995) also observed the favourable influence of foliar spray of lime water on pod yield of ground nut plants grown under moisture stress.

Fig. 18. Effect of seed primers, mulches and antitranspirants on relative water content



Stover yield of the crop also showed the same trend as that of pod yield and was significantly influenced by various treatments. The highest stover yield was recorded by farmers practice and the treatment which received irrigation at 5 days interval, due to minimum water stress (Fig. 13) which in turn resulted in higher nutrient uptake (Table 47) and vegetative growth (Fig. 16). Among water stress mitigation treatments, mulching either with polythene or plant residue and seed priming with NaCl recorded a higher stover yield due to the same reasons as that for pod yield. An increased biomass yield in soybean by wheat straw mulching was reported by Sekhon *et al*. (2005). Seed hardening with sodium chloride improved the growth of pearl millet (Sundaram and Kannaiyan, 1989). Among antitranspirants, lime water spray, a reflectant type antitranspirant, recorded significantly higher stover yield than atrazine and kaolin as a result of its positive influence on growth of cowpea plants through water stress mitigation.

Dry matter accumulation in cowpea plants during the cropping period was significantly influenced by various treatments. Exposure of cowpea plants to lesser water stress led to significantly higher growth and yield thereby higher dry matter accumulation in farmers practice compared to all other treatments. Among the seed primers, NaCl recorded significantly highest dry matter accumulation compared to $CaCl_2$ and KH_2PO_4 consequent to higher growth and yield resulted from the favourable influence of the treatment in mitigating water stress. Mulching either with polythene or with plant residue was found equally efficient in attaining more dry matter accumulation through its effect on higher soil moisture availability thereby more nutrient uptake, better growth and yield of cowpea plants. Among antitranspirants, lime water spray recorded significantly higher dry matter accumulation than kaolin and atrazine, the reason for which is the same as discussed above.

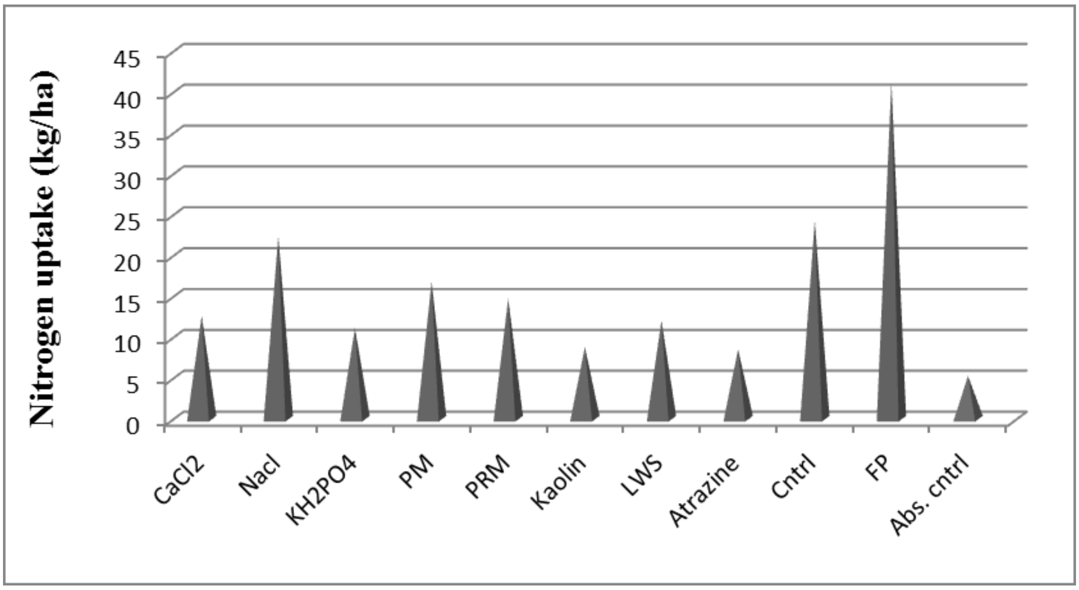
Due to enough water availability, the highest number of harvests with early crop completion was occurred in farmers practice and the treatment irrigated at 5 days interval. Among seed primers, mulches and antitranspirants, NaCl, polythene mulch and lime water spray recorded slightly more number of harvests by reducing the severity of water stress in plants along with an extension in the duration of the crop by one week due to the delay in attaining sufficient vegetative growth before flowering. Min-Li *et al.,* (1999) observed an increased length of the growing period and duration from flowering to harvest under plastic film mulching in spring wheat.

5.2.4. Quality parameters

Various water stress mitigation treatments significantly influenced the protein content in pod and stover of cowpea. The highest protein content in both pod and stover observed in farmers' practice and in irrigation at 5 days interval was due to lesser water stress. The higher protein content in pod by seed priming either with NaCl or KH_2PO_4 and that in stover by seed priming with $CaCl_2$ or NaCl might be due to the accumulation of stress proteins under priming (Conrath *et al*. 2006). Total protein content in green gram haloprimed with NaCl under water stress increased to the tune of 23 per cent (Jisha and Puthur, 2014).

Mulching either with plant residues or with polythene resulted an improvement in both pod and stover protein content due to better soil moisture availability (Fig. 13) and nitrogen uptake by the plants as evident from the data (Fig.19). Higher uptake of nitrogen by application of polythene mulch was reported by Choudhary *et al*. (2013).

Fig.19. Effect of seed primers, mulches and antitranspirants on nitrogen uptake



Spraying antitranspirants could not bring about any significant change in pod protein content compared to absolute control whereas lime water spray recorded significantly higher stover protein content on par with farmers practice and the treatment irrigated at 5 days interval. This is due to the maintenance of better water balance inside the plants (Fig. 18) and improved nitrogen uptake as evident from the data (Fig.19).

5.2.5. Nutrient uptake by the crop

Primary, secondary and micronutrient uptake by the cowpea plants was significantly influenced by various water mitigation treatments. In general, irrigation on alternate days and at 5 days interval resulted in a higher uptake of all nutrients due to higher soil moisture availability (Fig. 13).

Among seed primers, NaCl recorded a better uptake of almost all nutrients compared to $CaCl_2$ and KH_2PO_4. It showed the seed hardening effect of sodium chloride, which helped the plants to get acclimatised to water stress by way of osmotic adjustment. Cayuela *et al.* (1996) reported an increased osmolyte accumulation in tomato seedlings raised from NaCl primed seeds, which facilitated increased uptake of water, thereby maintenance of turgor and expansion of cells.

Polythene mulching was found better than plant residue mulching in terms of uptake of most of the elements which can be attributed to comparatively higher soil moisture availability and root growth. These results are in line with the findings of Wien *et al.* (1993), who obtained an increased tomato growth and yield by polyethylene mulching as a result of enhanced root growth and nutrient uptake.

Among antitranspirants, foliar spray of lime water was significantly superior in nutrient uptake compared to kaolin and atrazine by way of maintaining favourable water balance inside the plants through reduction in leaf temperature as a result of reflection of solar radiation (Fig. 18).

5.2.6. Soil characters

The treatments did not show much variation in soil pH and organic carbon content after the experiment compared to their values before the experiment. Soil pH ranged from 5.2 to 5.9 and organic carbon content from 1.2 to 1.5 per cent among treatments.

All elemental nutrients (except K, Ca, Mg, S, Fe, Cu and B) showed a reduction in their status compared to their content before the experiment due to their uptake and utilization by the crop. Various water mitigation treatments significantly influenced the primary (except N) P and K), secondary (Ca, Mg and S) and micro (Fe, Mn, Zn, Cu and B) nutrient content in soil after the experiment.

Among water stress mitigation treatments, atrazine spray was found superior in maintaining P, K, Zn and B status in the soil after the experiment. Mulching (either polythene or plant residues) was better in soil Ca status, seed priming (either NaCl or KH_2PO_4) showed an improved soil Cu and Mg status and kaolin spray were found better in maintaining soil Fe and S content. All stress mitigation treatments except seed priming with KH_2PO_4 was superior in soil Mn status.

5.2.7. Soil moisture content

In general, soil moisture status in the field was very low during the entire crop period due to high evaporation caused by high wind speed and temperature (Appendix I & II /Fig. 5). In seed priming and mulching treatments soil moisture content increased at 30 DAS compared to that at 15 DAS due to irrigation at 10 days interval and the effect of mulches on soil moisture retention. Plastic mulching in tomato conserved irrigation water due to soil moisture retention and increased the yield by 47 per cent compared to non-mulched control (Friake *et al*., 1990). Similar results on moisture conservation by mulches were also reported by Li *et al.* (2013). A gradual decline in soil moisture content from 15 DAS to 30 DAS was observed in antitranspirant sprayed treatments and in absolute control due to the imposition of water stress (Fig. 13). However at 45 DAS, water stress release from the above treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards due to the severity of high air temperature and faster evaporation from the soil. At 60 DAS, mulching and seed priming treatments maintained more or less same moisture status compared to that at 45 DAS. At final harvest, all treatments (except mulching) recorded very low values which can be attributed to the stoppage of irrigation in all treatments on attainment of full maturity of the crop.

1.2. Effect of nutrient management in mitigating water stress

The efficacy of different nutrient management practices in mitigating water stress in vegetable cowpea was evaluated in this experiment.

5.3.1. Growth characters

The general growth of cowpea plants in this experiment was also low due to their exposure to adverse weather conditions and aphid infestation. However, there was a progressive increase in the growth parameters like plant height, number of leaves, branches and leaf area up to final harvest in all treatments except in treatments irrigated at 2 days and 5 days interval, which recorded a lesser leaf number and leaf area at 60 DAS compared to that at 45 DAS. This is due to the leaf fall from plants as a result of attainment of early final maturity as a result of lesser exposure to water stress.

Among growth characters, plant height at any stage of observation was not significantly influenced by any of the nutrient management practices whereas number of leaves and branches per plant varied significantly among treatments at 45 and 60 DAS respectively. Leaf area index at 40 and 60 DAS also showed significant variation among treatments.

In general, plant growth was higher in farmer's practice and in treatment irrigated at 5 days interval as a result of lack of water stress. The treatments which received either FYM or biofertilizers or foliar spray of mineral nutrients during the water stress imposed period resulted in an increasing trend of plant height from 8 to 18 per cent and number of leaves from 21 to 42 per cent compared to that which received no treatment during the crop period. Among nutrient management practices, more number of branches at the final stage of the crop and higher leaf area index at 40 and 60 DAS were noticed in seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. This can be attributed to the favourable influence of PGPR mix I + rhizobium on plants' tolerance to drought stress by way of improving water retention inside plants and better soil aggregation around plant roots as reported by Timmusk *et al.* (2013) and that of zinc due to its role as a co-enzyme for the production of tryptophan, a precursor of auxin as suggested by Waraich *et al*. (2011) and Bennett and Skoog (2002).

Even though there was no significant difference among the treatments in the case of root length, all the nutrient management practices resulted in an increasing trend in root length compared to absolute control and a comparatively higher root length was noticed in seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. The favourable influence of plant growth promoting bacterial strains on the capacity of the plant to tolerate water stress by way of improving root growth was reported by (Hayat *et al*. 2010). Similarly, increase in auxin levels due to zinc application enhances the root growth which in turn improves the drought tolerance in plants (Waraich *et al*., 2011).

Root shoot ratio of cowpea plants was significantly influenced by various nutrient management practices. Significantly higher root shoot ratio was recorded by foliar spray of either $ZnSO_4$, or KCl, or DAP+KCl, and seed treatment with PGPR mix I + rhizobium. This can be attributed to the favourable influence of the treatments on root and shoot growth. Improved root length by stimulating auxin and increased shoot growth by encouraging antioxidant enzyme activity (reduced photooxidation) as a result of zinc application was reported by Waraich *et al*. (2011). Increased root and shoot growth by improving soil structure and moisture retention due to inoculation of various PGPRs were reported by (Hayat *et al*. 2010) and (Kim *et al.* 2012) respectively. Potassium spray increased the root growth, which in turn improved the water uptake and thereby ability of fodder beet plants to tolerate water stress (Kassab *et al.,* 2012). Phosphorus helps in better root growth, which enables the plant to absorb water from deeper layers of the soil and result in higher plant growth in cowpea (Choudhary *et al*., 2013).

Early flowering was noticed in farmer's practice and in treatment that received irrigation at 5 days interval due to attainment of sufficient vegetative growth in time as a result of lesser water stress. Cowpea plants which received foliar spray of $ZnSO_4$ also attained 50 per cent flowering on par with the above treatments due to the positive influence of the treatment in mitigating water stress which helped to attain sufficient vegetative growth in time.

5.3.2. Physiological parameters

Higher stomatal conductance, photosynthetic rate and transpiration rate were recorded by foliar spray of $ZnSO_4$. It can be attributed to the role of zinc in plants exposed to water stress for attaining higher leaf area, carbon fixation per unit leaf area and carbonic anhydrase activity as reported by Hacisalihoglu *et al.* (2003) and antioxidant enzyme activity which in turn reduce photooxidation by reactive oxygen species and chlorophyll degradation thereby increasing photosynthesis (Waraich *et al.*, 2011).

Significant difference among various nutrient management practices was noticed in the case of chlorophyll content of cowpea plants. Farmers practice recorded significantly higher chlorophyll content followed by the treatment irrigated at 5 days interval whereas the lowest by absolute control. Among different nutrient management treatments, seed treatment with PGPR mix I + rhizobium was found to be on par with the above treatments followed by foliar spray of KCl, DAP and its combination, $ZnSO_4$ and FYM alone. Abbasi *et al.* (2013) also reported increased chlorophyll content by PGPR application in soybean under stress. Application of farm yard manure in maize under stress resulted in increased leaf chlorophyll content (Paryan, *et al.*, 2012). Under drought stress condition, potassium spray was found to be more effective in increasing the chlorophyll content of corn (Zare *et al.*, 2014). Phosphorus application increased the chlorophyll content of cowpea compared to control (Mfilinge *et al.*, 2014). Foliar spray of zinc sulphate in corn under water stress resulted in higher chlorophyll content (Moghadam *et al.*, 2013)

Various nutrient management practices to mitigate water stress significantly influenced the relative leaf water content of cowpea plants. Highest relative leaf water content was recorded by farmers practice followed by the treatment irrigated at 5 days interval due to frequent irrigation received by the plants. Among different nutrient management treatments, foliar spray of KCl, DAP and its combination were found better followed by $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium. The role of phosphorus in improving root growth and maintaining high leaf water potential by way of improved water uptake under drought condition was reported by Waraich *et al*. (2011) and that of potassium in maintaining the osmotic potential by facilitating osmotic adjustment and cell turgidity was reported by Lindhauer (1995). Vazin (2012) also observed increased relative water content in corn by foliar spray of zinc sulphate. Higher relative water content in chickpea as a result of inoculation of rhizobium and PGPRs was reported by Jabbari and Khaleghnezhad (2014) and it can be due to higher soil moisture retention (Kim *et al.* 2012).

5.3.3. Yield and yield attributes

In general, pod yield obtained from the experiment was low due to lesser yield attributes resulted from lower vegetative growth of plants on exposure to unfavourable weather condition prevailed during the crop season accompanied by aphid infestation. However, pod yield was significantly influenced by various nutrient management practices. Among treatments, significantly highest pod yield was recorded by farmers' practice (Fig. 20) due to non exposure of cowpea plants to water stress as evident from data on physiological parameters (Fig. 21) and soil moisture content (Fig. 22) and the resultant better vegetative growth and yield attributes (Fig. 23 & 24).

Figure 20. Effect of nutrient management practices on yield of cowpea

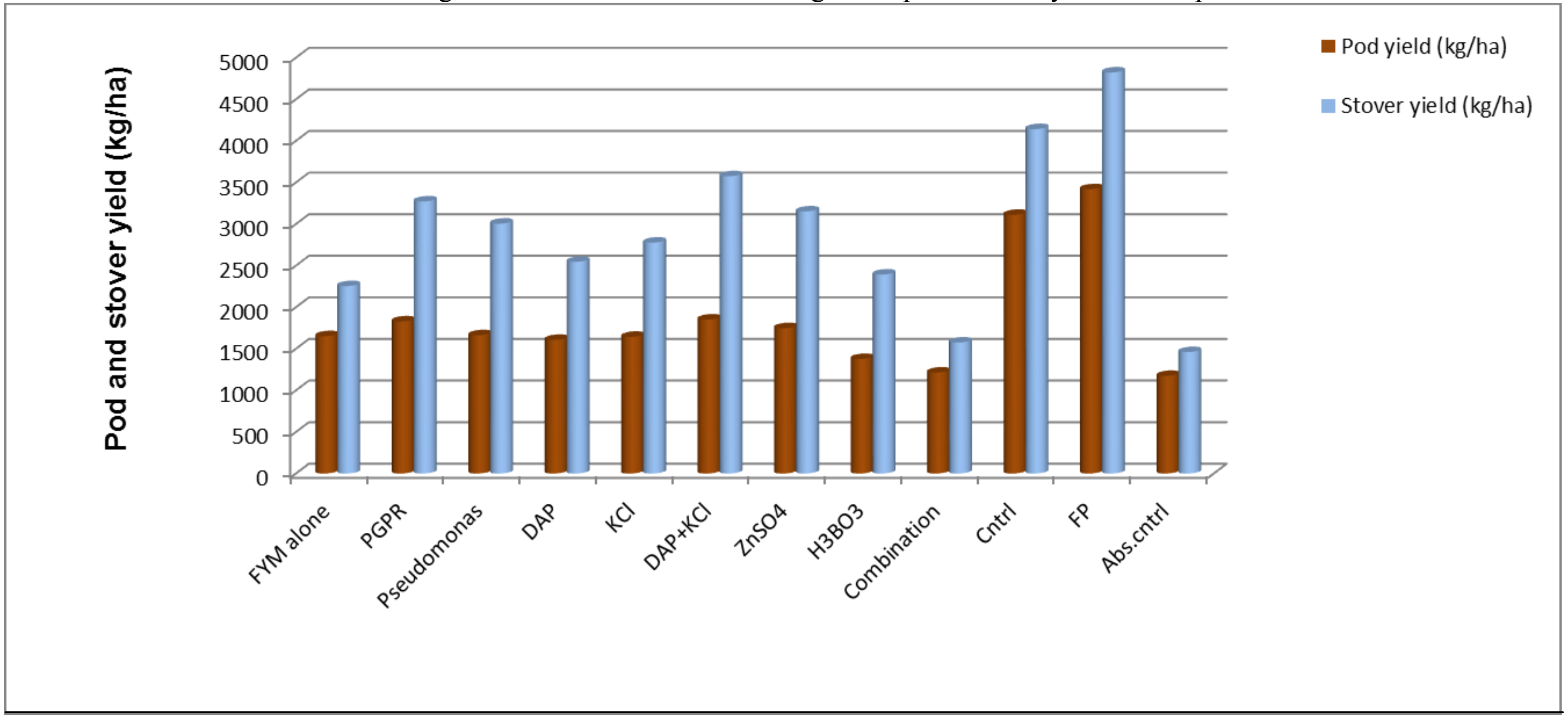
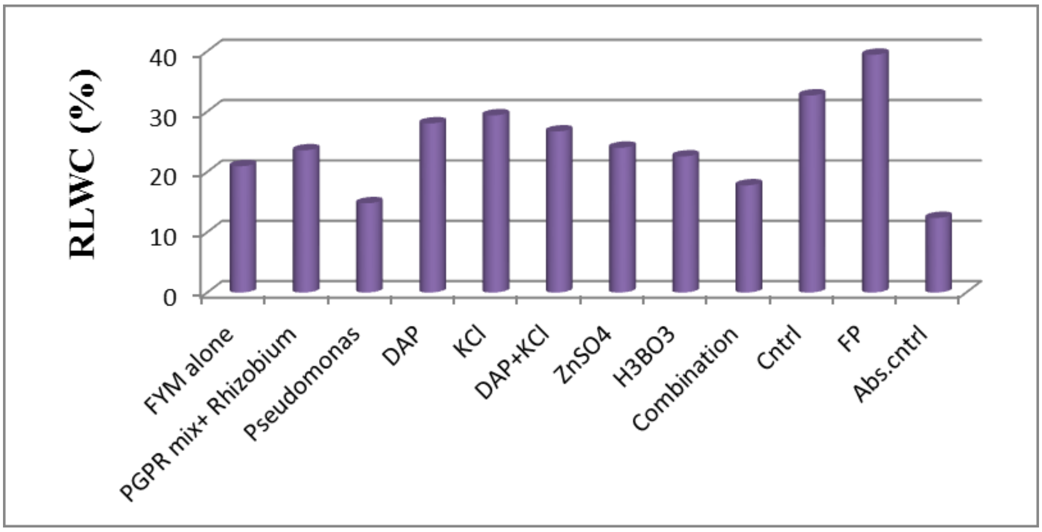


Fig. 21. Effect of nutrient management practices on relative leaf water content (RLWC)



Among various nutrient management practices, foliar spray of DAP+KCl, $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded a significantly higher pod yield than other treatments due to their favourable influence on mitigating water stress which resulted in better vegetative growth by way of improved physiological parameters and better translocation of assimilates to the economic part as evident from more number of pods per plant, pod length and pod weight. Foliar spray of DAP +KCl in black gram at flowering and pod filling stages recorded the highest yield parameters and yield due to the favourable effect of nitrogen, phosphorus and potassium on growth and physiology of the crop under water stress (Geetha and Velayutham 2009). Thalooth *et al*. (2006) reported higher pod yield in mung bean by foliar spray of zinc due to its positive effect on root growth, enzyme activity and photosynthesis. Inoculating chickpea seeds with rhizobium strains and PGPR resulted in better water relations and photosynthetic rate and finally more grain yield (Jabbari and Khaleghnezhad, 2014).

In general, lower vegetative growth of the crop due to exposure of plants to unfavourable weather condition prevailed during the crop season resulted in reduced stover yield. However, stover yield of the crop was significantly

Figure 22. Effect of nutrient management practices on soil moisture content

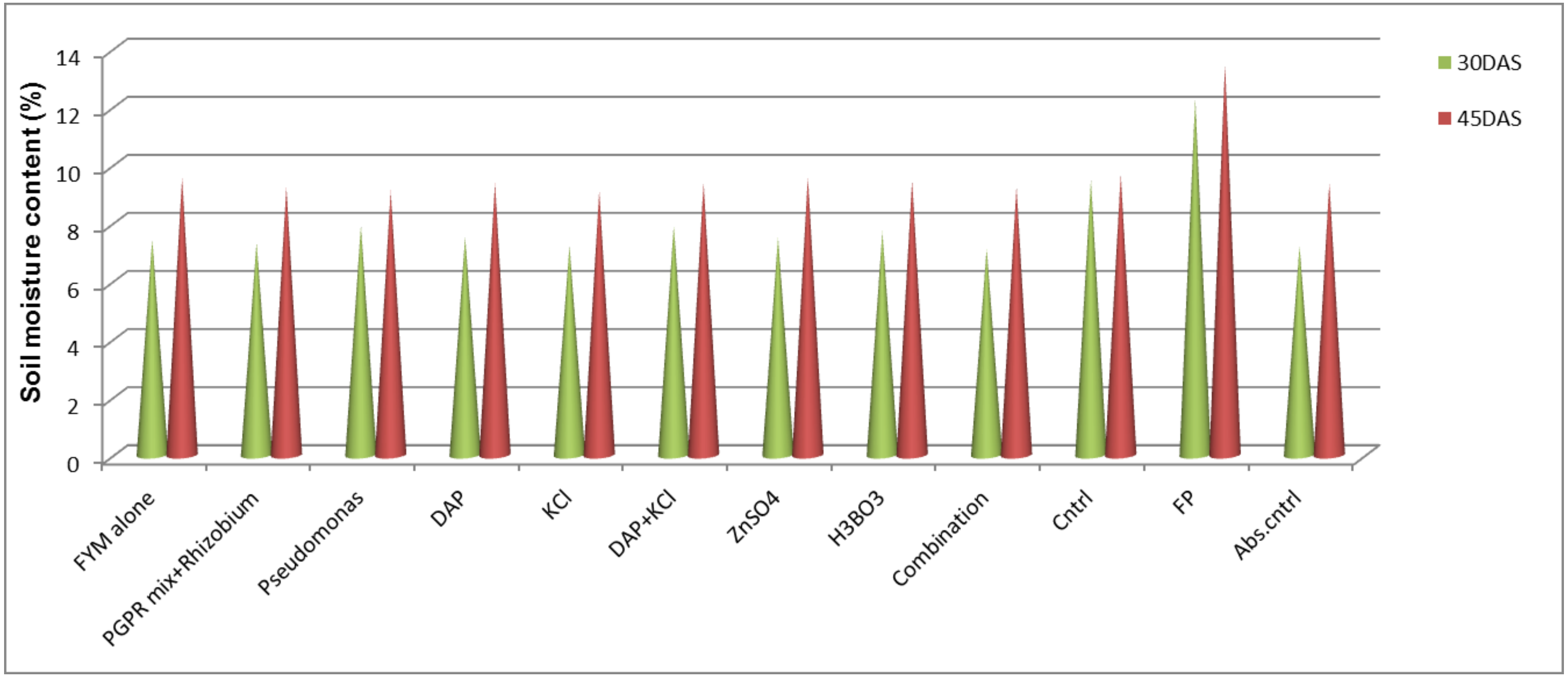


Figure 23. Effect of nutrient management practices on growth parameters

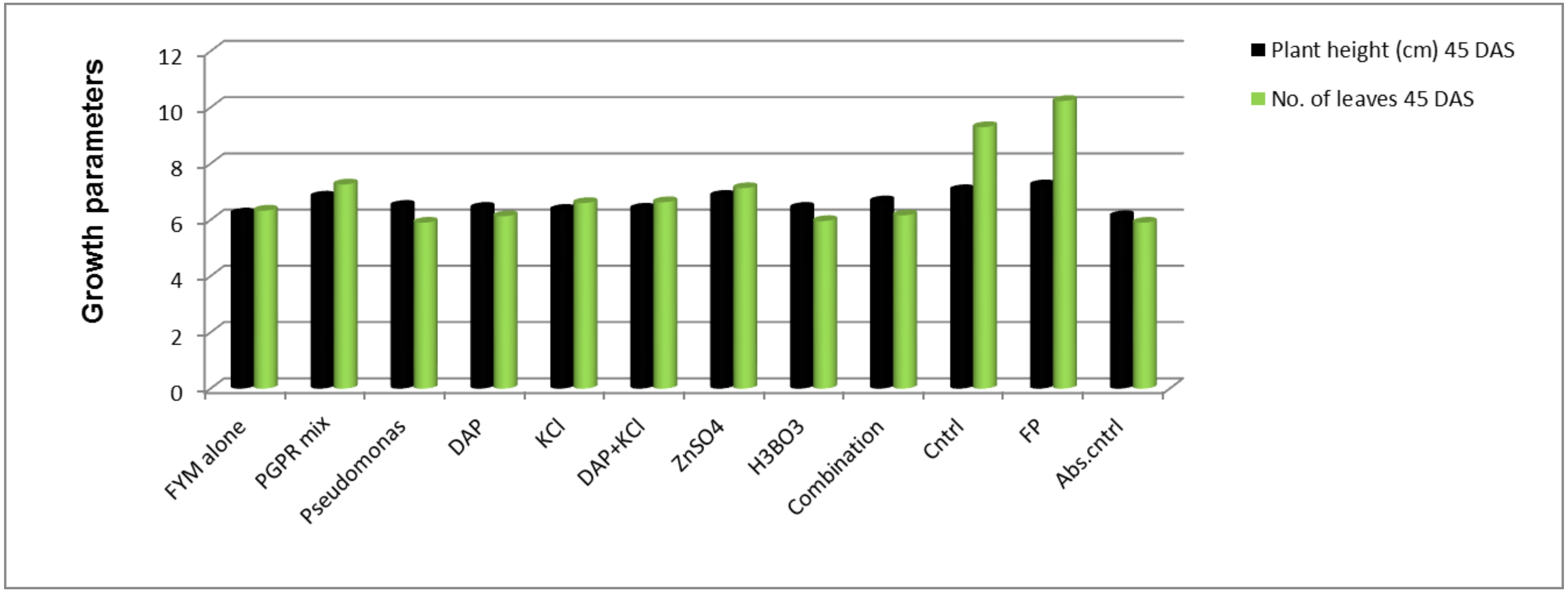
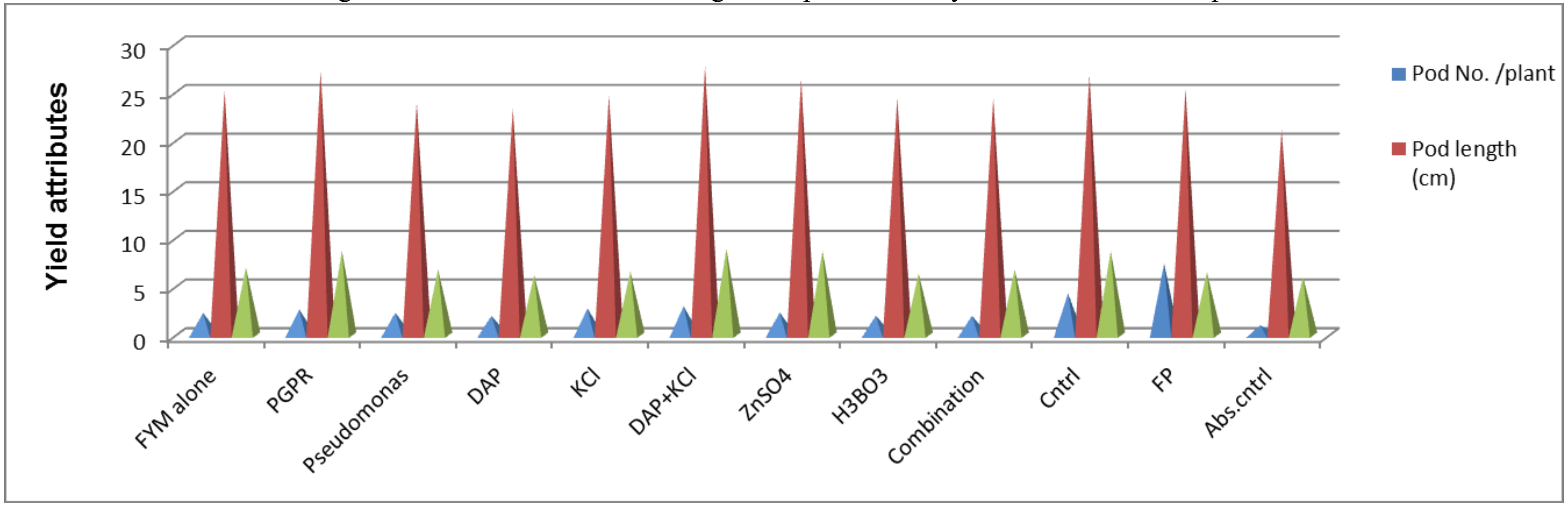


Figure 24. Effect of nutrient management practices on yield attributes of cowpea



influenced by various treatments. As in the case of pod yield, the highest stover yield was also recorded by farmers practice followed by the treatment which received irrigation at 5 days interval due to the reasons as discussed above. Among nutrient management practices, foliar spray of DAP+KCl recorded the highest stover yield and it was on par with seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_4$. This can be attributed to the role of phosphorus in improving the root growth, maintaining high leaf water potential which in turn results in improved water and nutrient uptake, nitrate assimilation and thereby better vegetative growth under drought condition (Waraich *et al*., 2011a). Similarly potassium maintains the osmotic potential and turgor of the cells (Lindhauer, 1995) and regulates the stomatal functioning under water stress conditions (Kant & Kafkafi, 2002) and thereby enhances photosynthetic rate, plant growth and yield under stress conditions (Egila *et al.,* 2001). Favourable effect of foliar spray of zinc on growth and physiology of mung bean under water stress resulted in higher stover yield (Thalooth *et al*., 2006). Increased plant growth in common bean, by improving hormone balance and stomatal conductance due to co-inoculation of PGPRs (*Rhizobium tropici* and *Paenibacillus polymyxa*) under drought stress was reported by Figueiredo *et al.* (2008).

All treatments which received different nutrient management practices to mitigate water stress could bring about significant influence on dry matter accumulation. Farmers practice recorded significantly highest dry matter accumulation due to lesser water stress and highest growth and yield compared to other treatments. Among nutrient management practices, foliar spray of DAP+KCl recorded the highest dry matter accumulation and it was statistically on par with seed treatment with PGPR mix I + rhizobium followed by foliar spray of 0.5% $ZnSO_4$. This can be attributed to the positive influence of the treatments in mitigating water stress by way of maintaining a favourable water balance inside the plants through modification of physiological parameters which led to higher growth and yield. Higher dry matter production in green gram with foliar application of KCl was reported by Govindan and Thirumurugan (2000). Shashikumar *et al*. (2013) observed higher growth components and total dry matter production in rainfed black gram by foliar spray of 2 per cent DAP. Zinc application resulted in higher biological yield and dry matter accumulation in mung bean Gupta *et al.* (2003). Bacterial inoculation resulted in improved root and shoot biomass in rice (Sharma *et al*., 2014) and maize (Gholami *et al*., 2009).

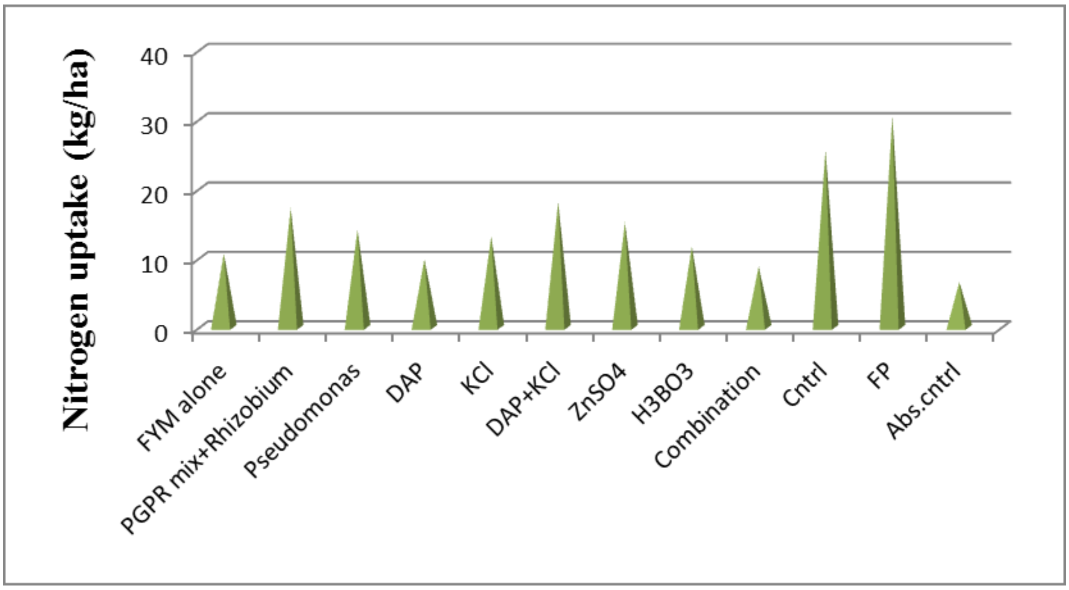
The highest number of harvests with early crop completion was occurred in farmers practice and the treatment irrigated at 5 days interval as there was less dearth of soil moisture for the plants to carry out their normal growth. Among nutrient management treatments, foliar spray of $ZnSO_4$, DAP+KCl and seed treatment with PGPR mix I + rhizobium recorded more number of harvests due to comparatively higher yield resulted from better vegetative growth and yield attributes consequent to their water stress mitigating influence on the plants. A comparatively longer duration of the crop in the above treatments is due to the delay in attaining sufficient vegetative growth before flowering as a result of imposed water stress.

5.3.4. Quality parameters

Protein content in cowpea pods and stover was significantly influenced by various treatments. In general, higher protein content in pod and stover was recorded by farmers practice, foliar spray of DAP+KCl and seed treatment with PGPR mix I + rhizobium due to higher nitrogen content (Appendix V) resulted from higher uptake of nitrogen (Fig. 25) due to lesser water stress/water stress mitigation effect of the treatments. Higher protein content in mung bean as a result of foliar spray of DAP+KCl was also reported by (Tahir *et al.,* 2014) which can be due to the activation of enzymes involved in protein synthesis by N and K application. Abbasi *et al*. (2013) reported improved nitrogen content in soybean whereas Naseem and Bano (2014) found improved protein concentration in the leaves of maize due to PGPR application under stress conditions.

Among various water stress mitigation nutrient management practices, foliar spray of $ZnSO_4$ recorded a higher pod protein but lowest stover protein content. This can be attributed to the higher uptake of nitrogen due to its water stress mitigation effect and better translocation of the nutrient to the economic part. Ved *et al*. (2002) reported that foliar applied zinc improved grain protein content of mung bean.

Fig. 25. Effect of nutrient management practices on nitrogen uptake



5.3.5. Nutrient uptake by the crop

Uptake of primary [nitrogen (N), phosphorus (P) and potassium (K)], secondary [calcium (Ca), magnesium (Mg) and sulphur (S)] and micro [iron (Fe), manganese (Mn), zinc (Zn) and boron (B)] nutrients was significantly influenced by various treatments. Significantly higher uptake of almost all nutrients by the crop was noted in farmers' practice followed by the treatment irrigated at 5 days interval due to the availability of enough soil moisture (Fig. 22) as a result of frequent irrigation in these treatments. The lowest elemental uptake by the crop was in absolute control, due to the extreme water stress experienced by the plants. Among nutrient management practices, foliar spray of DAP+KCl, $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded the better uptake of all nutrients compared to others due to their beneficial influence on growth (Fig. 23) and physiology (Fig. 21) of the crop under water stress. PGPRs promote plant growth by improving soil structure and moisture retention as well as by enhancing plant mineral-nutrient absorption (Kim *et al.* 2012). Ling and Silberbush (2002) found that foliar application of NPK helped in sufficient nutrient uptake in maize. Foliar spray of zinc (100ppm) resulted in better NPK uptake by tomato fruits due to its positive influence on biomass production (Mishra *et al*., 2012).

5.3.6. Soil characters

Soil pH and organic carbon content after the experiment did not show much variation compared to their values before the experiment. Soil pH ranged only from 5.1 to 5.9 and organic carbon content from 0.9 to 1.4 per cent among treatments even though significant difference was noticed among treatments.

Application of different treatments significantly influenced the primary (except N) P and K), secondary (Ca, Mg, and S) and micro (Fe, Mn, Zn Cu and B) nutrient content in soil after the experiment. All elemental nutrients (except Ca, Mg, S, Fe, Cu and B) showed a reduction in their status compared to their content before the experiment due to their uptake and utilization by the crop. In general, there was not much variation in the content of various nutrient elements after the experiment even though significant difference was noticed among treatments. Combined application of biofertilizers and elemental nutrients was found superior in maintaining higher soil P, Ca, Mg, Cu, Zn and B status after the experiment whereas foliar spray of DAP+KCl was better in K, S and Fe status and a higher Mn content was in seed treatment with PGPR mix I + rhizobium.

5.3.7. Soil moisture content

In general, soil moisture status in the field was very low during the entire crop period due to high evaporation caused by high wind speed and temperature (Appendix I & II/Fig. 5). A gradual decline in soil moisture content was observed from 15 DAS to 30 DAS in nutrient management treatments and in absolute control due to the imposition of water stress (Fig. 22). At 45 DAS, water stress release from the above treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards (except in FYM alone, seed treatment with PGPR mix I + rhizobium, soil drenching and foliar spray of pseudomonas) due to the severity of high air temperature and faster evaporation from the soil. The effect of FYM and PGPR mix I + rhizobium on higher soil moisture retention was reported by (Lawal and Girei, 2013) and (Timmusk *et al.,* 2013) respectively. Improved soil moisture content as a result of seed bacterization of maize with PGPR strains were also reported by Naseem and Bano (2014). At final harvest, all treatments recorded very low values due to the stoppage of irrigation in all treatments on attainment of full maturity of the crop.

5.4. Second year experiment

The experiment was conducted to evaluate the effect of various promising treatments selected from the first year experiments, alone and their combinations for mitigating water stress in vegetable cowpea.

5.4.1. Growth characters

The general growth of cowpea plants in second year experiment was better than that in first year experiments due to the receipt of unexpected rainfall during the later stage of the crop and the resultant extension of crop duration. There was a progressive increase in growth parameters of cowpea plants like plant height, number of leaves, number of branches and leaf area up to 60DAS in all treatments except in treatments irrigated at 2 days (farmers practice) and 5 days interval, which recorded a lesser leaf number and leaf area at 60 DAS compared to that at 45 DAS. This is due to the leaf fall from plants as a result of attainment of early final maturity as a result of non exposure of cowpea plants to imposed water stress.

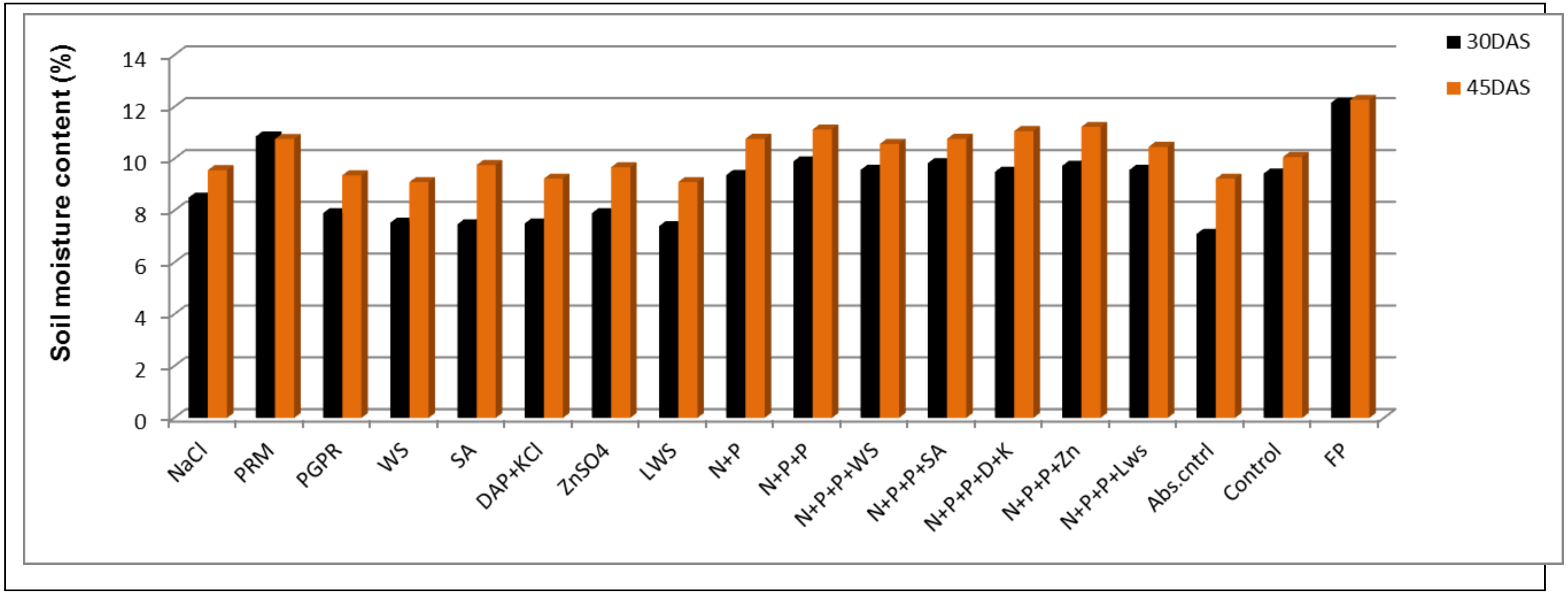
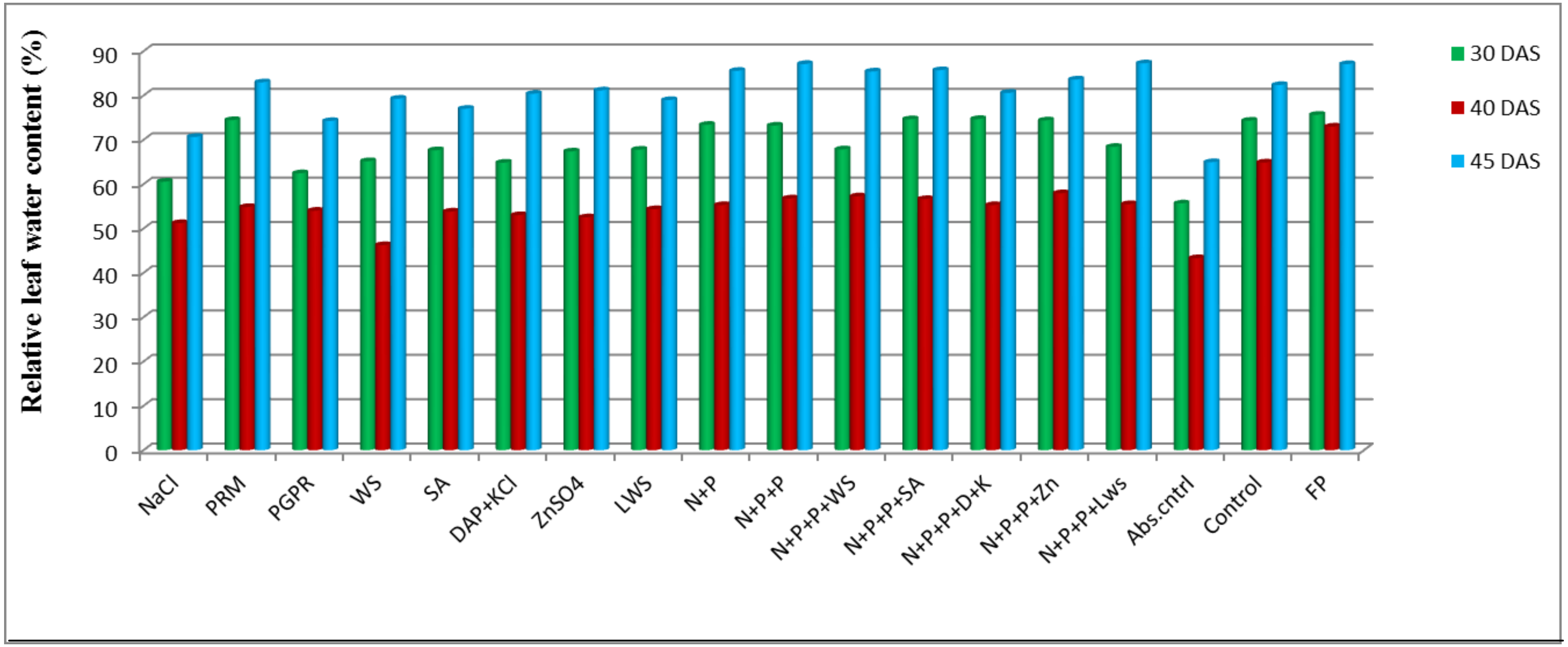


Figure 26. Effect of treatments on soil moisture content

Figure 27. Effect of treatments on relative leaf water content



All growth characters of cowpea plants were significantly influenced by various water stress mitigation treatments and resulted in an increase of plant height from 9.6 to 138.5 per cent, number of leaves from 2.3 to 107.7 per cent and leaf area index from 21.7 to 252 per cent compared to absolute control at 60 DAS. This showed the positive influence of water stress mitigation treatments on the growth of cowpea plants compared to no treatment.

In general, plant growth was higher in all mulched treatments, either alone or in combination with other treatments, compared to non mulched ones due to the effect of mulching on soil moisture conservation and relative leaf water content as evident from the data (Fig. 26 & 27). The importance of mulching for mitigating water stress in crop plants was reported by many workers; Lal (1974) in maize, Chakraborty *et al.* (2008) and Min-Li *et al.* (1999) in wheat.

Among treatments, combined application of NaCl+PRM+ (PGPR mix I + rhizobium)+ salicylic acid resulted in a better plant height and number of leaves per plant at most of the growth stages whereas higher number of branches and leaf area index were noticed in NaCl+PRM+ (PGPR mix I + rhizobium)+zinc sulphate at 60 DAS. This is due to the combined favourable influence of seed hardening with NaCl on seedlings to overcome water stress, that of PGPR by way of better nutrient availability and that of salicylic acid by its stimulatory effect on physiological traits (improving the antioxidant enzyme action)/role of zinc in tryptophan production, which is a precursor of auxin, in addition to better soil moisture availability through mulching. Cayuela *et al*. (1996) reported an increased tolerance of NaCl primed seedlings due to osmotic adjustment which facilitate increased uptake of water resulting in turgor which ultimately promotes the expansion of cells. Cook *et al.* (2006) reported the beneficial effect of mulching on soil water retention and temperature regulation. Favourable influence of PGPR mix I + rhizobium on plants' tolerance to drought stress by way of improving water retention inside plants and by enhancing plant mineral-nutrition absorption was reported by Kim *et al.* (2012). Improved drought tolerance of wheat, due to increased antioxidant enzyme activity by salicylic acid application was reported by (Horvath *et al*., 2007) and (Agarwal *et al.,* 2005). Waraich *et al*. (2011) also reported the role of zinc in tryptophan production.

Among individual application of selected treatments, positive influence of seed treatment with PGPR mix I + rhizobium on growth of cowpea plants was pronounced at most of the stages. This again showed the favourable influence of seed treatment with PGPR and rhizhobium on growth even under water stress situation. PGPRs, degrade ACC (1-aminocyclopropane-1-carboxylic-acid), the precursor for ethylene and thereby stimulate plant growth by reducing ethylene production under stress (Glick *et al.,* 2007). Foliar spray of salicylic acid exhibited a favourable influence on number of branches and leaf area index of cowpea plants at 60 DAS. Positive influence of salicylic acid on leaf area index was reported by (Afshari *et al*., 2013) in cowpea and (Sadeghipour and Aghaei, 2012) in common bean.

Root length of cowpea plants was also significantly influenced by various treatments and all mulched treatments resulted in an increasing trend in root length to the tune of 29.7 to 60 per cent compared to absolute control. Among individual application of treatments, a higher root length on par with the mulched ones was noticed in seed treatment with PGPR mix I + rhizobium. The favourable influence of plant growth promoting bacterial strains on the capacity of the plant to tolerate water stress by way of improving root growth was reported by (Hayat *et al*. 2010). Chakraborty *et al.* (2008) reported a favourable influence on root length of wheat during dry periods under rice husk mulching.

Root shoot ratio of cowpea plants was not significantly influenced by various water stress mitigation treatments. However, all treatments except water spray recorded a numerically higher root shoot ratio compared to absolute control. This can be attributed to the favourable influence of the treatments on both root and shoot growth.

Early flowering was noticed in farmer's practice and in all mulched treatments due to attainment of sufficient vegetative growth in time as a result of lesser water stress. Cowpea plants which received individual application of treatments showed a delay of four to seven days in attaining 50 per cent flowering compared to farmers' practice due to lack of sufficient vegetative growth in time on exposure to imposed water stress combined with lesser soil moisture availability. Delayed flowering as a result of imposed water stress due to insufficient vegetative growth was reported by French (2012) in faba bean.

5.4.2. Physiological parameters

Various water stress mitigation treatments significantly influenced the photosynthetic rate, transpiration rate, total chlorophyll content, stomatal conductance, relative leaf water content, proline content, nitrate reductase activity and chlorophyll stability index of cowpea plants. Most of the mulched treatments recorded higher photosynthetic rate, transpiration rate and stomatal conductance compared to non mulched ones due to lesser water stress experienced by the cowpea plants. Lower values of the above parameters in the non mulched treatments might be due to the stomatal closure consequent to higher water stress. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate recorded a higher photosynthetic rate at 60 DAS which can be attributed to the positive influence of NaCl, mulching, PGPR mix I+ rhizobium and zinc sulphate in maintaining a favourable water balance inside cowpea plants. Role of zinc in attaining higher leaf area, carbon fixation per unit leaf area and carbonic anhydrase activity under water stress was reported by Hacisalihoglu *et al*. (2003) and its role in antioxidant enzyme activity (which in turn reduce photooxidation by reactive oxygen species) and reduced chlorophyll degradation thereby increased photosynthesis was reported by Waraich *et al*. (2011). Improved photosynthesis in mulched pepper plants and PGPR inoculated chick pea plants were reported by (Thakur *et al.,* 2002) and Jabbari and Khaleghnezhad (2014) respectively.

Highest relative leaf water content was recorded by farmers practice (except at 60 DAS) due to non exposure of cowpea plants to water stress (Fig. 27). Most of the mulched treatments resulted in a better relative leaf water content compared to non mulched ones and they were on par with each other and also with farmers practice at most of the stages. This is due to the better soil moisture availability (Fig. 26) to cowpea plants throughout the crop growth period as a result of mulching by way of reduced soil water evaporation compared to non mulched treatments. Lal (1974), Cook *et al.* (2006), and Chakraborty *et al.,* (2008) also reported the beneficial influence of mulching in various crops by way of soil moisture retention. Among individual application of treatments, foliar spray of zinc sulphate resulted in higher relative leaf water content in almost all stages of crop growth. Increased relative leaf water content in corn due to zinc sulphate spray under stress was also reported by Vazin (2012). Gadallah (2000) also showed an improved leaf relative water content of soybeans by supplementary soil application of zinc, under water stress which can be due to its role in improvement of vascular tissue formation and prevention of their destruction (Gadallah and Ramadan, 1997), and osmotically active solute accumulation in roots (Gadallah, 2000). In general, various water stress mitigation treatments increased the relative leaf water content to the range of 8 to 44 per cent compared to no treatment at 60 DAS. This showed the favourable influence of the treatments on water stress mitigation in vegetable cowpea.

Among treatments, farmers practice recorded higher nitrate reductase activity at all stages except at 60 DAS due to non exposure of cowpea plants to water stress. Moreover, most of the mulched treatments showed a higher nitrate reductase activity compared to non mulched ones at all stages of crop growth. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate maintained its superiority in having higher nitrate reductase activity at all stages (except at 15 DAS) which can be attributed to the favourable influence of each treatment in the combination in mitigating water stress by way of better soil moisture availability and a favourable water balance inside the plants. Moreover, among individual application of treatments, foliar spray of zinc sulphate resulted in higher nitrate reductase activity at the stage when the plants were under maximum water stress (40 DAS). Crop residue mulching (crop straw returnings) significantly increased root activity, leaf nitrate reductase activity, leaf chlorophyll content and photosynthetic rate of cucumber (QingHai *et al.,* 2013). Plant-growth-promoting rhizobacterium, *Pseudomonas mendocina*, alone or in combination with arbuscular mycorrhizal fungus, *Glomus intraradices* in leaves of *Lactuca sativa* L. cv. Tafalla under drought stimulated nitrate reductase activity (Kohler *et al.,* 2008). Mishra *et al*. (2012) reported an improved NRase activity with foliar zinc application in tomato plants.

Among treatments, farmers practice recorded the lowest proline content followed by irrigation at 5 days interval as a result of non exposure of cowpea plants to water stress. All water stress mitigation treatments recorded higher proline content compared to absolute control. This is due to the favourable influence of the treatments on proline accumulation which in turn acts as an osmolyte in reducing the severity of water stress. Improved proline content in sunflower (Zafar *et al.,* 2014) and tomato (Hayat *et al.,* 2008) as a result of zinc and salicylic acid spray respectively was reported under water stress. Potato plants inoculated with PGPR isolates showed higher proline content induced by PGPR under drought stress which contributed to increased plant tolerance to water stress (Gururani *et al*., 2013). In general, most of the mulched treatments showed lower proline content compared to non mulched ones due to lesser water stress experienced by cowpea plants as a result of improved soil moisture availability. Among individual application of treatments, foliar spray of zinc sulphate resulted in higher proline accumulation which can be attributed to the role of zinc in mitigating water stress.

Most of the mulched treatments showed higher chlorophyll stability index compared to non mulched ones due to the same reason as explained above. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate and individual application of zinc sulphate recorded higher chlorophyll stability index among mulched and non mulched treatments respectively which showed the significant role of zinc sulphate in reducing chlorophyll degradation in cowpea plants under water stress situation. Reduced chlorophyll degradation by way of improved antioxidant enzyme action by zinc application was noticed by Waraich *et al*. (2011). Increased chlorophyll index of corn as a result of foliar spray of Zn under drought stress was reported by Mosavifeyzabadi *et al*. (2013).

Chlorophyll content of cowpea plants was significantly influenced by various water stress mitigation treatments at all stages except at 30 DAS. All water stress mitigation treatments recorded a significantly higher chlorophyll content compared to absolute control at 40, 45 and 60 DAS. Among mulched treatments, NaCl+PRM recorded higher chlorophyll content at all stages. Moreover, at 40 DAS, when the plants were exposed to maximum water stress, seed priming with NaCl recorded the highest chlorophyll content followed by PRM alone, NaCl+PRM and they were on par with each other. Similarly, foliar spray of zinc sulphate, NaCl+PRM+ (PGPR mix I +rhizobium), NaCl+PRM+(PGPR mix I +rhizobium)+water spray and NaCl+PRM+(PGPR mix I +rhizobium)+ zinc sulphate were found on par with PRM alone and NaCl+PRM. This shows the positive influence of seed treatment with NaCl, mulching alone and their combination with (PGPR mix I +rhizobium) or zinc sulphate in reducing the adverse effect on chlorophyll degradation by way of maintaining favourable water balance inside the plants. Sekhon *et al*. (2005) reported increased chlorophyll content in soybean under wheat straw mulching. Chlorophyll content in soybean was improved by PGPR application (Abbasi *et al*., 2013). Among individual application of treatments, foliar spray of zinc sulphate recorded better chlorophyll content at almost all stages due to the role of zinc in protecting major cellular components like chlorophyll by preventing their oxidation as reported by Waraich *et al*. (2011).

5.4.3. Yield and yield attributes

In general, pod yield obtained from the experiment plots was comparatively higher than that from the first year experiments due to the impact of rainfall received during the later stage of crop growth which resulted in a resurgence of growth, extension of duration and thereby more yield. Pod yield obtained from mulched treatments were higher than that from non mulched ones (Fig. 30) due to the favourable influence of better soil moisture availability (Fig. 26) on vegetative growth and efficient translocation of assimilates to the economic part as evident from the data on yield attributes (Fig. 28). The positive

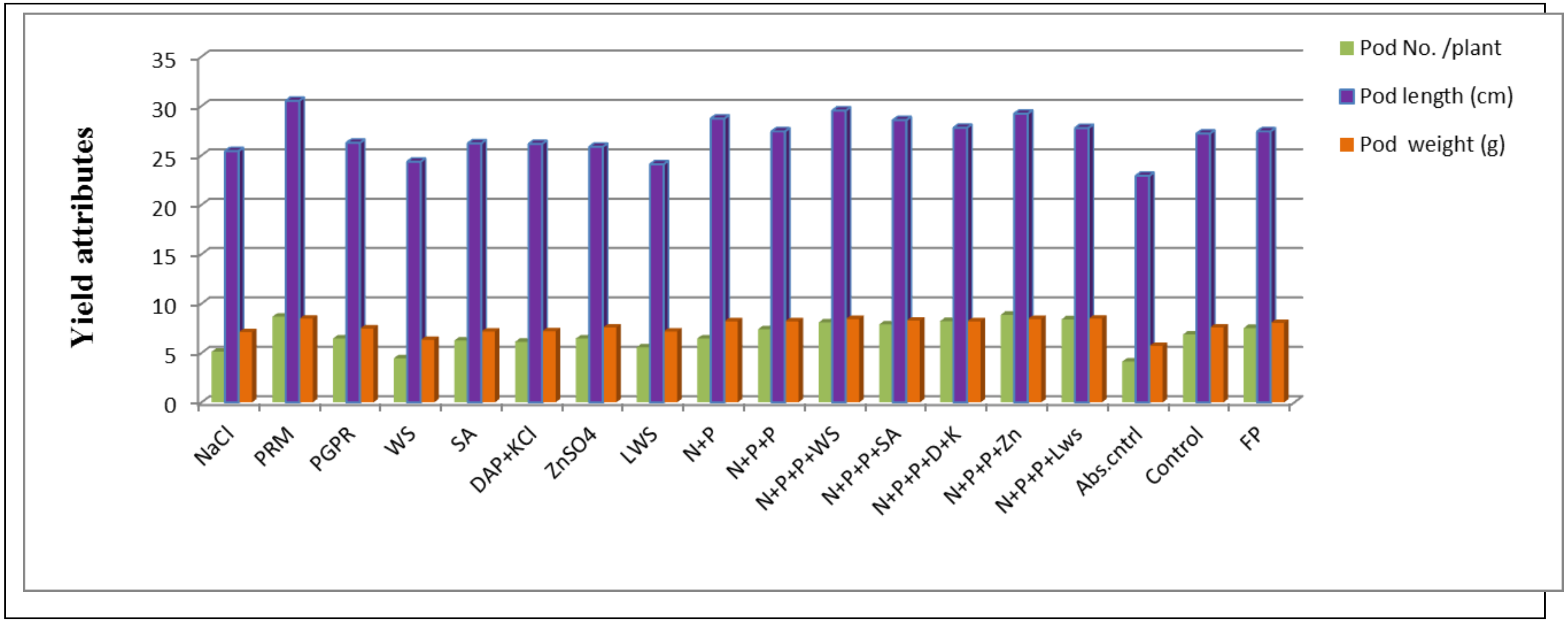
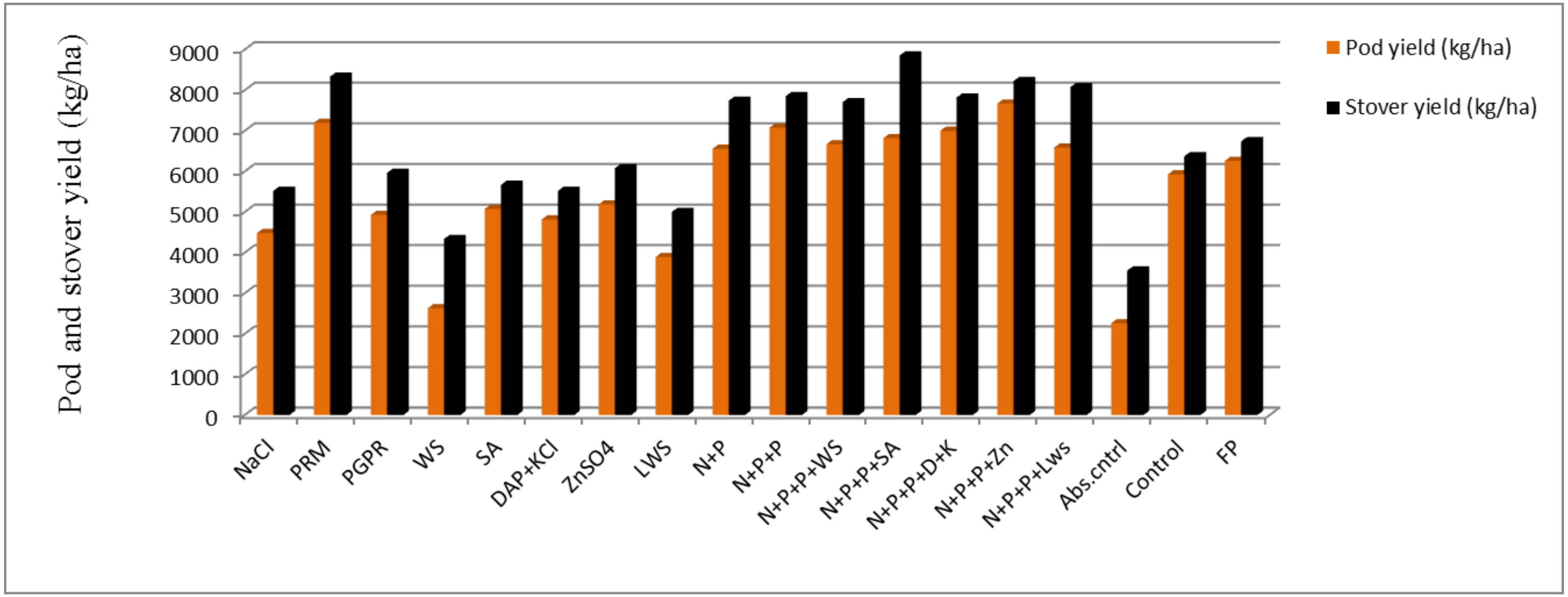


Figure 28. Effect of treatments on yield attributes on cowpea

Figure 30. Effect of treatments on pod and stover yield of cowpea



effect of mulching on crop yield by way of soil moisture conservation was well established. An increased number of pods per plant and seed yield in soybean under wheat straw mulching were reported by Sekhon *et al*. (2005). Moreover, all water stress mitigation treatments had a favourable effect on yield and yield attributes of cowpea plants compared to absolute control. This showed that either seed priming with NaCl or seed treatment with PGPR mix I + rhizobium or foliar spray of water or salicylic acid or DAP+KCl or zinc sulphate or lime water during water stress imposed period has a positive influence on yield of cowpea plants by way of mitigating water stress. Enhanced yield in sesame (Athari and Talebi, 2014), hybrid sunflower (Hussain *et al*., 2006), ground nut (Reddy and Setty, 1995) and black gram (Geetha and Velayutham, 2009) with foliar application of salicylic acid, osmopriming with NaCl, foliar spray of lime and foliar spray of 2 per cent DAP +1 per cent KCl respectively were previously reported.

Among treatments, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate recorded the highest pod yield and it was on par with all treatments in which mulching was included. Moreover, it was significantly superior to farmers practice, irrigation at 5 days interval, all individual application of treatments and absolute control. This showed the significant influence of mulching on pod yield of vegetable cowpea grown under water stress situation. A higher pod yield of about 470 kg was obtained from the above treatment compared to PRM alone which can be attributed to the positive effect of NaCl priming, zinc sulphate spray and PGPR mix I + rhizobium in mitigating water stress through various mechanisms as evident from data on physiological parameters (Table 34, 35 & 36). Zarmehri *et al.* (2013) also reported an improved the cob weight and grain yield in maize under water stress by zinc sulphate application. Higher grain yield in chick pea inoculated with PGPR was reported by Jabbari and Khaleghnezhad (2014).

Among individually applied treatments, foliar spray of either zinc sulphate or salicylic acid recorded higher pod yield on par with farmers practice. This is due to the cumulative effect of higher yield attributes recorded by the above treatments (Fig. 28) by way of water stress mitigation. The favourable influence of salicylic acid on pod formation in soybean was reported by Kumar *et al*. (1999) and on grain yield of corn by Yaghoubian *et al.* (2014). Positive effect of zinc application on biological yield of mung bean under water stress was observed by Thalooth *et al*. (2006). Absolute control, which received no treatment during the water stress imposed period, resulted in a reduction in pod yield to the tune of 16 to 239 per cent compared to other treatments, due to the impact of more water stress on growth and yield attributes. Reduction in yield due to water stress was reported by Nilanthi *et al.* (2014) in black gram, Samarah *et al.* (2006) in soybean and Nam *et al.* (2001) in red gram.

All water stress mitigation treatments except water spray recorded significantly higher stover yield than absolute control. In general, as in the case of pod yield and yield attributes, the mulched treatments either alone or in combination with other treatments resulted in higher stover yield, significantly higher than that from the treatment irrigated at 5 days interval, all individual application of treatments and absolute control due to the favourable influence of the treatments on growth characters of cowpea plants (Fig. 29) by way of better soil moisture availability. Among treatments, the highest stover yield was obtained from NaCl+PRM+ (PGPR mix I + rhizobium)+ salicylic acid due to the impact of better water availability on growth as a result of mulching (Fig. 26) and favourable effect of salicylic acid on physiological mechanisms of cowpea plants (Fig. 31) and thereby better growth. Salicylic acid application under water stress enhanced photosynthetic parameters, proline content, membrane stability index, leaf water potential, activities of nitrate reductase and carbonic anhydrase thus improved drought tolerance in tomato (Hayat *et al.,* 2008).

Among individual application of treatments, stover yield recorded by foliar spray of zinc sulphate, seed treatment with PGPR mix I+ rhizobium, foliar spray of salicylic acid, foliar spray of (DAP+ KCl) and seed priming with NaCl were on par with farmers practice and irrigation at 5 days interval. This is due to the resurgence of growth of cowpea plants in the above treatments, consequent to the receipt of rainfall during later part of crop growth, and the early crop completion in farmers practice and in treatment irrigated at 5 days interval.

Figure 29. Effect of treatments on growth parameters

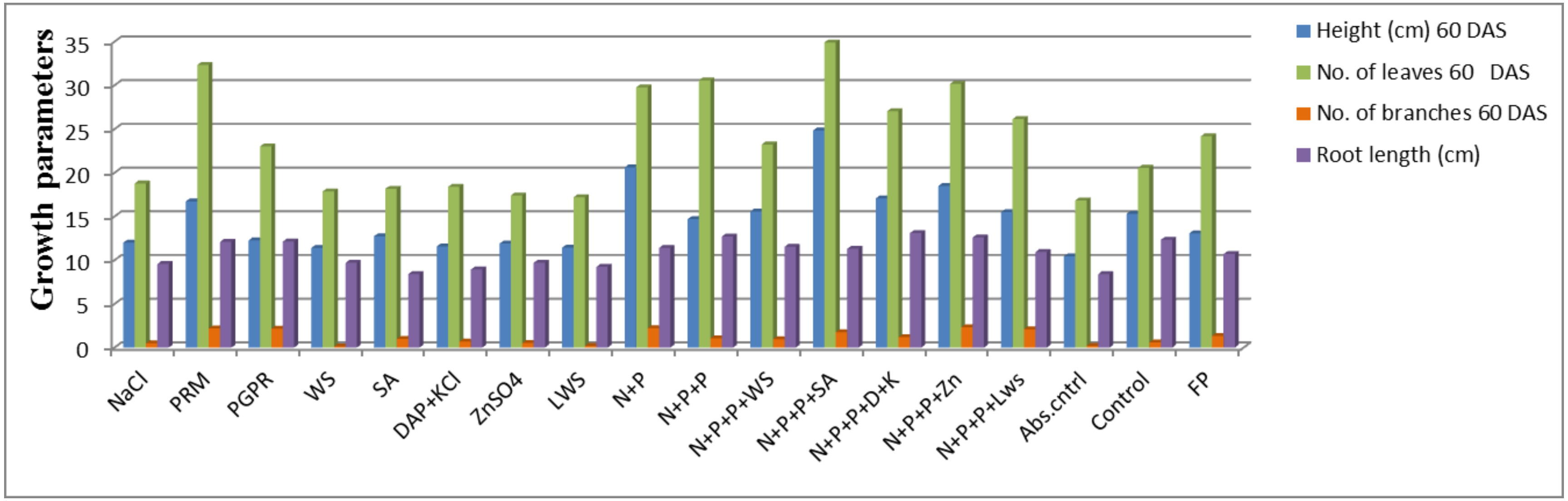
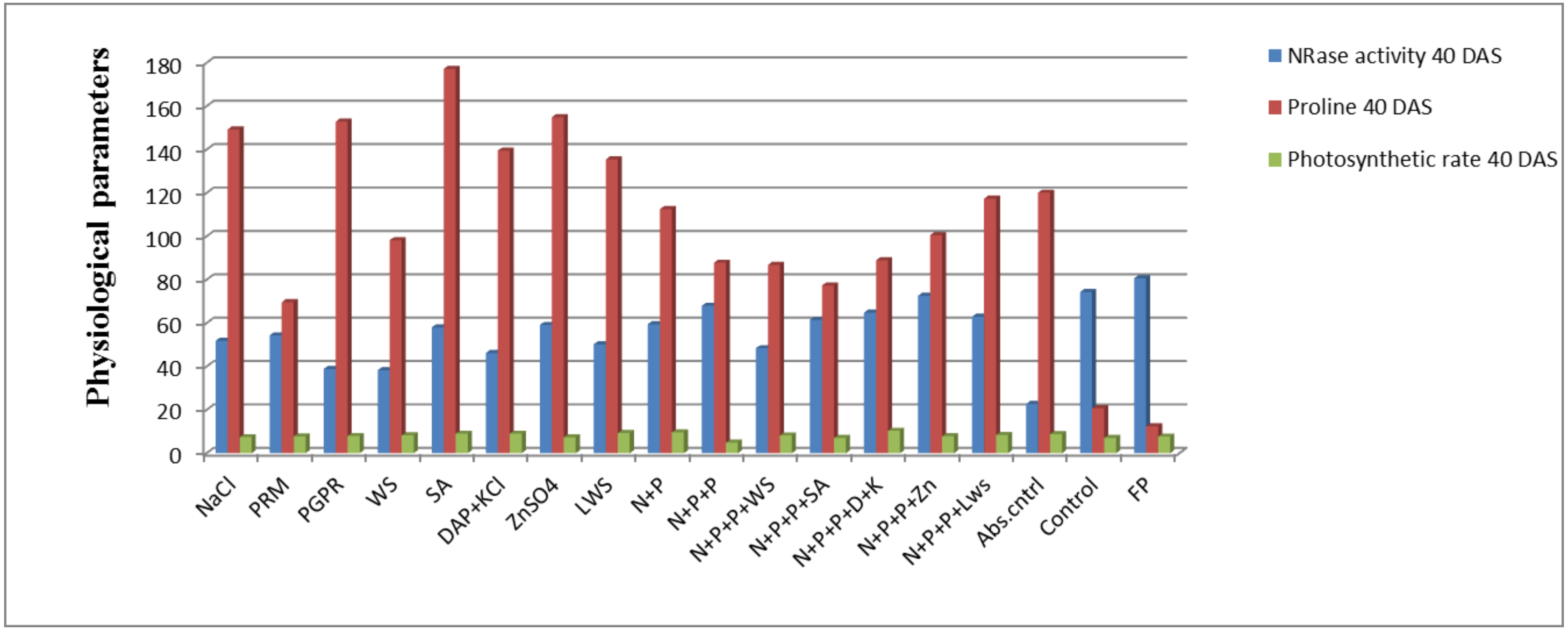


Figure 31. Effect of treatments on physiological parameters

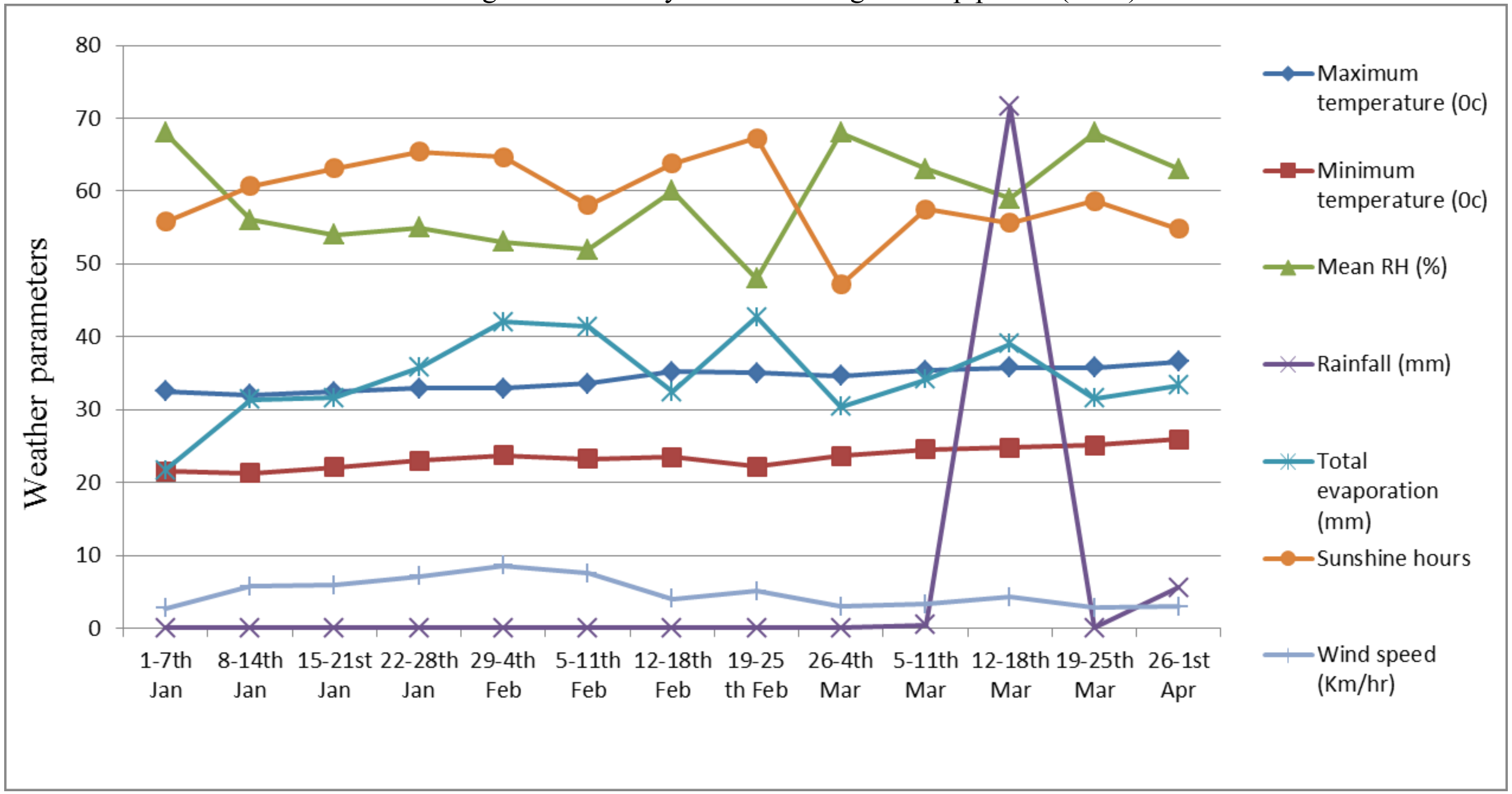


Detrimental effect of drought stress occurred at vegetative stage ws alleviated by rewatering (Akyeampong ,1985). However, individual application of treatments except water spray resulted in a significantly higher stover yield than absolute control. Increased stover yield in mung bean by foliar application of zinc during water stress period was noticed by Thalooth *et al.* (2006). Similarly, enhanced biomass yield in *Catharanthus roseus* treated with native PGPRs, under water deficit was observed by Jaleel *et al.,* (2007).

The impact of mulching and unexpected rainfall during the later part of crop season on growth and yield of the crop was reflected on total dry matter accumulation also and it was significantly influenced by various treatments. All water stress mitigation treatments could bring about 20 to 166 per cent increase in total dry matter production compared to absolute control as a result of their favourable influence on either growth or yield or both. Among various treatments, NaCl+PRM+ (PGPR mix I + rhizobium)+salicylic acid, NaCl+PRM+ (PGPR mix I + rhizobium)+zinc sulphate and PRM alone recorded the highest dry matter accumulation significantly superior to farmers' practice, where as absolute control recorded the lowest and the reason for which is the same as explained earlier. Biomass reduction in cowpea due to water deficit was reported by Anyia and Herzog (2004). Kumar *et al.*, (1995) reported an increased yield and dry matter production in green gram by black polythene mulching. Salicylic acid treatment in summer sesame improved the crop growth by improving physiology and there by dry matter accumulation and yield (Panda *et al.*, 2013). Similar results with improved anti oxidant enzyme activity and dry matter accumulation in wheat seedlings treated with salicylic acid was reported by Singh and Usha (2003).

Among individual application of treatments, foliar spray of zinc sulphate and seed treatment with PGPR mix I+ rhizobium recorded higher dry matter accumulation on par with farmers practice, and significantly superior to water spray and absolute control. This is due to the favourable influence of zinc on biological activity by way of better chlorophyll content (Table 35) and that of

Figure 32. Weekly weather during the crop period (2015)



PGPRs on plant growth by enhancing plant mineral-nutrition absorption. Effect of foliar spray of zinc on increased straw and grain yield of mung bean under water stress was reported by Thalooth *et al*. (2006). PGPR strains improve plant growth by better soil moisture retention and thereby increase plant mineral-nutrition absorption (Kim *et al.* (2012).

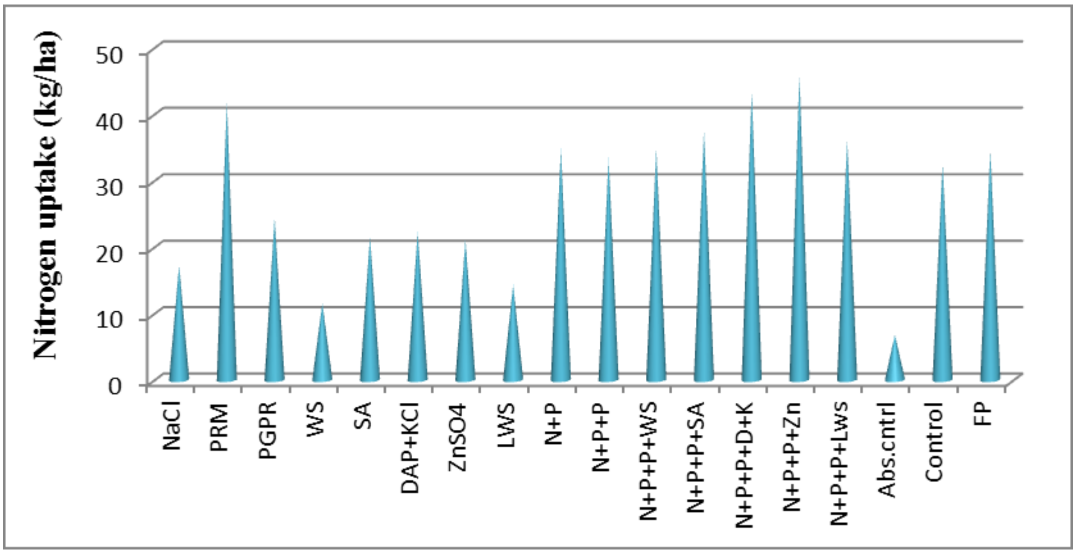
Number of harvests was not significantly influenced by various treatments and it varied from three harvests in water spray to five harvests in NaCl+PRM+ (PGPR mix I + rhizobium)+ (DAP+KCl), NaCl+PRM+ (PGPR mix I + rhizobium)+ lime water spray and PRM alone. Duration of the crop was influenced by water availability. The plants in treatments which received irrigation on alternate days (farmers practice) and at 5 days interval without any imposed water stress in between attained final maturity (65 days) earlier than the remaining treatments. Receipt of rainfall during later part of crop growth (Fig. 32) extended the crop duration by three weeks (85 days) in the remaining treatments including absolute control without any variation among them.

5.4.4. Quality parameters

Protein content in cowpea pods and stover was significantly influenced by various treatments. In general, most of the mulched treatments recorded a better pod and stover protein content compared to individual application of treatments and absolute control. Among them, NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl) and NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate recorded highest pod and stover protein content respectively, due to higher nitrogen content (Appendix VI) resulted from higher nitrogen uptake (Fig. 33). Ved *et al*. (2002) reported that foliar applied zinc improved grain protein content of mung bean.

Among individual application of treatments, higher protein content in pod and stover was recorded by foliar spray of (DAP+KCl) due to the activation of enzymes involved in protein synthesis as reported by (Tahir *et al.,* 2014) in mung bean and seed treatment with PGPR mix I + rhizobium due to better availability and uptake of nitrogen (Fig. 33). Abbasi *et al*. (2013) reported improved nitrogen content in soybean whereas Naseem and Bano (2014) found increased protein concentration in the leaves of maize due to PGPR application under water stress conditions.

Fig. 33. Effect of treatments on nitrogen uptake



5.4.5. Nutrient uptake by the crop

Uptake of primary [nitrogen (N), phosphorus (P) and potassium (K)], secondary [calcium (Ca), magnesium (Mg) and sulphur (S)] and micro [iron (Fe), manganese (Mn), zinc (Zn) and boron (B)] nutrients was significantly influenced by various water stress mitigation treatments. In general, mulched treatments recorded a higher nutrient uptake than most of the individual application of treatments and absolute control due to higher soil moisture availability. Among them, a higher uptake of all nutrients except B by the crop was noted in NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate due to the beneficial influence of NaCl, PGPR mix I+ rhizobium and zinc on growth and physiology in addition to the availability of soil moisture and nutrients as a result of mulching. The lowest elemental uptake (primary/secondary/micro nutrients) by the crop was in absolute control, due to the higher water stress experienced by the plants. Foliar spray of zinc (100ppm) resulted in better NPK uptake by tomato fruits due to its positive influence on biomass production (Mishra *et al*., 2012). Improved N and P uptake by rainfed wheat under mulching was reported by ShouYu *et al.,* (1997) as a result of enhanced soil moisture, improved aeration which facilitated the mineralization of organic matter in the soil.

Among individual application of treatments, seed treatment with PGPR mix I + rhizobium recorded better uptake of all nutrients except S, due to their beneficial influence on the availability of nutrients and consequent effect on growth (Fig. 29) and physiology (Table 34, 35 & 36) of the crop under water stress. Improvement in soil structure, soil moisture retention as well as enhanced plant mineral-nutrient absorption due to inoculation of PGPRs was reported by Kim *et al.* (2012).

5.4.6. Soil characters

Soil pH and organic carbon content after the experiment did not show much variation compared to their values before the experiment. However, a slight reduction in soil pH was noticed after the experiment and it ranged from 5.1 to 5.5 and organic carbon content ranged from 1.1 to 1.6 per cent, even though significant difference was noticed among treatments.

Various treatments significantly influenced the primary (N, P and K), secondary (Ca, Mg, and S) and micro (Fe, Mn, Zn Cu and B) nutrient content in soil after the experiment. Among nutrients, N, P, and Ca showed a reduction in their status compared to their content before the experiment due to their uptake and utilization by the crop. Most of the mulched treatments recorded a lesser content of most of the nutrient elements after the experiment which can be attributed to the higher crop removal as a result of more growth and higher yield. Foliar spray of zinc sulphate was found superior in maintaining higher soil N, Ca and Mg status after the experiment whereas foliar spray of (DAP+KCl) resulted in better P, S and Fe status. Higher Zn and Cu content were observed in seed treatment with PGPR mix I + rhizobium. The treatment combination, NaCl+

PRM+ (PGPR mix I+ rhizobium) + lime water spray recorded higher soil K, Mn and B content.

5.4.7. Soil moisture content

In general, soil moisture status was significantly influenced by various treatments and the highest soil moisture content was observed in farmers practice followed by various mulched treatments either alone or in combination, irrespective of stages, due to the irrigation received on alternate days and soil moisture retention property of mulches respectively. Lal (1974), Cook *et al.* (2006), and Chakraborty *et al.,* (2008) also reported the beneficial influence of mulching in various crops by way of soil moisture retention. A gradual decline in soil moisture was observed in all treatments (except in farmers practice and irrigation at 5 days interval) up to 30 DAS due to the imposition of water stress (Fig. 26). However at 45 DAS, water stress release from these treatments resulted in an increase in soil moisture content and maintained more or less the same level at 60 DAS. A progressive increase in SMC was observed at 69 DAS due to the receipt of unexpected rainfall on the previous day, and it showed a slight decline at 75 DAS and at final harvest.

5.4.8. Economics

Among treatments, the cost of cultivation for farmers practice was the highest (Rs.79,051/-) due to the higher labour charge for more number of irrigation as it was irrigated on alternate days whereas that for absolute control was the lowest (Rs.60,051/-). Among treatment combinations, NaCl+PRM+ (PGPR mix I+ rhizobium)+salicylic acid and among individual application of treatments, foliar spray of salicylic acid recorded the highest cost of cultivation due to the higher cost for salicylic acid.

In general, income, net profit and B:C ratio were higher from treatments which involve mulching and the highest net profit of Rs.2,03,389/- and B:C ratio of 4.1 were recorded by the treatment NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate as a result of higher yield, brought about by the beneficial effect of each treatment in the combination and the lowest was recorded by absolute control. However, mulching with plant residues (PRM) recorded a similar B:C of 4.1 as that of NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate, due to lesser cost involved and higher yield next to the above treatment. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest income, net profit and B:C ratio as a result of the positive effect of treatment on crop yield under water stress situation.

5.4.9. Field water use efficiency (FWUE)

Field water use efficiency of various treatments varied with yield and the total quantity of water applied during the crop season. The highest field water use efficiency was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate due to highest yield and the lowest by absolute control. A lower FWUE was recorded by farmers practice mainly due to more quantity of water applied.

5.4.10. Incidence of pests and diseases

None of the water stress mitigation treatments tried was found effective in preventing the infestation of aphids as it was noticed in all plots irrespective of treatments.

Conclusion

The results of the study revealed that mulching has a significant role in mitigating water stress in vegetable cowpea. Seed hardening with 0.5% NaCl, followed by seed treatment with PGPR mix I+ rhizobium followed by foliar spray of 0.5% zinc sulphate during water stress period can give added benefit to mulching for improving the growth and yield of vegetable cowpea grown under water stress situation.

Future line of work

1. As mulching was found to be the best practice for mitigating water stress, different materials and quantity of mulches have to be standardised

2. Seed treatment with PGPR mix I + Rhizobium, as well as foliar spray of 2% salicylic acid or 0.5% $ZnSO_4$ was found to be good in this study. So repeated application of these have to be tested

3. Effect of hydropriming needs to be evaluated

4. Promising treatments from this experiment can be evaluated in other crops also

SUMMARY

6. SUMMARY

Field experiments were conducted during the summer season of 2014 and 2015, at Agronomy Research Farm, College of Horticulture, Vellanikara to develop an agronomic package for mitigating water stress in vegetable cowpea. There were three experiments during the first year to evaluate the (1) effect of exogenous application of plant growth regulators (PGRs), (2) effect of seed priming, antitranspirants and soil moisture conservation practices and (3) effect of nutrient management practices for mitigating water stress in vegetable cowpea. The best treatments from the first year experiments were selected and their independent and combinations were evaluated in an experiment during the subsequent year.

6.1. Effect of plant growth regulators in mitigating water stress

There was a progressive increase in plant height, number of leaves, number of branches and leaf area up to final harvest. Higher number of leaves and leaf area index noticed in NAA 40 ppm and salicylic acid 2% at 60 DAS. Among exogenously applied treatments, salicylic acid 2% recorded a higher root length on par with farmers practice.

All water stress imposed treatments showed a slight delay in flowering compared to those received irrigation on alternate days and at 5 days interval.

Among PGRs, salicylic acid recorded the highest chlorophyll content and relative leaf water content.

Significantly highest pod yield was recorded by farmers’ practice. Among exogenously applied treatments, salicylic acid 2% recorded the highest pod yield and NAA 40 ppm recorded the highest stover yield and dry matter accumulation.

Early crop completion was noticed in treatments which received irrigation on alternate days and at 5 days interval (65 days). Absolute control as well as exogenous application of either PGRs, or coconut water or water extended the duration of the crop by one week (72 days).

Higher protein content both in pods and stover was recorded by farmers practice, irrigation at 5 days interval, NAA 40 ppm and salicylic acid 2%.

Among exogenous application of treatments, NAA 40 ppm recorded a comparatively higher uptake of all nutrients, whereas salicylic acid 2% improved the uptake of primary nutrients.

A gradual decline in soil moisture content was observed from 15 DAS to 30 DAS in exogenously applied treatments due to the imposition of water stress. However at 45 DAS, water stress release from these treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards due to the severity of high air temperature and faster evaporation from the soil.

6.2. Effect of seed priming, antitranspirants and moisture conservation practices in mitigating water stress

All growth characters such as plant height, number of leaves/branches per plant and leaf area index were significantly influenced by various treatments and there was a progressive increase in the growth of plants up to final harvest. In general, plant growth was significantly highest in farmers' practice which was irrigated on alternate days followed by the treatment irrigated at 5 days interval. Among water stress mitigation treatments, mulching either with polythene or plant residues, seed hardening with 0.5% NaCl and foliar spray of lime water as 2% $Ca(OH)_2$ recorded better growth of cowpea plants under water stress.

Better root shoot ratio was recorded by mulching either with polythene or plant residues and seed priming with NaCl.

Comparatively early flowering (45 DAS) was noted in seed priming treatments, on par with farmers practice and irrigation at 5 days interval.

Better stomatal conductance, transpiration rate and photosynthetic rate were observed in farmers practice and mulched treatments. Higher values of chlorophyll content and relative water content were observed in seed priming with NaCl, mulching either with polythene or plant residue and lime water spray as antitranspirant.

Comparatively higher pod yield was recorded by mulching either with polythene or plant residues, seed priming with NaCl and foliar application of lime water. Stover yield and dry matter production also showed the same trend as that of pod yield and was significantly influenced by various treatments.

Higher protein content in pod was recorded by seed priming either with NaCl or KH_2PO_4 and that in stover by seed priming with $CaCl_2$ or NaCl. Mulching either with plant residues or with polythene were equally effective in improving both pod and stover protein content.

Among seed primers, NaCl recorded a better uptake of almost all nutrients compared to $CaCl_2$ and KH_2PO_4. Polythene mulching was found better than plant residue mulching in terms of uptake of most of the elements. Among antitranspirants, foliar spray of lime water was significantly superior in nutrient uptake compared to kaolin and atrazine.

In seed priming and mulching treatments, soil moisture content increased at 30 DAS compared to that at 15 DAS due to irrigation at 10 days interval and the effect of mulches on soil moisture retention. A gradual decline in soil moisture content from 15 DAS to 30 DAS was observed in antitranspirant sprayed treatments and in absolute control due to the imposition of water stress. However at 45 DAS, water stress release from the above treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards due to the severity of high air temperature and faster evaporation from the soil.

6.3. Effect of nutrient management in mitigating water stress

The treatments which received either FYM or biofertilizers or foliar spray of mineral nutrients during the water stress imposed period resulted in an increasing trend of plant height from 8 to 18 per cent and number of leaves from 21 to 42 per cent compared to absolute control. Among nutrient management practices, more number of branches at the final stage of the crop and higher leaf area index at 40 and 60 DAS were noticed in seed treatment with PGPR mix I + rhizobium and foliar spray of $ZnSO_{4.}$

Significantly higher root shoot ratio was recorded by foliar spray of either ZnSO4, or KCl, or DAP+KCl, and seed treatment with PGPR mix I + rhizobium.

Cowpea plants which received foliar spray of $ZnSO_4$ also attained 50 per cent flowering on par with the above treatments.

Higher stomatal conductance, photosynthetic rate and transpiration rate were recorded by foliar spray of $ZnSO_4$. Among different nutrient management treatments, seed treatment with PGPR mix I + rhizobium was found superior in chlorophyll content followed by foliar spray of KCl, DAP and its combination, $ZnSO_4$ and FYM alone whereas foliar spray of KCl, DAP and its combination were found better followed by $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium in relative leaf water content.

Among various nutrient management practices, foliar spray of DAP+KCl, $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded a significantly higher pod yield, stover yield and dry matter production than other treatments. Higher protein content in pod and stover was recorded by farmers practice, foliar spray of DAP+KCl and seed treatment with PGPR mix I + rhizobium.

Among nutrient management practices, foliar spray of DAP+KCl, $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium recorded the better uptake of all nutrients compared to other nutrient management treatments.

A gradual decline in soil moisture content was observed from 15 DAS to 30 DAS in nutrient management treatments and in absolute control due to the imposition of water stress. At 45 DAS, water stress release from the above treatments resulted in a slight increase in soil moisture content which again showed a slight decline from 60 DAS onwards (except in FYM alone, seed treatment with PGPR mix I + rhizobium, soil drenching and foliar spray of pseudomonas) due to the severity of high air temperature and faster evaporation from the soil.

6.4. Second year experiment

There was a progressive increase in growth parameters of cowpea plants like plant height, number of leaves, number of branches and leaf area up to 60 DAS. In general, plant growth was higher in all mulched treatments, either alone or in combination with other treatments, compared to non mulched ones. Among treatments, combined application of NaCl+PRM+ (PGPR mix I + rhizobium)+ salicylic acid resulted in a better plant height and number of leaves per plant at most of the growth stages whereas higher number of branches and leaf area index were noticed in NaCl+PRM+ (PGPR mix I + rhizobium)+zinc sulphate at 60 DAS.

All mulched treatments resulted in an increasing trend in root length to the tune of 29.7 to 60 per cent compared to absolute control. Among individual application of treatments, a higher root length on par with the mulched ones was noticed in seed treatment with PGPR mix I + rhizobium. Comparatively early flowering was observed in farmer's practice and in all mulched treatments.

Most of the mulched treatments recorded higher photosynthetic rate, transpiration rate and stomatal conductance compared to non mulched ones. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate recorded a higher photosynthetic rate at 60 DAS. Most of the mulched treatments resulted in a better relative leaf water content compared to non mulched ones and they were on par with each other and also with farmers practice at most of the stages. Among individual application of treatments, foliar spray of zinc sulphate resulted in higher relative leaf water content in almost all stages of crop growth. Moreover, most of the mulched treatments showed a higher nitrate reductase activity compared to non mulched ones at all stages of crop growth. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate maintained its superiority in having higher nitrate reductase activity at all stages (except at 15 DAS).

In general, most of the mulched treatments showed lower proline content compared to non mulched ones. Among individual application of treatments, foliar spray of zinc sulphate resulted in higher proline accumulation.

Most of the mulched treatments showed higher chlorophyll stability index compared to non mulched ones. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate and individual application of zinc sulphate recorded higher chlorophyll stability index among mulched and non mulched treatments respectively. All water stress mitigation treatments recorded a significantly higher chlorophyll content compared to absolute control. Among mulched treatments, NaCl+PRM recorded higher chlorophyll content at all stages.

Pod yield obtained from mulched treatments were higher than that from non mulched ones. Among treatments, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate recorded the highest pod yield and it was on par with all treatments in which mulching was included. Moreover, it was significantly superior to farmers practice, irrigation at 5 days interval, all individual application of treatments and absolute control. Among individually applied treatments, foliar spray of either zinc sulphate or salicylic acid recorded higher pod yield on par with farmers practice.

In general, as in the case of pod yield and yield attributes, the mulched treatments either alone or in combination with other treatments resulted in higher stover yield, significantly higher than that from the treatment irrigated at 5 days interval, all individual application of treatments and absolute control. Among treatments, the highest stover yield was obtained from NaCl+PRM+ (PGPR mix I + rhizobium)+ salicylic acid. Among individual application of treatments, stover yield recorded by foliar spray of zinc sulphate, seed treatment with PGPR mix I+

rhizobium, foliar spray of salicylic acid, foliar spray of (DAP+ KCl) and seed priming with NaCl were on par with farmers practice and irrigation at 5 days interval.

Among various treatments, NaCl+PRM+ (PGPR mix I + rhizobium)+salicylic acid, NaCl+PRM+ (PGPR mix I + rhizobium)+zinc sulphate and PRM alone recorded the highest dry matter accumulation significantly superior to farmers' practice, where as absolute control recorded the lowest.

The plants in treatments which received irrigation on alternate days (farmers practice) and at 5 days interval without any imposed water stress in between attained final maturity (65 days) earlier than the remaining treatments. Receipt of rainfall during later part of crop growth extended the crop duration by three weeks (85 days) in the remaining treatments including absolute control. The treatment combinations, NaCl+PRM+ (PGPR mix I+ rhizobium)+(DAP+KCl) and NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate recorded highest pod and stover protein content respectively.

Among mulched treatments, a higher uptake of all nutrients except boron by the crop was noted in NaCl+PRM+(PGPR mix I+ rhizobium)+ zinc sulphate. Among individual application of treatments, seed treatment with PGPR mix I + rhizobium recorded better uptake of all nutrients except sulphur.

A gradual decline in soil moisture was observed in all treatments (except in farmers practice and irrigation at 5 days interval) up to 30 DAS due to the imposition of water stress. However at 45 DAS, water stress release from these treatments resulted in an increase in soil moisture content and maintained more or less the same level at 60 DAS. A progressive increase in SMC was observed at 69 DAS due to the receipt of unexpected rainfall on the previous day, and it showed a slight decline at 75 DAS and at final harvest.

In general, income, net profit and B:C ratio were higher from treatments which involve mulching and the highest net profit and B:C ratio were recorded by the treatment NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate. However, mulching with plant residues (PRM) recorded a similar B:C ratio as that of NaCl+PRM+ (PGPR mix I+ rhizobium)+zinc sulphate, due to lesser cost involved and higher yield next to the above treatment. Among individual application of treatments, foliar spray of zinc sulphate recorded the highest income, net profit and B:C ratio. The highest field water use efficiency was recorded by NaCl+PRM+ (PGPR mix I+ rhizobium)+ zinc sulphate and the lowest by absolute control.

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APPENDICES

APPENDICES

Appendix I. Monthly weather data during the crop period during 2014 and 2015

Month	Maximum	Minimum	RH morning	RH evening	Rainfall	Total evaporation	Sunshine	Wind speed
2014								
January	32.9	23.0	66	36	0	171.3	277.6	6.9
February	34.7	22.9	75	37	0	145.0	240.8	4.5
March	36.7	24.2	76	34	0	191.5	264.2	3.9
2015								
January	32.5	22.1	75	41	0	135.4	271.5	5.6
February	34.3	23.0	73	37	0	157.4	246.7	5.8
March	35.8	24.9	83	44	77.6	151.6	248.6	3.3

Appendix II. Weekly weather data during the crop period during 2014 and 2015

Week	Maximum	Minimum	Mean RH	Rainfall	Total evaporation	Sunshine	Wind speed
2014							
1/1/2014 to	32.6	22.4	54	0	36.1	64.9	5.8
8/1/2014 to	32.8	23.1	53	0	35.8	56.7	6.3
15/1/2014to	33.2	23.7	50	0	37.6	61.4	5.8
22/1/2014to	32.5	23.3	51	0	44.5	65.4	8.8
29/1/2014 to	33.7	22 .3	47	0	43.3	69.2	7.8
5/2/2014 to	35.1	21	37	0	38.2	68.9	3.9
12/2/2014to	33.6	22.6	70	0	25.4	51.9	2.4
19/2/2014to	35.0	24.3	54	0	37.7	52.8	5.3
26/2/2014 to	35.2	24.6	60	0	37.4	61	3.9
5/3/2014to	35.1	25.1	54	0	41.6	50.4	4.9
12/3/2014to	37.4	22.7	42	0	53.9	67.8	5.2
19/3/2014to	37.3	24.7	65	0	38.2	59.6	2.7
26/3/2014 to	38.1	24.3	56	0	44.1	62.1	2.9
2015							
1/1/2015 to	32.5	21.5	68	0	21.7	55.8	2.7
8/1/2015 to	32.0	21.3	56	0	31.4	60.7	5.7

15/1/2015to 21/1/2015	32.4	22.1	54	0	31.6	63.1	5.9
22/1/2015to 28/1/2015	32.9	23.0	55	0	35.8	65.4	7.1
29/1/2015to 4/2/2015	32.9	23.7	53	0	42.0	64.7	8.6
5/2/2015 to 11/2/2015	33.6	23.2	52	0	41.4	58.1	7.5
12/2/2015to 18/2/2015	35.2	23.5	60	0	32.4	63.8	4.0
19/2/2015to 25/2/2015	35.0	22.2	48	0	42.7	67.3	5.1
26/2/2015 to 4/3/2015	34.6	23.6	68	0	30.4	47.2	3.0
5/3/2015 to 11/3/2015	35.4	24.5	63	0.4	34.1	57.5	3.3
12/3/2015to 18/3/2015	35.8	24.8	59	71.6	39.0	55.6	4.3
19/3/2015to 25/3/2015	35.8	25.1	68	0	31.5	58.6	2.8
26/3/2015 to 1/4/2015	36.6	25.9	63	5.6	33.3	54.8	3.0

Appendix III. Nutrient content in cowpea plants of first experiment

Trts.	Nutrient content (%)																			
	N		P		K		Ca		Mg		S		Fe		Mn		Zn		B	
	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod
CCC 10	0.76	2.9	0.2	0.42	3.4	1.9	0.88	0.06	0.27	0.13	0.06	0.05	0.06	0.02	0.14	0.01	0.005	0.006	0.002	0.001
CCC 20	0.71	3.1	0.17	0.46	3.1	1.7	0.82	0.08	0.26	0.11	0.06	0.04	0.07	0.01	0.17	0.02	0.008	0.004	0.002	0.001
SA 1 %	0.75	2.2	0.21	0.42	3.5	2.4	0.85	0.08	0.24	0.17	0.09	0.03	0.08	0.03	0.14	0.02	0.005	0.005	0.002	0.001
SA 2%	0.81	3.6	0.15	0.45	2.9	2.6	0.87	0.07	0.27	0.14	0.09	0.02	0.09	0.02	0.18	0.02	0.006	0.004	0.001	0.001
AA 1%	0.83	2.4	0.15	0.42	2.5	2.8	0.86	0.08	0.21	0.17	0.06	0.02	0.05	0.02	0.1	0.02	0.004	0.004	0.002	0.001
AA 2%	0.76	3.3	0.17	0.41	2.6	2.1	0.83	0.05	0.29	0.15	0.09	0.02	0.06	0.02	0.14	0.02	0.004	0.004	0.002	0.001
NAA 20	0.74	3.0	0.21	0.43	2.8	2.0	0.89	0.06	0.28	0.17	0.08	0.05	0.09	0.02	0.16	0.01	0.007	0.005	0.002	0.001
NAA 40	0.86	3.6	0.18	0.41	2.9	2.2	0.9	0.07	0.27	0.21	0.06	0.04	0.08	0.02	0.17	0.01	0.005	0.005	0.001	0.001
Br. 0.5	0.71	2.1	0.17	0.43	3.2	2.4	0.89	0.08	0.29	0.18	0.06	0.03	0.06	0.01	0.18	0.02	0.006	0.006	0.001	0.001
Br. 1	0.81	3.1	0.16	0.43	3.4	2.5	0.87	0.07	0.24	0.19	0.07	0.05	0.07	0.01	0.16	0.02	0.004	0.004	0.001	0.001
CW	0.76	2.9	0.16	0.4	2.7	2.5	0.89	0.07	0.29	0.18	0.06	0.02	0.05	0.01	0.14	0.01	0.005	0.004	0.001	0.001
WS	0.73	3.7	0.19	0.42	2.4	2.6	0.88	0.06	0.21	0.17	0.07	0.03	0.05	0.02	0.12	0.01	0.004	0.004	0.001	0.001
Control	0.81	3.5	0.18	0.41	2.4	2.5	0.88	0.06	0.25	0.19	0.07	0.06	0.07	0.01	0.18	0.02	0.005	0.005	0.001	0.001
FP	0.86	3.6	0.22	0.43	2.9	2.1	0.89	0.07	0.29	0.21	0.05	0.07	0.06	0.01	0.17	0.03	0.006	0.005	0.001	0.001
Abs. control	0.74	2.7	0.13	0.31	2.8	2.2	0.83	0.07	0.28	0.17	0.06	0.02	0.05	0.02	0.1	0.01	0.004	0.003	0.001	0.001

Appendix IV. Nutrient content in cowpea plants of second experiment

Treatments	Nutrient content (%)																			
	N		P		K		Ca		Mg		S		Fe		Mn		Zn		B	
	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod
$CaCl_2$	**0.88**	**2.10**	**0.14**	**0.34**	**2.62**	**1.90**	**0.86**	**0.05**	**0.28**	**0.13**	**0.07**	**0.05**	**0.12**	**0.02**	**0.16**	**0.01**	**0.003**	**0.006**	**0.001**	**0.001**
NaCl	**0.85**	**3.15**	**0.17**	**0.38**	**2.56**	**1.94**	**0.74**	**0.07**	**0.26**	**0.19**	**0.11**	**0.05**	**0.13**	**0.03**	**0.17**	**0.02**	**0.005**	**0.005**	**0.001**	**0.001**
KH_2PO_4	**0.70**	**2.98**	**0.11**	**0.36**	**2.66**	**1.99**	**0.65**	**0.05**	**0.21**	**0.18**	**0.07**	**0.03**	**0.12**	**0.02**	**0.15**	**0.02**	**0.003**	**0.006**	**0.001**	**0.001**
PM	**0.88**	**2.65**	**0.17**	**0.41**	**2.79**	**2.20**	**0.74**	**0.06**	**0.29**	**0.21**	**0.15**	**0.04**	**0.12**	**0.02**	**0.18**	**0.01**	**0.005**	**0.005**	**0.001**	**0.001**
PRM	**0.70**	**2.92**	**0.16**	**0.4**	**2.9**	**1.80**	**0.71**	**0.05**	**0.3**	**0.22**	**0.07**	**0.04**	**0.13**	**0.02**	**0.15**	**0.01**	**0.003**	**0.005**	**0.001**	**0.001**
Kaolin	**0.75**	**2.95**	**0.14**	**0.32**	**2.82**	**1.50**	**0.56**	**0.05**	**0.24**	**0.18**	**0.07**	**0.03**	**0.09**	**0.01**	**0.15**	**0.01**	**0.002**	**0.005**	**0.001**	**0.001**
LWS	**0.88**	**2.80**	**0.14**	**0.37**	**2.69**	**1.57**	**0.93**	**0.06**	**0.25**	**0.18**	**0.06**	**0.05**	**0.12**	**0.02**	**0.15**	**0.01**	**0.003**	**0.006**	**0.001**	**0.001**
Atrazine	**0.70**	**2.63**	**0.14**	**0.33**	**2.36**	**1.37**	**0.53**	**0.05**	**0.22**	**0.17**	**0.04**	**0.03**	**0.10**	**0.01**	**0.13**	**0.01**	**0.003**	**0.005**	**0.001**	**0.001**
Control	**0.85**	**2.95**	**0.20**	**0.41**	**2.72**	**2.07**	**0.73**	**0.06**	**0.28**	**0.2**	**0.14**	**0.06**	**0.13**	**0.03**	**0.17**	**0.02**	**0.005**	**0.007**	**0.001**	**0.001**
FP	**0.88**	**3.30**	**0.22**	**0.45**	**3.06**	**2.17**	**0.85**	**0.07**	**0.26**	**0.22**	**0.13**	**0.07**	**0.12**	**0.03**	**0.18**	**0.03**	**0.006**	**0.007**	**0.001**	**0.001**
Abs. control	**0.70**	**2.58**	**0.09**	**0.25**	**2.53**	**1.27**	**0.50**	**0.04**	**0.22**	**0.16**	**0.03**	**0.03**	**0.06**	**0.01**	**0.15**	**0.01**	**0.003**	**0.005**	**0.001**	**0.001**

Appendix V. Nutrient content in cowpea plants of third experiment

Treatments	Nutrient content (%)																			
	N		P		K		Ca		Mg		S		Fe		Mn		Zn		B	
	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod
FYM alone	**0.74**	**2.66**	**0.12**	**0.27**	**2.93**	**1.71**	**0.88**	**0.05**	**0.26**	**0.11**	**0.1**	**0.06**	**0.13**	**0.02**	**0.16**	**0.03**	**0.005**	**0.004**	**0.001**	**0.001**
PGPR mix+ Rhizobium	**0.87**	**3.76**	**0.16**	**0.28**	**3.33**	**2.11**	**0.87**	**0.06**	**0.27**	**0.15**	**0.12**	**0.08**	**0.14**	**0.02**	**0.17**	**0.02**	**0.006**	**0.004**	**0.001**	**0.001**
Pseudomonas	**0.69**	**3.58**	**0.12**	**0.27**	**3.28**	**2.17**	**0.87**	**0.07**	**0.25**	**0.12**	**0.06**	**0.08**	**0.14**	**0.02**	**0.16**	**0.01**	**0.006**	**0.004**	**0.001**	**0.001**
DAP	**0.71**	**2.3**	**0.12**	**0.23**	**3.03**	**1.71**	**0.83**	**0.06**	**0.27**	**0.12**	**0.11**	**0.07**	**0.13**	**0.02**	**0.14**	**0.01**	**0.006**	**0.005**	**0.001**	**0.001**
KCl	**0.77**	**3.23**	**0.12**	**0.28**	**2.93**	**1.81**	**0.89**	**0.05**	**0.26**	**0.17**	**0.08**	**0.08**	**0.08**	**0.01**	**0.18**	**0.02**	**0.009**	**0.005**	**0.001**	**0.001**
DAP+KCl	**0.84**	**3.88**	**0.18**	**0.28**	**3.13**	**1.98**	**0.88**	**0.08**	**0.26**	**0.14**	**0.09**	**0.06**	**0.11**	**0.03**	**0.17**	**0.03**	**0.008**	**0.004**	**0.001**	**0.001**
$ZnSO_4$	**0.69**	**3.71**	**0.17**	**0.29**	**2.90**	**1.61**	**0.90**	**0.08**	**0.25**	**0.12**	**0.11**	**0.09**	**0.14**	**0.03**	**0.18**	**0.02**	**0.010**	**0.009**	**0.001**	**0.001**
H_3BO_3	**0.74**	**3.54**	**0.11**	**0.20**	**1.93**	**1.78**	**0.83**	**0.07**	**0.25**	**0.15**	**0.06**	**0.05**	**0.11**	**0.01**	**0.12**	**0.01**	**0.006**	**0.005**	**0.01**	**0.001**
Combination*	**0.75**	**3.18**	**0.08**	**0.24**	**2.03**	**1.31**	**0.88**	**0.07**	**0.27**	**0.14**	**0.07**	**0.06**	**0.13**	**0.02**	**0.15**	**0.02**	**0.009**	**0.004**	**0.001**	**0.001**
Control	**0.74**	**3.79**	**0.19**	**0.38**	**3.23**	**1.88**	**0.85**	**0.06**	**0.24**	**0.16**	**0.07**	**0.07**	**0.13**	**0.01**	**0.16**	**0.02**	**0.004**	**0.004**	**0.001**	**0.001**
FP	**0.84**	**3.96**	**0.31**	**0.34**	**2.93**	**1.98**	**0.88**	**0.07**	**0.27**	**0.17**	**0.08**	**0.08**	**0.13**	**0.02**	**0.16**	**0.03**	**0.007**	**0.005**	**0.001**	**0.001**
Abs. control	**0.76**	**2.09**	**0.05**	**0.16**	**1.43**	**1.31**	**0.85**	**0.05**	**0.27**	**0.13**	**0.04**	**0.05**	**0.12**	**0.01**	**0.14**	**0.03**	**0.005**	**0.004**	**0.001**	**0.001**

* PGPR mix I with rhizobium (seed treatment) + Pseudomonas (soil drenching) +DAP+ KCl+ $ZnSO_4$ + Boric acid (foliar spray)

Appendix VI. Nutrient content in cowpea plants of second year experiment

Treatments	Nutrient content (%)																			
	N		P		K		Ca		Mg		S		Fe		Mn		Zn		B	
	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod	plant	pod
NaCl	**0.87**	**2.36**	**0.23**	**0.67**	**2.25**	**2.59**	**0.91**	**0.09**	**0.43**	**0.19**	**0.26**	**0.14**	**0.11**	**0.03**	**0.18**	**0.01**	**0.011**	**0.010**	**0.006**	**0.001**
PRM	**0.78**	**2.01**	**0.28**	**0.64**	**2.44**	**1.93**	**0.85**	**0.11**	**0.42**	**0.17**	**0.17**	**0.27**	**0.12**	**0.02**	**0.21**	**0.02**	**0.014**	**0.008**	**0.005**	**0.001**
PGPR	**0.87**	**2.36**	**0.31**	**0.59**	**2.51**	**2.27**	**0.88**	**0.11**	**0.39**	**0.23**	**0.19**	**0.18**	**0.13**	**0.04**	**0.18**	**0.02**	**0.011**	**0.009**	**0.007**	**0.001**
WS	**0.43**	**2.36**	**0.19**	**0.36**	**2.33**	**2.38**	**0.89**	**0.11**	**0.42**	**0.19**	**0.28**	**0.15**	**0.14**	**0.03**	**0.22**	**0.02**	**0.012**	**0.008**	**0.006**	**0.002**
SA	**0.78**	**2.97**	**0.32**	**0.25**	**2.50**	**2.13**	**0.89**	**0.16**	**0.37**	**0.23**	**0.27**	**0.14**	**0.10**	**0.03**	**0.14**	**0.02**	**0.009**	**0.008**	**0.005**	**0.001**
DAP+KCl	**0.96**	**2.53**	**0.28**	**0.55**	**2.27**	**2.27**	**0.86**	**0.08**	**0.45**	**0.21**	**0.34**	**0.22**	**0.11**	**0.03**	**0.18**	**0.02**	**0.009**	**0.008**	**0.005**	**0.002**
$ZnSO_4$	**0.78**	**2.01**	**0.21**	**0.36**	**1.87**	**1.92**	**0.92**	**0.09**	**0.44**	**0.23**	**0.25**	**0.09**	**0.14**	**0.03**	**0.20**	**0.01**	**0.013**	**0.009**	**0.006**	**0.001**
LWS	**1.05**	**2.53**	**0.24**	**0.34**	**2.25**	**2.13**	**0.93**	**0.11**	**0.43**	**0.27**	**0.37**	**0.22**	**0.13**	**0.03**	**0.21**	**0.01**	**0.011**	**0.009**	**0.007**	**0.001**
NaCl+PRM	**0.70**	**2.18**	**0.22**	**0.51**	**1.91**	**1.81**	**0.92**	**0.11**	**0.45**	**0.24**	**0.23**	**0.08**	**0.11**	**0.02**	**0.22**	**0.02**	**0.012**	**0.010**	**0.006**	**0.001**
NaCl+PRM+ PGPR	**0.61**	**2.01**	**0.36**	**0.35**	**2.19**	**1.98**	**0.89**	**0.11**	**0.39**	**0.25**	**0.19**	**0.13**	**0.12**	**0.02**	**0.20**	**0.02**	**0.009**	**0.008**	**0.007**	**0.002**
NaCl+PRM+ PGPR+WS	**1.05**	**2.01**	**0.29**	**0.39**	**1.96**	**2.46**	**0.92**	**0.10**	**0.44**	**0.24**	**0.21**	**0.16**	**0.10**	**0.02**	**0.18**	**0.01**	**0.011**	**0.008**	**0.005**	**0.002**
NaCl+PRM+ PGPR+SA	**0.70**	**2.53**	**0.34**	**0.61**	**1.92**	**1.71**	**0.91**	**0.09**	**0.37**	**0.23**	**0.18**	**0.13**	**0.10**	**0.03**	**0.16**	**0.01**	**0.009**	**0.008**	**0.007**	**0.001**
NaCl+PRM+ PGPR+DAP+KCl	**0.87**	**2.53**	**0.28**	**0.31**	**1.83**	**2.11**	**0.91**	**0.09**	**0.41**	**0.25**	**0.33**	**0.09**	**0.12**	**0.02**	**0.22**	**0.02**	**0.011**	**0.009**	**0.006**	**0.002**
NaCl+PRM+ PGPR+$ZnSO_4$	**0.61**	**2.18**	**0.29**	**0.51**	**2.27**	**2.66**	**0.92**	**0.11**	**0.45**	**0.27**	**0.19**	**0.21**	**0.11**	**0.02**	**0.21**	**0.03**	**0.011**	**0.009**	**0.005**	**0.001**
NaCl+PRM+ PGPR+LWS	**0.87**	**2.71**	**0.31**	**0.35**	**2.05**	**2.84**	**0.86**	**0.10**	**0.44**	**0.23**	**0.29**	**0.21**	**0.10**	**0.03**	**0.14**	**0.01**	**0.009**	**0.007**	**0.007**	**0.002**
Abs.control	**0.78**	**2.18**	**0.17**	**0.57**	**1.73**	**2.85**	**0.88**	**0.09**	**0.41**	**0.27**	**0.26**	**0.19**	**0.09**	**0.02**	**0.19**	**0.02**	**0.011**	**0.005**	**0.006**	**0.002**
Control	**0.96**	**3.06**	**0.41**	**0.58**	**1.77**	**2.24**	**0.87**	**0.09**	**0.45**	**0.25**	**0.31**	**0.21**	**0.12**	**0.04**	**0.21**	**0.03**	**0.015**	**0.009**	**0.007**	**0.001**
FP	**0.52**	**2.53**	**0.48**	**0.78**	**1.75**	**2.43**	**0.86**	**0.09**	**0.44**	**0.22**	**0.23**	**0.18**	**0.13**	**0.03**	**0.18**	**0.01**	**0.013**	**0.008**	**0.006**	**0.001**

Appendix VII. Details of cost of inputs

Manures and fertilizers	**Quantity /ha**	**Cost (Rs./ha)**
FYM	20t	17,600@880/t
Factomphos	150kg	2250 @15/kg
MOP	17kg	200.60 @11.8/kg
Seed	15kg	9000@600/kg
CCC (Lihocin) 10ppm	5ml	5@98/100ml
CCC (Lihocin) 20ppm	10ml	10@98/100ml
Salicylic acid 1%	5kg	4700@470/500g
Salicylic 6acid 2%	10kg	9400@470/500g
Ascorbic acid 1%	5kg	67500@1350/100g
Ascorbic acid 2%	10kg	135000@1350/100g
NAA 20ppm	10g	76@191/25g
NAA 40ppm	20g	153@191/25g
Brassinolide (Double) 0.5ppm	0.25ml	1.125@225/50ml
Brassinolide (Double) 1ppm	0.5ml	2.25@225/50ml
$CaCl_2$	100g	62.40@312/500g
NaCl	25g	8.70@174/500g
KH_2PO_4	50g	60@600/500g
Atrazine	0.2kg	72.5@181/500g
$Ca(OH)_2$	100g	41.80@209/500g
Kaolin	100g	61.60@308/500g
Plastic mulch	10,000m^2	83,333.30@4000/480m^2
FYM (for 3rd experiment alone)	8t	7040 @880/t
PGPR Mix I	1.5kg	105@70/kg
Rhizobium	1.5kg	105@70/kg
Pseudomonas	5.5kg	385@70/kg
DAP	30kg	720@24/kg
KCl	15kg	4170@139/500g
$ZnSO_4$	5kg	3360@336/500g
H_3BO_3	2kg	3288@822/500g
PP chemicals	-	1000

Appendix VIII. Number of irrigations given in various treatments

Treatments	Number of irrigations
First experiment	
CCC 10	14
CCC 20	14
SA 1 %	14
SA 2%	14
AA 1%	14
AA 2%	14
NAA 20	14
NAA 40	14
Br. 0.5	14
Br. 1	14
CW	14
WS	14
Control (irrigation at 5 days interval)	18
FP	38
Abs. control	14
Second experiment	
$CaCl_2$	11
NaCl	11
KH_2PO_4	11
PM	11
PRM	11
Kaolin	14
LWS	14
Atrazine	14
Control (irrigation at 5 days interval)	18
FP	38
Abs. control	14
Third experiment	
FYM alone	14
PGPR mix+ Rhizobium	14
Pseudomonas	14
DAP	14
KCl	14
DAP+KCl	14
$ZnSO_4$	14
H_3BO_3	14
Combination	14
Control (irrigation at 5 days interval)	18
FP	38
Abs.control	14
Second year experiment	
NaCl	17
PRM	17
PGPR	17
WS	17

SA	17
DAP+KCl	17
$ZnSO_4$	17
LWS	17
NaCl+PRM	17
NaCl+PRM+PGPR	17
NaCl+PRM+PGPR+WS	17
NaCl+PRM+PGPR+SA	17
NaCl+PRM+PGPR+DAP+KCl	17
NaCl+PRM+PGPR+$ZnSO_4$	17
NaCl+PRM+PGPR+LWS	17
Absolute control	17
Control (irrigation at 5 days interval)	16
FP	33

Appendix IX. Details of cost of cultivation

Particulars	NaCl	PRM	PGPR	WS	SA	DAP +KCl	$ZnSO_4$	LWS	N+P	N*+P**+ P***	N+P+P+ WS	N+P+P+SA	N+P+P+D+K	N+P+P+Zn	N+P+P+ LWS	Abs. control	Control	FP
A. Field Operations																		
Ploughing &levelling	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**
Applying manures and fertilizers	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**
Seed treatment of PGPR mix I +	-	-	**600**	-	-	-	-	-	-	**600**	**600**	**600**	**600**	**600**	**600**	-	-	-
Dibbling seeds (10W@	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**
Collection& spreading plant	-	**3000**	-	-	-	-	-	-	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	-	-	-
Spraying (2M@Rs.500/M)	-	-	-	**1000**	**1000**	**1000**	**1000**	**1000**	-	-	**1000**	**1000**	**1000**	**1000**	**1000**	-	-	-
Spraying PP chemicals	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**
Weeding	**1500**	-	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	-	-	-	-	-	-	-	**1500**	**3000**	**3000**
Irrigation(2M/	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**17000**	**16000**	**33000**
Harvesting	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**	**2400**	**3000**
B. Inputs																		
FYM(20t @Rs.880/t)	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**	**17600**
Factomphos (150kg@	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**	**2250**

MOP(17kg	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.60**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**	**200.6**
Seeds(15kg	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**	**9000**
NaCl (200g @Rs.348/kg)	**8.70**	-	-	-	-	-	-	-	**8.70**	**8.70**	**8.70**	**8.70**	**8.70**	**8.70**	**8.70**	-	-	-
PGPR Mix I (5.25 kg @70/kg)	-	-	**52.5**	-	-	-	-	-	-	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	-	-	-
Rhizobium (5.25kg @70/kg)	-	-	**52.5**	-	-	-	-	-	-	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	-	-	-
DAP (20kg @24/kg)	-	-	-	-	-	**240**	-	-	-	-	-	-	**240**	-	-	-	-	-
KCl (10kg @278/kg)	-	-	-	-	-	**1390**	-	-	-	-	-	-	**1390**	-	-	-	-	-
Zinc sulphate (5kg @672/kg)	-	-	-	-	-	-	**1680**	-	-	-	-	-	-	**1680**	-	-	-	-
SA 2 (20 kg @940/kg)	-	-	-	-	**9400**	-	-	-	-	-	-	**9400**	-	-	-	-	-	-
$Ca(OH)_2$(200g@ Rs.418/kg)	-	-	-	-	-	-	-	**41.8**	-	-	-	-	-	-	**41.8**	-	-	-
PP chemicals	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**

*NaCl, **PRM, ***PGPR, W@- women, M#- men

AGROTECHNIQUES FOR MITIGATING WATER STRESS IN VEGETABLE COWPEA (*Vigna unguiculata* (L.) Walp.)

By

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ABSTRACT OF THE THESIS

submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
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2016

ABSTRACT

Water stress is one of the major abiotic stresses that limits crop production. Vegetable cowpea is an important non season bound crop in Kerala and water scarcity limits its area under cultivation during summer season. Research reports indicate that water stress in crop plants can be mitigated by foliar spray of plant growth regulators, seed hardening, mulching, antitranspirant sprays and nutrient management. However, research works in this line in Kerala are meagre. Hence a study was taken up to develop a package for mitigating water stress in summer vegetable cowpea by assessing the effect of above practices on the growth and yield of the crop.

Field experiments were conducted during the summer season (Jan-Mar) of 2014 and 2015, using the variety *Kashi Kanchan*. There were three experiments during the first year to evaluate the effect of (1) exogenous application of plant growth regulators (PGRs), (2) seed priming, antitranspirant sprays and soil moisture conservation practices, and (3) nutrient management practices for mitigating water stress in vegetable cowpea. The best treatments from each of the first year experiments were selected and their effects independently and in combinations were evaluated in an experiment during the second year of study.

The first experiment was done to evaluate the effect of various plant growth regulators in mitigating water stress in vegetable cowpea. Among the treatments, farmers practice (irrigation at 2 days interval) recorded the highest growth and yield and absolute control the lowest. Among plant growth regulators, salicylic acid 2 per cent and NAA 40 ppm recorded higher growth and yield by way of their favourable influence on mitigating water stress.

The second experiment was conducted to evaluate the effect of seed priming, mulching, and antitranspirant sprays in mitigating water stress. The results showed that, among seed primers, seed hardening with 0.5 per cent NaCl recorded better growth and yield of cowpea compared to that with 2 per cent $CaCl_2$ and 1 per cent KH_2PO_4 due to the comparatively better efficacy of sodium

chloride in equipping the cowpea plants for drought tolerance. Mulching with polythene and plant residues were equally effective in recording better plant growth and yield due to their favourable influence on soil moisture availability. Among antitranspirants, foliar spray of lime water as 2 per cent $Ca(OH)_2$ during the water stress imposed period resulted in better growth and yield of cowpea plants due to increased albedo.

The third experiment was conducted to evaluate the effect of various nutrient management practices in mitigating water stress. The results revealed that among nutrient management practices, foliar spray of 2 per cent DAP+1 per cent KCl, 0.5 per cent $ZnSO_4$ and seed treatment with PGPR mix I + rhizobium were better in attaining higher growth and yield under water stress.

In the second year, the best treatments from each of the first year experiments were selected and their independent and combinations were evaluated. In general, plant growth was higher in all mulched treatments, either alone or in combination with other treatments, compared to non mulched ones. The treatment combination, NaCl+PRM+ (PGPR mix I + rhizobium)+ zinc sulphate recorded the highest growth, yield income, net profit (Rs.2,03,389/-) and B:C ratio (4.1) which was even higher than farmers practice. Plant residue mulching alone also recorded higher yield and B:C ratio than farmers practice which showed the significant influence of mulching in mitigating water stress. Among the independent treatments, foliar spray of either zinc sulphate or salicylic acid was found better compared to others in terms of growth and yield of vegetable cowpea.

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