EFFECT OF SEED HARDENING ON ESTABLISHMENT, GROWTH AND PRODUCTIVITY OF SEMI-DRY RICE

By

K. MOHANASARIDA

THESIS

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Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that the thesis entitled **"Effect of seed hardening on establishment, growth and productivity of semi-dry rice"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara **K. Mohanasarida**

(99-11-51)

CERTIFICATE

Certified that this thesis entitled **"Effect of seed hardening on establishment, growth and productivity of semi-dry rice"** is a record of research work done independently by **Ms. K. Mohanasarida**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellanikkara

Dr. Jose Mathew
Major Advisor, Advisory Committee
Associate Professor,
Department of Agronomy
College of Horticulture
Vellanikkara

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Ms. K. Mohanasarida**, a candidate for the degree of **Master of Science in Agriculture** with major field in Agronomy, agree that the thesis entitled **"Effect of seed hardening on establishment, growth and productivity of semi-dry rice"** may be submitted by **Ms.K. Mohanasarida**, in partial fulfilment of the requirement for the degree.

9/8/02
Dr. Jose mathew
Major Advisor, Advisory Committee,
Associate Professor,
Department of Agronomy,
College of Horticulture,
Vellanikkara

09/8/02
Dr. C. T. Abraham
Member, Advisory committee,
Associate Professor and Head,
Department of Agronomy,
College of Horticulture,
Vellanikkara

9/8/2002
Dr. U. Jaikumaran
Member, Advisory committee,
Associate Professor and Head,
Agricultural Research Station,
Mannuthy,
Thrissur

9/8/02
Dr.T. Girija
Member, Advisory committee
Assitant Professor
Department of Agronomy
College of Horticulture,
Vellanikkara

EXTERNAL EXAMINER

9/8/2002
(S. D. SUNDAR SINGH)
PROF OF AGRONOMY
DEPT OF AGRONOMY
TNAU
COIMBATORE

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MOHANASARIDA. K

Dedicated

to my

Parents and Parents in Law

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LIST OF ABBREVIATIONS

@	- at the rate of
°C	- Degree Celsius
ARS	- Agricultural Research Station
ATS	- Active tillering stage
DAS	- Days after sowing
DMP	- Dry matter production
FYM	- Farmyard manure
Fig.	- Figure
FS	- Flowering stage
g	- gram
ha	- hectare
HI	- Harvest index
K	- Potassium
kg	- kilogram
kg ha^{-1}	- kilogram per hectare
LAI	- Leaf area index
LAD	- Leaf area duration
m	- meter
mm	- millimeter
m^2	- square meter
%	- per cent
N	- Nitrogen
P	- Phosphorus
PIS	- Panicle initiation stage
ppm	- parts per million
RH	- Relative humidity
RLWC	- Relative leaf water content
t	- tonnes

Introduction

1. INTRODUCTION

Rice, the most important food crop of India, is grown under different ecosystems in our country in tune with the different agro-climatic and edaphic resources of the locality and the socio-economic status of the farmers. However, the most important single factor that is responsible for the adoption of a specific system of rice culture in a locality is the water.

Rice culture can be broadly classified as rainfed and irrigated depending on the source of water it receives. Out of the 42.7 M ha of land under rice in India, 50 per cent of the area under rice is irrigated and the remaining rainfed. This is almost true in the case of Kerala also wherein 48.4 per cent of the rice area is irrigated (FIB, 2001).

The scope for bringing more area under irrigated rice is rather limited due to increasing water scarcity and prohibitive costs of irrigation projects. Hence one of the major options to step up rice production in our country is to maximize the yield levels in the diverse rainfed ecosystem. The high yield technology, designed exclusively for risk free irrigated condition, has so far bypassed the ecologically fragile rainfed environment. The situation warrants increased research efforts in the rainfed ecosystem to realize increased yields.

Moisture stress of varying degree, due to inadequate and erratic rainfall, is the major factor limiting rice productivity in rainfed situation. In Kerala, more than 60 per cent of the area under rice during *kharif* season is established through dry seeding in lowlands, known as dry seeded lowland or semi-dry rice, which is completely rainfed. The semi-dry rice involves the growing of rice just like an upland crop upto the 3-4 leaf stage and thereafter bringing it under submergence with the onset of south- west monsoon.

Though the system successfully exploits the pre-monsoon showers, the crop is often confronted with moisture stress due to inadequate and ill distributed rainfall. Receipt of sufficient rains during the early stages from sowing up to the onset of regular monsoon for a period of around six weeks is a very critical factor influencing the productivity of semi-dry rice. The non-receipt of adequate quantity of rains and consequent moisture stress adversely affects the germination, emergence and seedling vigour leading to yield reduction of varying degree. Several reports suggest that incidence of stress in early stage of rice, even at low magnitude, can cause a permanent strain to the crop and so management practices that can improve the tolerance of the crop to drought and improve the vigour of the crop to overcome the effect of abiotic stress is to be developed to realize increased yields from semi-dry rice. Pre-sowing hardening of seeds (also called seed priming) with water, nutrient solutions or growth regulating compounds are found to be effective in many rainfed crops to induce early germination and promote vigourous growth of seedlings as well as to overcome the adverse effect of moisture stress.

The present study entitled "Effect of seed hardening on establishment, growth and productivity of semi-dry rice" was taken up in this background with the following main objectives:

- To study the effect of seed hardening treatments on germination, emergence, establishment and early vigour of semi-dry rice.

- To assess the impact of seed hardening treatments on moisture stress tolerance in the early stages of semi-dry rice.
- To investigate the effect of treatments on growth and yield attributes of crop.
- To work out the economics of the treatments.

Review of Literature

2. REVIEW OF LITERATURE

In India, with nearly 60 per cent of rice area exposed to rainfed ecology and in lieu of the limited scope for bringing more area under irrigated rice, the scientists and policy makers have been prompted alike to shift the research and development emphasis from irrigated to rainfed environment (Siddiq, 1990). Moreover, the increased contribution to the rice pool from the rainfed areas created a new impetus in rainfed research. A critical factor limiting the productivity of rainfed rice is the occurrence of moisture stress at different growth stages. An attempt is made in the chapter to review the studies related to the occurrence of drought, its effect on crop performance and the management strategies.

2.1 Effect of drought on rice plant

Direct seeded low land rice eco-system in many rice growing areas is characterized by moisture stress in most of the growth phases. It suffers from initial drought after sowing until the receipt of sufficient rains. It may also occasionally experience moisture stress at different growth phases due to the intermittent failure of rains.

2.1.1 Seed germination and seedling vigour

Tanaki (1991) reported inhibition in the germination of rice seeds by decrease in water potential of the medium. Drought resistance at the seedling stage did not necessarily correlate with that at older stages of development. But, this initial resistance improved the vigour of the plant and enabled the plant to pass through the moisture stress period without much morphological abnormalities.

2.1.2 Growth and growth characters

Senewiratne and Mikkelsen (1961) reported that rice plants under unflooded culture, made an initial vigorous start but soon showed poor tillering and depressed growth of leaves as compared to the flooded plants. According to Narayanasamy (1985), drought at tillering period retarded plant height.

Soil moisture stress at the vegetative stage of rice caused a decrease in tiller number, leaf area index, photosynthetic rate and plant dry matter leading to permanent stress and increased the ratio of shoot to root dry mass (Cruz and O'Toole, 1984).

Turner *et al.* (1986) recorded reduced plant height, relative growth rate and daily rate of leaf expansion due to moisture stress during the pre-flowering stage of rice. Ramakrishnayya and Murty (1991) reported from studies on fifty rice varieties that imposition of soil moisture stress caused reduction in plant height and tiller number and further relief of stress caused an increase in tiller number.

From the above results, it was evident that soil moisture stress adversely affects the growth characters viz., plant height, tiller number and leaf area.

2.1.3 Root characteristics

According to Levitt (1972), deep rooted plants showed greater drought avoidance than shallow rooted ones if ground water was available.

Sharma *et al.* (1975) concluded that decreased soil water from flooding to field capacity reduced the root and shoot dry weight in rice.

Yoshida and Hasengawa (1982) opined that a deep, wide spreading and much branched root system could exploit water from deeper layers and might been essential feature for drought tolerance.

2.1.4 Yield and yield attributes

Chaudhry and Mclean (1963) found that the most striking effects of moisture stress in rice were delayed flowering and high spikelet sterility resulting in significant reduction in yield. Sahu and Rao (1974) observed that moisture stress during the vegetative phase of rice caused reduction in grain yield to the extent of 26 per cent. He also observed that stress during reproductive phase delayed heading by a week and reduced the length of panicle and number of grains panicle^{-1}.

Occurrence of moisture stress at the panicle initiation stage of rice caused reduction in yield, whereas stress at the dough stage had no effect on yield (Singh and Misra, 1974). Soil moisture stress reduced the number of spikelets panicle^{-1} and ripe grain percentage resulting in yield reduction up to 49.3 per cent in rice (Lee *et al.*, 1985).

Rahman and Yoshida (1985) observed that panicle exertion showed an inhibitory effect due to water stress under moisture stress conditions. Sudhakar *et al.* (1989) reported that moisture stress during tillering stage resulted in significant reduction in panicle number, while stress during panicle development and ripening reduced the percentage of filled grains in rice.

Fussel *et al.* (1991) reported that grain yield in rice was reduced by 45 to 49 per cent under stress, mainly due to reduction in grain yield per panicle rather than reduction in panicle number. Lenka and Garnayak (1991) found that grain sterility is directly related to stress during flowering to panicle ripening and prolonged stress during the initial stages increased the crop duration.

Ramakrishnayya and Murty (1991) observed that tillers produced till the end of drought were mostly productive and contributed to yield whereas those developed during recovery phase had no influence on yield. Stress at tillering induced irreparable loss in total biomass but the grain yield reduced more due to water deficit at booting stage (Ram *et al.*, 1985).

2.1.5 Physiological parameters

2.1.5.1 Water relations in plant

Ishihara and Saito (1983) observed that at water potentials less than –2 bar, the photosynthetic rate decreased in rice and reached almost zero at –12 bar. The relative water content (RWC) in leaves of field grown rice ranged from 88 to 96 per cent under saturated conditions as compared to 80 to 86 per cent under stress conditions (Nayak *et al.*, 1983). Water deficit had no effect on midday water potential in rice (IRRI, 1989).

Studies by Agarwal *et al.* (1990) revealed that the upland variety Azucena maintained high leaf water potential throughout the stress period as compared to the low land type IR 36. Jing and Ma (1991) revealed that when the leaf water potential values were higher than –1.20 MPa, the water use efficiency of upland rice was lower than Maize.

Ramakrishnayya and Murty (1991) reported that with increase in soil moisture stress, there was decrease in RWC and water potential of leaf. They also reported that the cultivar, which maintained high RWC and positive turgor, had optimum photosynthesis and solute accumulation, inspite of reduced leaf water potential during stress.

2.1.5.2 Chlorophyll content

Jayapal (1971) could not obtain any correlation between drought and chlorophyll content of rice and he pointed out that chlorophyll synthesis was a varietal character and was not very much altered by drought conditions.

From studies conducted at CRRI, Cuttack, Sudhakar *et al.* (1989) reported that the rice cultivars which exhibited the highest drought resistance, had maximum chlorophyll content and yield when stress was imposed at three stages of growth viz., tillering, panicle initiation and ripening.

Stuhlfauth *et al.* (1990) found that in stressed plants in which the leaf water potential fell from 0.70 to 2.50 MPa, the contents of chlorophyll 'a' and 'b' on leaf area basis were not significantly altered. This indicated that the photosynthetic apparatus remained basically intact under moisture stress condition.

2.1.6 Nutrient uptake

Chaudhry and Mclean (1963) revealed that N content in all plant parts of rice was higher under unflooded conditions whereas P and Mn contents were lesser, compared to submerged conditions. The concentration of P, Fe and Mn was higher under submerged conditions than under upland conditions (Gangawar and Mann, 1972 and Padhihar and Dikshit, 1985).

Increased uptake of N and P due to submergence was reported by Yoshida and Patre (1975). Moisture stress affected the bio-chemical pathway to a larger extent (Singh *et al.*, 1976). They also reported that a limited water supply caused a reduction in nitrogen and phosphorus contents of rice. Increased uptake of K by rice under submergence was observed by Jha *et al.* (1978) and Pillai and De (1980).

Patil and Ghildyal (1983) found that maximum absorption of nutrients (N, P, K, Mn and Zn) was with submergence compared to unsaturated conditions. Das and Mandal (1986) also reported increased uptake of P, Fe, Mn and Zn by roots, straw and grains by plants grown under water logged conditions than under unsaturated conditions.

Tanguilig *et al.* (1987) reported decline in total N, P and K uptake by both root and shoot, nine days after the imposition of drought as compared to control. Ichwantorai *et al.* (1989) found that uptake of N by rice was more sensitive to drought than other nutrients.

2.2 Methods for overcoming drought in rice

As early as in 1934, Henkel and Kolotova suggested seed hardening technique as a means to improve the drought tolerance of plants. Graft *et al.* (1949) reported that excessive water loss could be prevented by seed hardening. The physiological induction as a cause of seed conditioning towards increased drought resistance in crops was reported by Henkel (1961).

Line seeding at deeper depth (5-7 cm) and application of FYM and fertilizers on lines mitigate early drought in rice cv. Heera at Phubbani (AICARP, 1995).

Soil mulch, spray of urea or phenyl mercuric acetate 250 cc ha^{-1} at initial drought stress and 5 cm depth of water did not produce any significant grain yield increase to terminal drought (AICARP, 1995).

The irrigation interval could be prolonged to a week or a fortnight upto 60 DAS in rice cv. ADT 36 because of seed hardening with mepiquat chloride 125 ppm (Asokaraja, 1998). He further reported that foliar spray of KCl 0.5 per cent at 45 and 60 DAS had significant favourable influence to mitigate the stress in the early vegetative phases of semi-dry rice.

2.3 Seed hardening for drought tolerance

Seed hardening is a process of subjecting seeds before sowing to alternate cycle of wetting and drying to induce tolerance to drought.

Under upland condition moisture stress occurring at any stage of rice may adversely affect the growth and yield. Tailoring the plants to withstand moisture stress by seed hardening was reported to be effective under such conditions. Seed hardening is a low cost method to induce drought tolerance and improve dry land farming. Plethora of information are available on the beneficial effect of seed hardening for inducing drought resistance in plants.

Hafeex (1969) reported that drymatter and leaf area were higher in plants emerged from hardened seeds with water for 12 h.

Seed pre-treatment in its simple form is to allow the seeds to take up water and subsequently dry them back near to their original moisture content, a process which may be repeated a number of times (Heydeker and Coolbear, 1977). The same process has been termed as 'pre-sowing drought hardening' (May *et al.*, 1962 and Henckel, 1964).

Devika (1983) observed that seed treatment with water for 48 h increased panicle number, thousand grain weight and grain yield of rice varieties raised during the first crop season at Onattukara, Kerala.

2.3.1 Mechanism of seed hardening

Pre-sowing hardening of seeds is found to bring about some physiological and biochemical changes. Increased viscosity of protoplasm, high rate of photosynthesis and low rate of respiration were exhibited by hardened plants (May and Milthrope, 1962). Henckel (1964) observed that higher photosynthetic rate in hardened plants especially during drought, more often during slight water deficits, resulted in more active accumulation of dry matter and more active growth.

During hardening process, a number of physio-chemical changes occur modifying the protoplasmic characters and increasing the physiological activity of the embryo and associated structure. Eventually, this results in the absorption of more water due to increase in the elasticity of cell wall and development of a stronger and efficient root system (Urs *et al.*, 1970).

Berrie and Drennan (1971) found that the pre-treated seeds had higher protease activity and germinated faster after wetting and drying treatment.

Azospirillum inoculation has been reported to significantly increase the growth and yield of vegetable crops not only because of atmospheric nitrogen fixation, but also due to the production of growth promoting and antifungal substances, which accelerate the physiological processes like synthesis of carbohydrates (Chattoo *et al.*, 1997). Similar results are reported by other workers on different crops (Balakrishnan, 1988; Kumaraswamy and Madalageri, 1990 and Kalyani *et al.*, 1992).

Seed biofortification with Azospitrillum (10g/kg of seeds) increased the amylase activity during germination and secretion of gibberellins by the bacterium may be the reason for this increase and subsequent hydrolysis, resulting in enhanced seedling vigour encompassing speed of germination, seedling length and dry weight (Ramamoorthy *et al.*, 2000).

2.3.2 Methods of seed hardening

Seed hardening treatment or 'P.A.Genkels method' of pre-sowing seed treatment imparts increased drought resistance in crop plants. Pre-sowing soaking of crop seeds in water or solutions of growth regulating compounds to induce early germination, establishment, better root and shoot growth and to enhance yield of crop varieties has been employed by many workers.

Such pre-treatment confer drought resistance on the ensuing plants (Henckel *et al.*, 1968 and Henckel, 1970).

Different workers have recommended different duration of sowing. However, Heydeker and Coolbear (1977) concluded that the amount of water taken up in a seed pre-treatment must be carefully controlled so that germination does not proceed beyond the first phase. This may be achieved by limiting either the inhibition time or the quantity of water made available to the seed.

Mathew (1989) obtained significant increase in plant height, leaf area and tiller production of rice by pre-sowing seed hardening with 100 ppm succinic acid. Paul *et al.* (1995) noted that soaking toria seeds for 10 h resulted in significantly higher seed germination than 6 h soaking. Seed hardening followed by foliar spray with 1.0 per cent KCl followed by 0.1 per cent succinic acid and 3.0 per cent kaolin at vegetative and reproductive stages increased the yield of rice cv. PKM 1 up to 44.5 per cent (Vaithilingam and Rajaram, 1995). Soaking wheat seeds for more than 12 h did not increase germination further, and beyond 21 h germination was markedly decreased (Ahmad *et al.*, 1998).

2.3.2.1 Water soaking

Domanskii (1959) observed high degree of tolerance to drought subsequent to seed hardening with water particularly at the seedling stage of barley.

Grain yield and yield parameter values were generally greatest with soaking the rice seeds in water for 24 h, followed by soaking in water for 12 h (Suresh *et al.*, 2000).

2.3.2.2 Nutrient soaking

Rao *et al.* (1985) reported increased yield when paddy seeds were treated with one per cent KCl. The favourable influence of seed hardening with one per cent KCl solution in increasing thousand grain weight and grain yield of rice was reported by Chockalingam (1986).

Priming the rice seeds with four per cent KCl and KH_2PO_4 generally gave the highest germination percentage and rate, vigour index and seed yield (Borgohain and Phukon, 1994). Germination, tillering, plant height, root length, dry matter production and yield of ragi were favourably influenced by hardening with salts like sodium chloride and zinc sulphate (Karivaratharaju and Ramakrishnan, 1985).

2.3.2.3 Fungicide and insecticide seed treatment

Ramadas and Sivaprakasam (1989) reported that seeds treated with carbendazim had the highest germination rate in cowpea, when compared to untreated control.

Seed treatment with bavistin + diathane M-45 and bavistin + thiram were significantly superior to other fungicides in increasing the germination and seedling vigour of rice (Sachan and Agarwal, 1994).

Bavistin and bavistin + thiram (100 ppm) used as seed dressers, improved germinability, plant stand and grain yield as compared with dry seed in maize (Kardikeri *et al.*, 1995).

Haesaert *et al.* (1998) noted that maize seeds hardened with imidacloprid increased yield by more than 10 per cent.

2.3.2.4 Biofertilizer seed inoculation

Auxin, gibberellin and cytokinin production have been reported with *Azospirillum* inoculation and it is still a matter of investigation whether the stimulation of plant growth may be due to nitrogen fixation or to the biologically active substances produced by them (Morgenstern and Okon, 1987). Cacciari *et al.* (1989) clearly established the production of gibberellins and cytokinins by *Azospirillim*. As a consequence, *Azospirillim* inoculated roots had larger proportion of younger roots and seminal root elongation, resulting in increased size and number of root hairs (Kapulnik *et al*, 1985). In addition, the bacterium had some affinity to root hairs and colonises them efficiently (Murthy and Ladha, 1987) to cause an improvement in mineral and water uptake by the inoculated plant in the early growth stages of rice.

Azospirillum inoculation has been reported to significantly increase the growth, yield, nutrient uptake, dry matter and vitamin C contents in cabbage, cauliflower, tomato and chilli (Balakrishnan, 1988; Subbiah, 1990 and Kalyani *et al.*, 1992).

Nirmaladevi *et al.* (1995) indicated that the seed treatment with *Azospirillum* enhanced the seedling vigour of chillies. *Azospirillum lipoferum* seed treatment improved seedling vigour and plant height in rice (Jayabal and Kuppuswamy, 1998).

Ramamoorthy *et al.* (2000) suggested that seed biofortification with one per cent *Azospirillum* increased amylase activity, speed of germination, seedling length and seedling dry weight in low and high vigour seeds.

2.3.2.5 Seed pelleting

Sorghum seeds hardened with aqueous solutions of botanicals such as *Albizzia amara* and *Pongamia glabra* performed significantly better than control. The synergistic effect of leaf powder pelleting is due to presence of saponins and GA_3 in traces and micronutrients, especially zinc. These biocontents might have synergistically interacted with aminoacids especially tryptophan to form indole acetic acid in the germinating seeds to bring about enhancement in seedling growth (Jagathambal, 1996).

According to Patil and Dighe (1983), coating cotton seed with any form of indigenous materials such as ash and cow dung or their combination did not result in better seed germination.

According to Joseph and Nair (1989), seed hardening of rice with 10 per cent cow dung extract registered its superiority in earliness, germination, root and shoot growth and vigour index.

2.3.3 Effect on germination and establishment

Seed hardening accelerates germination rate of seedlings. Hardened seeds withstands highest temperature for prolonged period without loss of viability. Seedlings are also able to compete efficiently with weeds as they emerge early.

Rice seeds, when soaked in water for 24 h followed by drying at 40 to 42°C, resulted in production of vigorous seedlings and such seedlings in pot culture studies were shown to exhibit lower water requirement. In subsequent field trials during summer, these seedlings survived better after wilting and transpired less (Parija and Pillai, 1945).

Henckel (1964) observed that the dehydration of seeds after soaking conferred high drought resistance and did not interfere with germination, growth and yield. All these parameters decreased when untreated plant were subjected to soil moisture stress during the growing period.

Mehrotra *et al.* (1967) reported that when rice seeds were subjected to soaking in KH_2PO_4 solutions of different concentrations for eighteen hours, the initial germination was retarded but the total germination at the end of seven days was not affected.

Increased seedling vigour in ragi on soaking in water for 24 h and shade drying was reported by Rajasekhar *et al.* (1970). Similar result was observed in respect of seedling vigour in paddy raised from hardened seeds (Urs *et al.*, 1970).

Rice seeds soaked for 48 h in one per cent sodium hypochloride enhanced the germination as well as the rate of elongation of plumule and radicle (Singh and Tomar, 1972).

The germinability and vigour of upland rice seedlings in the early stages could be enhanced by seed hardening (Basu *et al.*, 1974).

A decrease in the number of days needed for germination was reported in barley (Singh *et al.*, 1975) when hardened seeds were used.

Basu (1977) reported that asimple 'soaking and drying method' was enough for the maintenance of vigour and viability of seeds in a number of field and vegetable crops. When seeds were imbibed, dried and then reimbibed, they take less time to germinate than untreated seeds (Vincent and Cavers, 1978).

Singh and Chatterjee (1981) suggested that best stand of upland rice could be obtained by treating rice seeds with water. Similar results were reported by Chatterjee (1982).

On the contrary, Narayanasamy (1985) obtained no effect on seed germination and crop stand by hardening rice seeds.

Bhati and Rathore (1986) observed that seed treatment with potassium dihydrogen phosphate enhanced germination of wheat seeds by reducing the days of emergence and increased the number of seedlings per unit area. Dry matter accumulation and seedling height of wheat were also increased.

In pot culture experiment using rice seeds treated with 0.1 per cent zinc sulphate solution for 4 h showed marked increase in zinc content in seeds, germination percentage and growth (Gukova *et al.*, 1986).

Germination and seedling vigour of hardened paddy seeds were studied by Joseph and Nair (1989) and observed that cow dung extract treatment was significantly superior in inducing earliness in germination followed by water soaking.

Mathew (1989) concluded that seed hardening with two per cent KH_2PO_4 induced earliness and uniformity in germination and produced vigorous and healthy seedlings.

Shanmugasundaram and Kannaiyan (1989) observed that when *Pennisetum typhoides* seeds were soaked in 1.0 per cent sodium chloride, the highest percentage of germination, root: shoot ratio, and vigour index was obtained.

Kuppusamy *et al.* (1992) noted that germination of green gram was lowest when pelleted with 50 per cent slurry + 5 per cent KCl (76.8%) and highest in seeds pelleted with 50 per cent slurry (98.4%).

Paul and Choudhury (1993) observed that wheat cv. Sonalika seeds soaked in 0.5, 1.0 or 2.0 per cent concentration of potassium chloride or potassium dihydrogen phosphate for 18 h registered more germination, shoot and root length and seedling vigour. Seed hardening had little effect on germination of sorghum, but germination of cotton was increased by hardening (Nirmala *et al.*, 1994).

Seeds subjected to a pre-inhibition treatment had significantly better germination rates, vigour and chilling resistance compared with the control (She *et al.*, 1994). Enhanced germination, root length and shoot length due to storage of cowpea seeds pelleted with KH_2PO_4 was obtained by Sujatha (1994).

Vaid *et al.* (1994) pointed out that treatment with carbendazim at the rate of 2 g/kg seed was the best seed dressing treatment for improving germinability of discoloured rice.

Sunflower seeds inoculated with *Azospirillum brasilense* strain SFA-3 gave the highest germination percentage of 93.3 per cent. Seedling height and vigour index were also increased by treatments with *Azospirillum* with strain TT-2 giving the best result (Stalin *et al.*, 1995).

The seed treatment with 0.1 per cent *Azospirillum* induced higher germination and seedling vigour (Nirmaladevi *et al.*, 1995).

Seeds of ragi hardened with KCl one per cent followed by pelleting with pungam leaf powder at the rate of 60 g kg^{-1} seed recorded higher germination and seedling vigour over control (Palanisamy and Punithavathi, 1998).

Lee *et al.* (1999) reported that primed seeds showed 7.5 per cent more germination than non-primed seeds.

Andoh and Kobata (2000) observed that hardening treatments with shorter soaking times increased germination and coleoptile length in some cultivars of rice.

The review showed that earliness in germination and vigour of seedlings in early stages of rice and other crops could be significantly improved by seed hardening with suitable chemicals. Seed hardening also helped the seedlings to withstand moisture stress during the growth period.

2.3.4 Effect on growth and growth characters

Several reports suggested that crops raised with seeds subjected to pre-sowing seed hardening performed significantly better in stress situations and produced higher yields as compared to crops raised from unhardened seeds by imparting a positive effect on the various growth components.

Seed hardening produced remarkable increase in growth components like tiller number, plant height, length and width of leaves, girth of stem and root length in ragi (Dawson, 1965 and Rajasekhar *et al.*, 1970).

Growth characters like plant height and tiller number were little influenced by soaking paddy seeds in KH_2PO_4 solution of five to twenty five per cent concentration (Mehrotra *et al.*, 1967).

Increase in plant height and tiller number in rice by seed hardening with water was reported by Singh and Chatterjee (1981). Similar result was also reported by Narayanasamy (1985).

Pre-sowing seed hardening in water for 48 h had no effect on plant height of rice, but showed increased tiller production, LAI and dry weight (Devika, 1983).

Chockalingam (1986) observed that seed treatment had no influence on plant height and tiller number in kharif season, whereas during summer season seed treatment with one per cent KCl recorded profound increase in plant height.

Sheela and Alexander (1995) reported that seedling emergence, seedling vigour and grain yield were highest when rice seeds were hardened with 2.5 per cent KCl for 18 h. Salakinkop *et al.* (1998) reported that seed treatment with KCl recorded higher dry matter production at all crop growth stages in dry sown rice than untreated treatments due to better shoot vigour.

Though few studies reported little response to seed hardening in respect of growth characters, most of them revealed the favourable influence of seed hardening on plant height, leaf area and tiller production.

2.3.5 Effect on root characteristics

Rice crop established from seeds treated with water had greater root mass when compared with untreated control (Singh and Chatterjee, 1981).

Pre-sowing seed treatment of paddy with water or suitable chemicals improved deep roots and root:shoot ratio of plants (Chatterjee, 1982).

Chockalingam (1986) reported increased root length in summer rice by pre-sowing seed hardening with one per cent KCl.

According to Joseph and Nair (1989), seed hardening of rice with 10 per cent cow dung extract registered its superiority in root growth.

Azospirillum seed treatment increased the root prolifiration, root volume and its weight (Parvatham *et al.*, 1989).

Shanmugasundaram and Kannaiyan (1989) reported that when wheat seed was soaked in 1.0 per cent sodium chloride, it improved root:shoot ratio.

Paul and Choudhury (1993) observed that wheat seeds soaked in 0.5, 1.0 or 2.0 per cent concentrations of potassium chloride or potassium dihydrogen phosphate solutions for 18 h registered more root length. Seed treatment with *Azospirillum* had greater root development when compared with untreated control (Chattoo *et al.*, 1997).

Seed hardening with water and KCl was found to induce stress tolerance in rainfed rice by way of better root growth (Sheela *et al.*, 1998).

2.3.6 Effect on yield and yield attributes

Pre-sowing hardening of rice seeds induced drought resistance and increased the grain yield significantly (Henckel and Kolotova, 1934; Parija, 1943 and Urs *et al.*, 1970).

Zubenko (1959) observed 40 per cent increase in total above ground growth and 32 per cent increase in grain yield from maize soaked in water for 24 h and dried in two stages.

According to Mehrotra *et al.* (1967), soaking paddy seeds in KH_2PO_4 solution, increased number of grains per panicle, grain yield and straw yield.

Krishnasastry *et al.* (1969) observed that pre-sowing seed hardening in ragi resulted in early germination, vigorous seedling production and increased yield. Seed hardening recorded a higher ear weight and increased mean yield of ragi (Rajasekhar *et al.*, 1970, 1971). He also noted that the hardened seeds showed better response to fertilizers.

Urs *et al.* (1970) stated that pre-sowing hardening of rice seeds in water increased yield under normal conditions. Similar result was also reported by Borthakur *et al.* (1973) when KH_2PO_4 solution was used for hardening.

Pre-sowing treatments with 0.05 per cent $ZnSO_4$ led to improved yields of maize compared with pre-soaking in distilled water both under normal and water stress condition (El-Kadi *et al.*, 1975).

Experiments conducted at Aduthurai, Tamil Nadu revealed that pre-sowing soaking of rice seeds in water and subsequent soaking in KH_2PO_4 solution resulted in an yield increase of 626 kg ha^{-1} (Directorate of Agriculture, Tamil Nadu, 1978).

Rice yield was increased by pre-sowing seed hardening with one per cent KCl (Kalaimani *et al.*, 1979).

Pre-sowing seed soaking in water for ten hours increased rice yields (Rajagopalan *et al.*, 1979).

Ramanathan (1980) stated that hardening of rice seed with four per cent KH_2PO_4 increased grain yield by 13 per cent and straw yield by 14 per cent over control. Peeran and Natanasabapathy (1980) obtained highest rice yield when the seeds were treated with one per cent KCl.

Singh and Chatterjee (1980) reported 14 to 26 per cent higher rice yields when upland rice was raised after pre-sowing seed hardening with water. Seed hardening with water treatment (over-night) gave 20 per cent yield increase in rice over untreated control (Chatterjee, 1982).

Kundu and Biswas (1985) obtained significant increase in panicle number and yield of direct seeded rainfed rice by seed hardening. They observed that seed hardening with sodium chloride was better than simple hydration, though ten per cent yield increase was obtained by simple hydration of seeds.

Chockalingam (1986) reported the favourable influence of seed hardening with one per cent KCl solution in increasing the 1000 grain weight and grain yield of rice.

Soaking maize seeds in 0.02 per cent zinc sulphate solution for 12 h hastened development and increased number of grains per ear and 100 grain weight (Guo *et al.*, 1992).

Sheela (1993) observed an yield increase of 24 per cent with 2.5 per cent KCl treatment due to increased panicle number, panicle weight, increased number of filled grains and thousand grain weight. Priming rice seeds with four per cent KCl solution for 24 h significantly increased the upland rice yield due to more number of tillers and grains per panicle (Thakuria and Sarma, 1995).

Kardikeri *et al.* (1995) stated that seeds treated with KH_2PO_4 and carbendazim + thiram (1 g each per kg of seed) increased grain yield of maize compared with dry seeds.

Chattoo *et al.* (1997) reported that *Azospirillum* inoculants might have played a vital role in increasing yield and yield related attributes of Knol-Khol. Similar findings were also reported by other workers (Balakrishnan, 1988 and Kumaraswamy and Madalageri, 1990).

Seed treatment with mepiquat chloride 125 ppm with foliar spray of KCl 0.5 per cent has recorded higher grain yields of semi-dry rice (Asokaraja, 1998).

Treating rice seeds with biodigested slurry, zinc sulphate and *Azospirillum lipoferum* produced the highest mean yield of 6 t ha^{-1}, which was 8.8 per cent higher than the control (Jayabal and Kuppuswamy, 1998).

Seed hardening with water and KCl recorded 23 to 26 per cent higher grain yield of rice (Sheela *et al.*, 1998). Seed hardening with potassium salt improved water economy, water use efficiency and yield of direct seeded upland rice (Pathak *et al.*, 1999).

Rathinavel *et al.* (2000) observed that yield and yield components of cotton were generally higher with arappu + micronutrients + *Azospirillum* seed treatment.

Yilmaz *et al.* (2000) reported that $ZnSO_4$ seed treatment increased grain yield of cereals.

Rice seeds hardened with $ZnSO_4$ (2.8g $ZnSO_4$ kg^{-1} seed) increased the dry matter, tissue Zn concentration and grain yield than soil applied Zn (Slaton *et al.*, 2001).

2.3.7 Effect on nutrient uptake

Pre-sowing seed hardening with 1.0 per cent KH_2PO_4 solution for 12 h favourably influenced plant growth, nutrient uptake, 1000 seed weight and seed yield of rainfed sorghum (Chinnaveeraju, 1970).

Pacovsky *et al.* (1985) stated that pre-sowing seed soaking with *Azospirillum* slurry increased the uptake of nitrogen and potassium.

Azospirillum seed treatment increased the root proliferation, root volume and weight and there by facilitated higher uptake of all nutrients by increasing root surface area (Parvatham *et al.*, 1989). Increase in growth attributes with *Azospirillum* seed treatment could be because of the secretion of certain growth promoting substances by the *Azospirillum* inoculants, which in turn, might have led to better root development, better transportation of water and uptake of nutrients, as observed by Chattoo *et al.* (1997).

Sheela *et al.* (1998) reported that seed hardening with water and KCl was found to induce stress tolerance in rainfed rice by way of better root growth and consequent absorption of more nutrients and water.

Jayabal and Kuppuswamy (1999) stated that seeds of rice coated with biodigested slurry (S), S + *Azospirillum* (A), S + A + Phosphobacteria (B) and S + A + B + Zinc sulphate had varying effect on nutrient uptake.

2.3.8 Effect on chlorophyll content

Fletcher and Hofstra (1990) reported a striking increase in the synthesis of chlorophyll of fresh leaves of wheat raised after uniconzole in combination with KCl seed treatment. The treatment increased the chlorophyll content more than twice that of the control.

Pre-sowing seed hardening with water for 24 h, KCl for 18 h and cattle manure treatment for 24 h increased chlorophyll content (Sheela and Alexander, 1995).

Seed treatment with one per cent KCl substantially increased the chlorophyll content (4.45 mg/g), net photosynthetic rate (27.3 μmol CO^{-2} m^{-2} Se^{-1}) and photosynthetic efficiency (0.65%) of the semi dry rice. It also increased yield significantly compared with other treatments (Venkataraman *et al.*, 2000).

2.3.9 Effect on leaf water content

Singh and Chatterjee (1981) observed that the leaves of rice plants raised from treated seeds had significantly lower water saturation deficit than the leaves of plants raised from untreated seeds. Biswas *et al.* (1982) and Nayak *et al.* (1983) reported that seed treatment with $CaCl_2$ helped to maintain better leaf water potential in rice under moisture stress conditions.

Sheela (1993) observed that relative water content and proline accumulation were favourably influenced by seed hardening in rice.

Seed hardening with four per cent KCl significantly increased plant moisture content and leaf nitrate reductase activity and simultaneously reduced the proline content in direct seeded rice (Sarma *et al.*, 1995).

Sheela and Alexander (1995) claimed that pre-sowing seed hardening with water for 24 h, 2.5 per cent KCl for 18 h and cattle manure for 24 h increased water and proline content of rice while stomatal index and frequency were reduced.

2.3.10 Effect on pest and disease incidence

Seed treatment with bavistin and bavistin + thiram were found more effective in reducing the seed borne inoculum in rice as compared to other fungicides (Schan and Agarwal, 1994 and Agarwal and Singh, 1973).

Rao and Panwar (1996) claimed that seed treatment with imidacloprid, a synthetic insecticide, at higher concentration (10 g kg^{-1}), significantly reduced dead heart formation in maize. Imidacloprid seed treatment is widely used on sorghum to control a number of pests. Wilde *et al.* (1999) found that imidacloprid seed treatment increase the yield of sorghum in the absence of observable pest activity.

2.3.11 Economics

The enhancement in grain and straw yields by hardening of seed with succinic acid and KH_2PO_4 resulted in higher net income and benefit:cost ratio

(Mathew, 1989). Sheela et al. (1998) observed higher net income and benefit:cost ratio in semi-dry rice through seed hardening with water and KCl treatments.

Materials and Methods

3. MATERIALS AND METHODS

The objective of the present investigation was to assess the effect of seed hardening on establishment, growth and productivity of semi-dry rice under moisture stress situations. The details of the materials used and methods adopted for the study are presented in this chapter. The study consisted of a field trial and a laboratory experiment.

3.1 Location

The field trial was conducted in the wetland of the Agricultural Research Station, Mannuthy, Thrissur.

The station is situated at 10°31' N latitude, 76°13' E longitude and at an altitude of 40.3 m above mean sea level. It is located six kilometers away from Thrissur city on the southern side of Thrissur-Palakkad National Highway.

3.1.1 Soil

The soil of the experimental site was sandy clay loam, belonging to the taxonomical order oxisol. The soil was acidic in reaction with a pH at 4.6.

The pre-experiment physio-chemical properties of the soil are presented in Table 1.

3.1.2 Climate

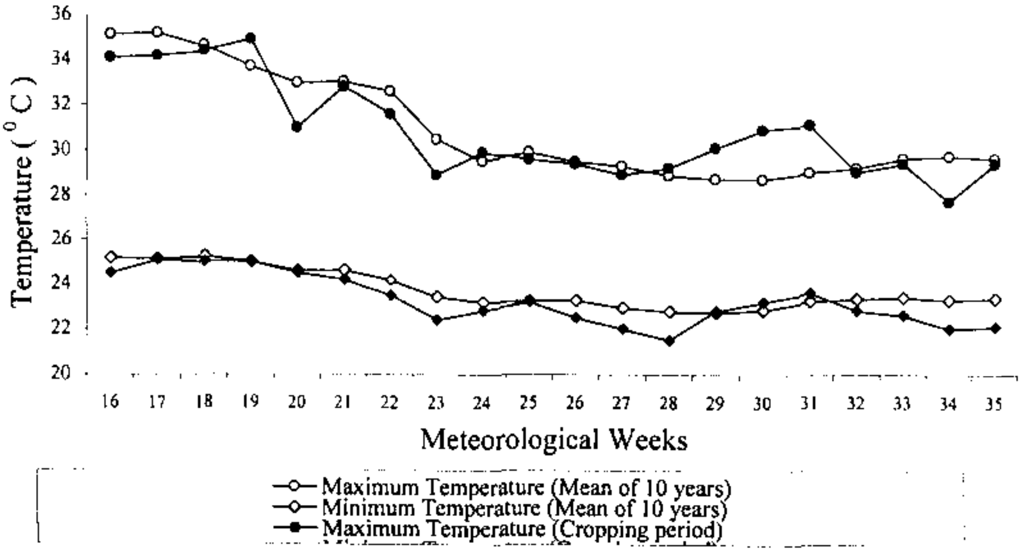
The area of the experimental site enjoys a humid tropical climate. The mean weekly average of the important weather parameters observed during the cropping period and the previous ten years are given in Appendix I and II and graphically presented in Fig. 1.1 and 1.2.

Table 1. Initial physio-chemical characteristics of the soil of the experimental site

Parameter	Value	Method used
a) Mechanical composition		Hydrometer method (Piper, 1966)
Sand (%)	75.9	
Silt (%)	4.4	
Clay (%)	18.4	
b) Physical composition		
Field capacity (0.3 bars)	19.68	
Permanent wilting point (15 bars)	11.32	
Bulk density g cc^{-1}	1.33	
Water holding capacity (%)	49.1	
b) Chemical composition		
Organic carbon (%)	0.66	Walkley and Black method (Jackson, 1958)
Available N (kg ha^{-1})	257.6	Alkaline permanganate distillation (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	11.4	Bray I extractant - Ascorbic acid reductant method (Watenabe and Olsen, 1965)
Available K (kg ha^{-1})	98.8	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)

Fig. 1.1. Average weekly weather data during the cropping period as compared to the mean of 10 years (1990 to 1999)

Maximum and minimum Temperature



Morning and Afternoon Relative humidity

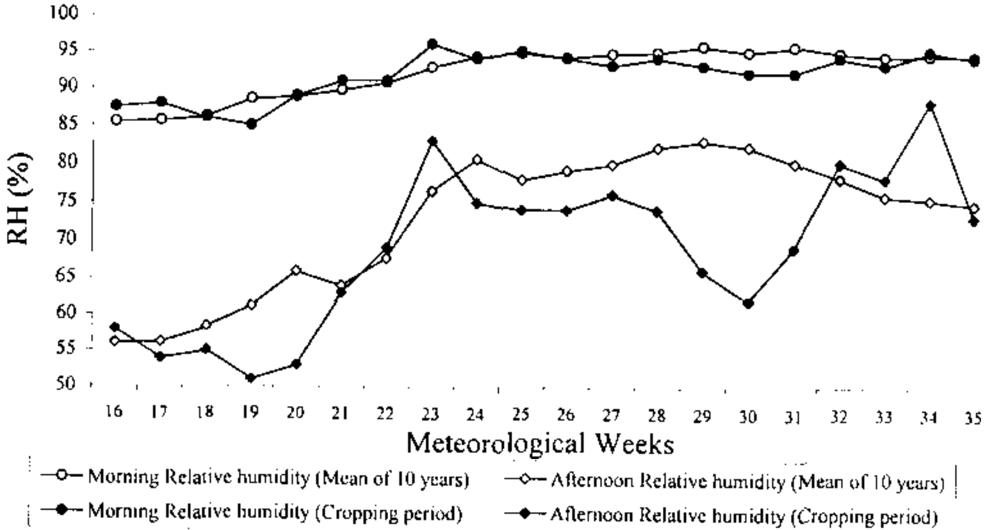
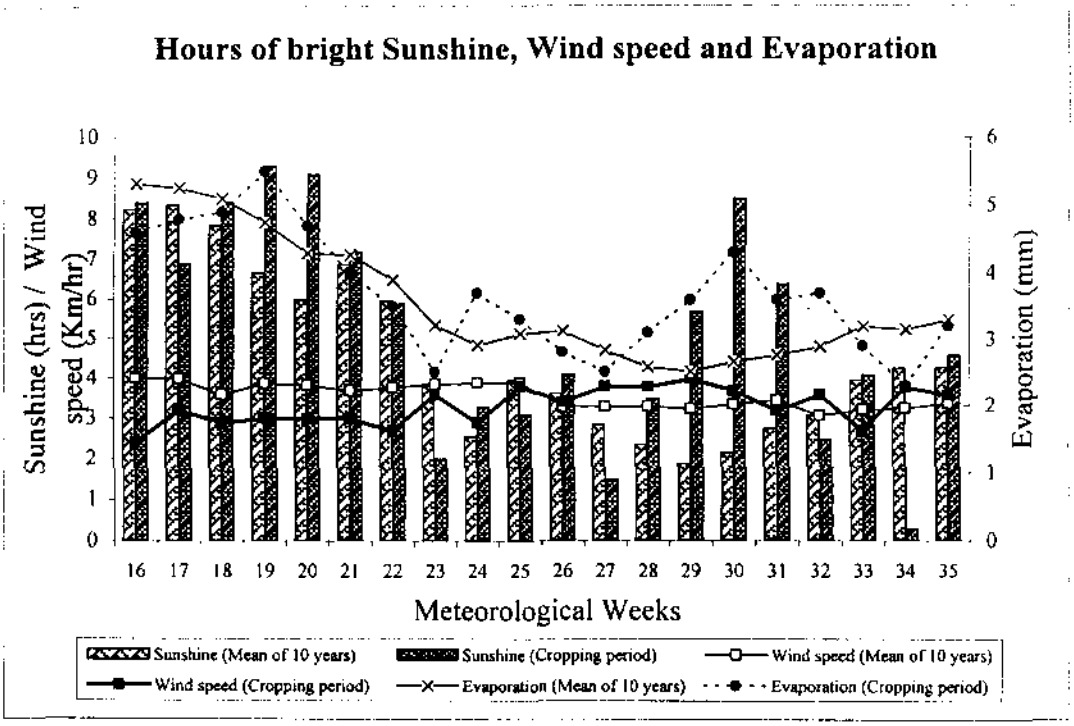
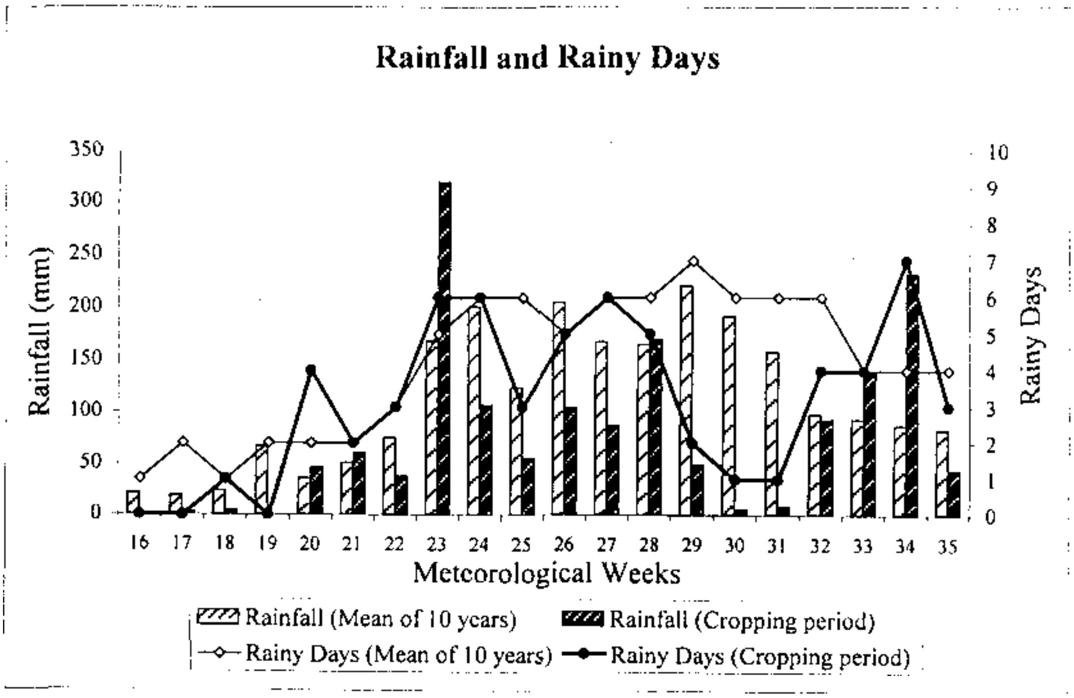


Fig. 1.2. Average weekly weather data during the cropping period as compared to the mean of 10 years (1990 to 1999)





Comparison of weather parameters during the experimental period and that during the previous 10 years indicated that the experimental period was a normal one. However there was slight variation in respect of different weather parameters.

In respect of the amount of rainfall and the number of rainy days, it was observed that almost the same pattern was followed during the experimental period as compared to the average data. However during the initial period (16th to 22nd week), the amount of rainfall and the number of rainy days were found to be very less during the cropping period, leading to severe moisture stress. This indicate that the weather parameters during cropping period was congenial for the study in terms of the manifestation of the treatment effects.

In the beginning of the cropping period (17th to 18th week) the maximum temperature was less than that of the previous 10 years, and afterwards it was fluctuating upto 22nd week. The minimum temperature during the cropping period and that of the previous 10 years were more or less similar during the early weeks.

During the cropping period, there was decrease in sunshine hours during the initial weeks compared to the mean of 10 years. A sudden increase was observed afterwards for the next three weeks.

3.1.3 Season

The field trial was conducted during the early virippu season from April to August 2000.

The laboratory study was conducted simultaneously.

3.2 Material used

3.2.1 Seeds

Genetically and physically pure seeds of paddy cv. Jyothi obtained from the Agricultural Research Station, Mannuthy, formed the basic material for the study. Jyothi is a variety suitable for direct seeding during virippu (Kharif) season, having a duration of 110-125 days. The grains are red, long and bold. The variety is tolerant to BPH and susceptable to sheath blight and capable of producing moderately good yields under stress conditions.

3.2.2 Cropping history of the experimental site

The field trial was conducted in a double cropped wetland Bulk crop of rice was raised in the previous season in the experimental field.

3.2.3 Treatments

The experiment consisted of 13 treatments, constituted by seed hardening with water or with aqueous solutions/slurries containing salts/fertilizers (KCl, NaCl, KH_2PO_4, zinc sulphate and Single Super Phosphate (SSP), plant protection chemicals (Carbendazim and imidacloprid), biofertilizer (*Azospirillum*), botanical extract (*Pongamia glabra*) or organic manures (wood ash and cow dung) or some of their combinations and an absolute control. The details of the treatments are furnished below:

T_1 - Control (Dry seed)

T_2 - Water for 24 hours

T_3 - KCl (2% solution) for 18 hours

T_3 - NaCl (0.5% solution) for 18 hours

T_5 - KH_2PO_4 (2% solution) for 18 hours

T_6 - $ZnSO_4$ (1% solution) for 18 hours

T_7 - Carbendazim (0.2% solution) for 24 hours

T_8 - Imidacloprid (0.05% solution) for 24 hours

T_9 - Cow dung slurry (10%) for 24 hours

T_{10} - Cow dung - wood ash slurry (10% each) for 24 hours

T_{11} - Cow dung - SSP slurry (10% and 1%) for 24 hours

T_{12} - *Azospirillum* slurry (2%) for 24 hours

T_{13} - 1% Aqueous leaf extract of *ungu* (*Pongamia glabra*) for 24 hours

Random samples of the hardened seeds from each treatment, used for field experiment, were used for the laboratory experiment. So the laboratory study also involved the same treatments as that of the field experiment.

3.2.4 Seed hardening

The seed was immersed in seed hardening solution/ slurry at the rate of one kg of seed per litre of solution/slurry for 18 to 24 hours depending upon the treatment. The seed was then drained and dried in shade to the original weight. The hardened seeds were immediately used for sowing.

3.2.5 Design and layout

Design	- Randomised Block Design
Treatments	- 13
Replications	- 3
Plot size	
Gross	- 5.0 x 4.0 m
Net	- 4.4 x 3.6 m
Spacing	- 15 x 10 cm

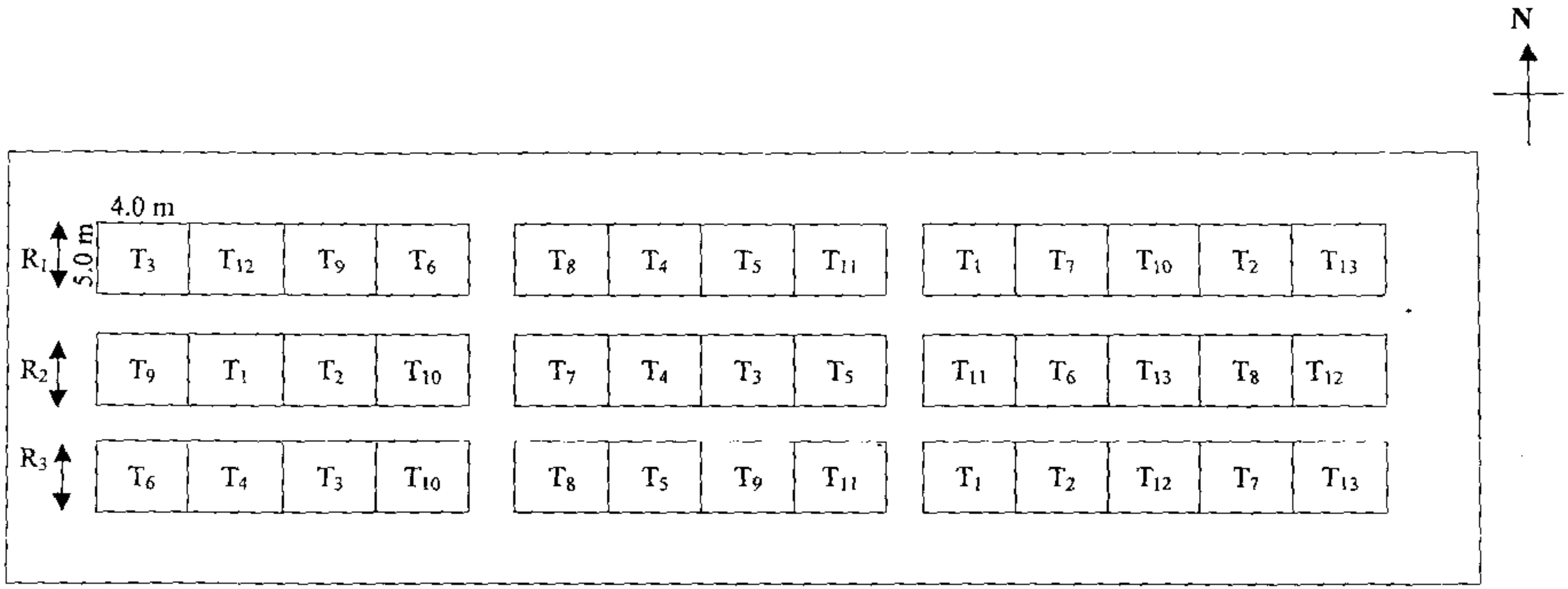


Fig. 2. Layout of the experiment

Plate 1. General views of the experimental field

a. Active tillering stage

b. Harvest stage

The layout plan is given in Fig.2 and the general views of the experimental field at active tillering and harvest stages are presented in Plates 1(a) and 1(b).

The laboratory experiment was conducted in Completely Randomized Design with three replications.

3.3 Laboratory experiment

The laboratory study consisting of the germination test was conducted with 2 x 25 mature and well-developed seeds from each treatment in paper medium (ISTA, 1993) by roll towel method and kept in vertical position in tray containing water (Plate 2). The germination paper was always kept moist.

3.3.1 Observations

Observation on germination and growth characters were recorded on 5, 10 and 15 days after keeping the seeds for germination.

3.3.1.1 Germination percentage

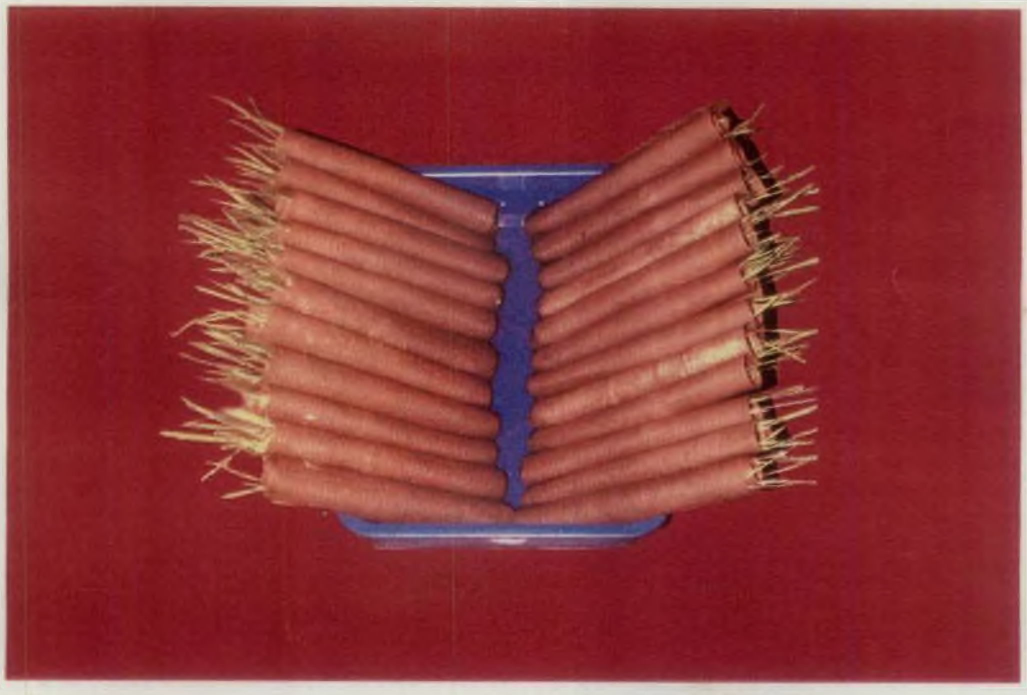
The number of normal seedlings were counted on the days of observation and the germination per cent was calculated and expressed in whole number.

3.3.1.2 Speed of germination

From the mean per cent germination recorded on each day of observation, speed of germination was calculated employing the formula suggested by Maguire (1962).

$$\text{Speed of germination} = \frac{X_1}{Y_1} + \frac{X_2 - X_1}{Y_2} \;\ldots\ldots\; + \frac{X_n - X_{(n-1)}}{Y_n}$$

Plate 2. Laboratory study – Roll towel paper method



Where

X_n - Per cent germination on nth day

Y_n - Number of days from sowing to nth count

3.3.1.3 Shoot length

Ten normal seedlings taken at random were used for shoot measurement. The length from the collar region to the tip of the plumule was measured and the mean value expressed in cm.

3.3.1.4 Root length

The seedlings taken for shoot measurement were used for measuring the root length also. It was measured from the collar region to the tip of primary root and the mean value expressed in cm.

3.3.1.5 Dry weight of seedlings

Ten seedlings used for growth measurements were dried in a hot air oven at 80°C to a constant weight, weighed and expressed as mg per seedling.

3.3.1.6 Vigour index

Vigour index was computed adopting the procedure of Baki and Anderson (1973) and expressed as whole number.

Vigour index = Germination percentage x (Total seedling length)

3.4 Field experiment

3.4.1 Sowing and harvesting

Date of sowing - 25-04-2000

Date of harvesting - 27-08-2000

Duration of the crop (days) - 124

3.4.2 Cultivation operations

3.4.2.1 Land preparation

The experimental area was ploughed thoroughly under moist condition, levelled and laid out as per the design. Initial soil samples were taken for analysis. The individual plots were perfectly levelled before sowing.

3.4.2.2 Sowing

Sowing was done in finely prepared soil by dibbling. The soil moisture was optimum at the time of sowing with the receipt of pre-monsoon showers.

3.4.2.3 Weeding

Butachlor @ 1.5 kg a.i ha^{-1} was applied as pre-emergent spray on the 8th day after sowing followed by hand weeding at 30 and 50 days after sowing.

3.4.2.4 Manures and fertilizer

FYM @ 5 t ha^{-1} was applied uniformly to plots and incorporated by digging before sowing.

Urea (46% N), mussorie rock phosphate (20% P_2O_5) and muriate of potash (60% K_2O) were the fertilizers used for the experiment.

Fertilizers were applied uniformly to all the plots at the rate of 70:35:35 kg N, P_2O_5 and K_2O ha^{-1}. The entire quantity of P, 2/3 N and ½ K were applied as basal and the remaining quantity of N and K were applied as top dressing at panicle initiation stage (KAU, 1996).

3.4.2.5 Plant protection

Dimecron 85 per cent EC at the rate of 250 ml ha^{-1} was sprayed against gall midge and stem borer 55 days after sowing. During the flowering stage, methyl parathion @ 500 ml ha^{-1} was sprayed to control rice bug. For the control of sheath blight and sheath rot, sevin 50WP @ 2.5 kg ha^{-1} was applied.

3.4.2.6 Harvesting

Harvesting was done 124 days after sowing. Two border rows all around the plots were harvested first and removed. Six hills were uprooted at random from each plot for observations on panicle characteristics and for chemical analysis. Afterwards, the crop was harvested from the net plot. The harvested produce was threshed and grains separated. The grain and straw were sun dried for two days and the weight recorded.

3.4.3 Observations

Six hills were randomly selected from each plot as suggested by Gomez (1972) for recording the growth and yield observations. The following observations were recorded at active tillering stage (ATS), panicle initiation stage (PIS), flowering stage (FS) and at harvest.

3.4.3.1 Observations on growth characters

3.4.3.1.1 Germination percentage

Percentage of germination was recorded at two days intervals from 7th day after sowing (DAS) onwards until 27 DAS. Number of hills germinated were counted from a randomly selected quadrat of one m^2 from each plot and was expressed as germination percentage.

3.4.3.1.2 Days to emergence

Number of days taken to reach 50 per cent of the hills to germinate from the date of sowing was recorded from each plot.

3.4.3.1.3 Seedling population

Number of seedlings were counted from a randomly selected quadrat of one m^2 from each plot. It was done from 7 to 27 DAS at two days intervals.

3.4.3.1.4 Height of plant

Plant height was measured from the base to the tip of the top most leaf at ATS and PIS. At harvest, the height was recorded from the base of the plant to the tip of the longest panicle and the mean height was computed and expressed in cm.

3.4.3.1.5 Root length

Each sample hill was carefully uprooted from the destructive row, roots carefully washed and the maximum length was measured and the mean expressed in cm.

3.4.3.1.6 Dry matter production

Dry matter production (DMP) was estimated at ATS, PIS, and FS and at harvest. At each observation, six sample hills were uprooted, roots separated, sundried, oven dried at 70-80°C to constant weight and shoot DMP was computed and expressed in kg ha^{-1}. At harvest, the sum total of the grain and straw yields were taken as the total DMP.

3.4.3.1.7 Root weight

Roots separated from the sample hills were washed, dried in oven at 70-80°C to a constant weight and the dry weight expressed in g m^{-2}.

3.4.3.1.8 Shoot : root ratio

It was worked out from the shoot DMP and root weight at the respective stages.

3.4.3.1.9 Number of tillers m ^{2}

The number of tillers were counted in a quadrat of one m^2 selected at random at important growth stages and at harvest.

3.4.3.1.10 Leaf area index (LAI)

LAI was calculated at ATS, PIS and FS using the length-width method suggested by Gomez (1972). Accordingly, leaf area = k x l x w

Where

k = adjustment factor (0.75)

l = the length of leaf

w = the maximum width of leaf

LAI was calculated from the leaf area considering the area occupied by the plants.

3.4.3.1.11 Pest and disease incidence

Incidence of the important pests and diseases viz., leaf folder, stem borer, gall midge and sheath blight were recorded from each plot as per the procedure suggested by IRRI (1980).

3.4.3.2 Observations on yield and yield attributes

3.4.3.2.1 Days to 50 per cent flowering

Number of days taken by 50 per cent of the plants to come to flowering from the date of sowing was recorded from each plot.

3.4.3.2.2 Panicles m^{-2}

At harvest, number of panicles were counted from a randomly selected quadrat of one m^2 from each plot.

3.4.3.2.3 Panicle length

Ten main panicles were collected randomly from each plot, length measured from the neck to the tip and the average expressed in cm.

3.4.3.2.4 Panicle weight

Ten main panicles were separately weighed from each plot at random, mean weight worked out and expressed in g.

3.4.3.2.5 Number of filled grains per panicle

The filled grains were removed from each panicle, counted and the mean number of grains per panicle worked out.

3.4.3.2.6 Percentage of filled grains

The grains from the randomly selected panicles from each plot were separated to filled and unfilled grains and counted to work out the percentage of filled grains.

3.4.3.2.7 1000 grain weight

1000 grains collected from the randomly selected panicles from each plot was counted and the weight recorded in g.

3.4.3.2.8 Grain yield

The grain from each plots were sundried, cleaned, winnowed and weighed and expressed in kg ha^{-1}.

3.4.3.2.9 Straw yield

Straw from each plot was dried in sun uniformly, weighed and expressed in kg ha^{-1}.

3.4.3.2.10 Harvest Index (HI)

Harvest Index (HI) was calculated using the data on grain yield and straw yield as per the following formula.

$$\mathrm{HI} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Grain + straw yield (kg ha}^{-1}\text{)}}$$

3.4.3.3 Physiological and chemical estimations

3.4.3.3.1 Relative leaf water content (RLWC)

The method proposed by Weatherley (1950), which was later modified and described in detail by Slatyer and Barrs (1965), was used to determine RLWC. It was calculated as percentage from the following equation.

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

3.4.3.3.2 Chlorophyll content

Total chlorophyll content was estimated from the third fully opened leaf from the top at ATS, PIS and FS by the method suggested by Arnon (1949).

Total chlorophyll and chlorophyll 'a' and 'b' were estimated colorimetrically in a Spectronic-20, using the following formula and expressed in mg g^{-1} fresh weight of leaf.

Total chlorophyll = 8.05 A 663 + 20.29 A 645

Chlorophyll 'a' = 12.72 A 663 - 2.58 A 645

Chlorophyll 'b' = 22.87 A 645 - 4.67 A 663

3.4.3.3.3 Cell sap pH

Cell sap pH was estimated at ATS, PIS and FS using pH meter. A 1: 2.5 leaf sample: water suspension was utilized for the reading (Jackson, 1958).

3.5 Chemical analysis

3.5.1 Plant analysis

Sample plants collected from each plot at ATS, PIS, FS and harvest were sun dried, ovendried to constant weight, grain and straw separated, ground, digested and nutrient content estimated. The N content (Microkjeldhal method), P content (Vanadomolybdophosphoric yellow colour method) and K content (Flame photometer method) were estimated for grain and straw separately (Jackson, 1958).

3.5.2 Uptake of nutrients

The content of N, P and K were multiplied with the respective dry matter yields to get the uptake values and expressed as kg ha^{-1}.

3.5.3 Soil analysis

Soil samples were collected from the experimental area before and after the experiment from each plot, dried in shade, sieved through 2 mm sieve and analysed.

The available N content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956), available P by Bray's method and available K by ammonium acetate method (Jackson, 1958).

3.5.4 Economic analysis

The economics of cultivation of the crop treatment wise was worked out and the net income and benefit:cost ratio (BCR) were calculated as follows:

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

3.6 Statistical analysis

Statistical analysis was done using the analysis of variance technique (Panse and Sukhatme, 1978). MSTATC and MS-Excel soft wares were used for computation and analysis.

Results

4. RESULTS

Laboratory and field experiments were conducted at the College of Horticulture, Vellanikkara and Agricultural Research Station, Mannuthy to study the effect of different seed hardening treatments in dry seeded low land rice under moisture stress condition. The experimental data collected were analysed statistically and the results are presented in this chapter.

4.1 Laboratory experiment

4.1.1 Germination percentage (Table 2)

The percentage of germination was significantly influenced by the hardening treatments with different solutions/slurries at five and ten days after keeping the seeds for germination, but at the 15th day, the effect was not significant. Hardening the seeds with 0.05 per cent imidacloprid recorded the maximum germination percentage (90%) at the fifth day followed by *Azospirillum* (86%) and the treatments involving *Ungu*, KH_2PO_4 and KCl recorded comparable values. At the tenth day also, imidacloprid recorded the highest germination percentage, but it was comparable with all other hardening treatments except water and cow dung slurry.

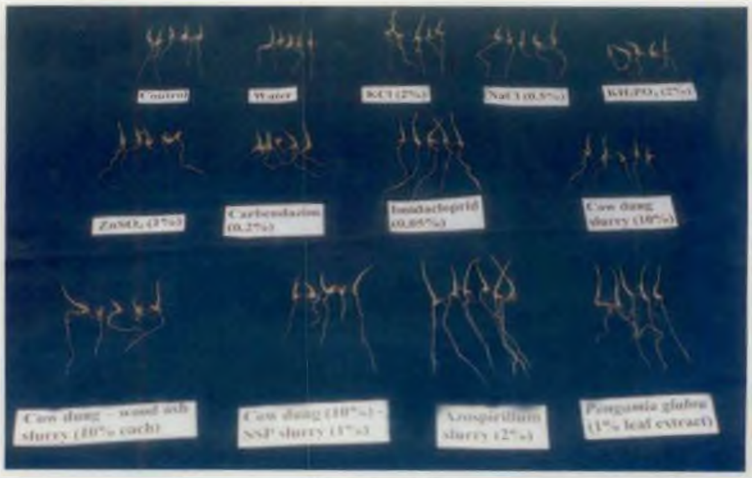
4.1.2 Speed of germination (Table 2)

The data revealed that the hardening treatments had significant influence on speed of germination. The treatment with imidacloprid recorded the highest speed of germination of 4.65 which was on par with *Azospirillum*, *Ungu*, KCl, KH_2PO_4 and cow dung-SSP slurry treatments and was significantly superior than control (3.98).

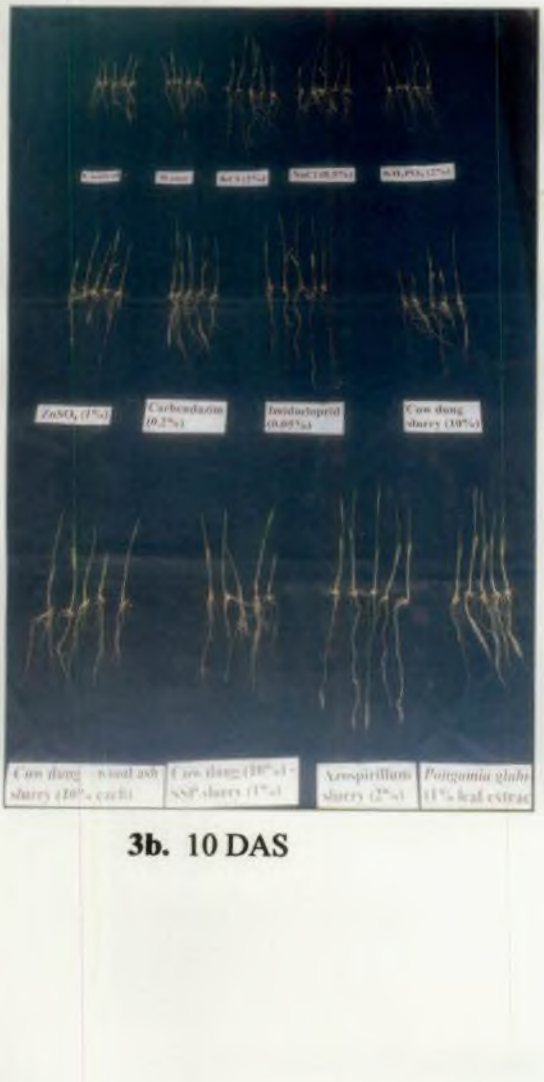
Table 2.Effect of seed hardening on germination percentage, speed of germination and shoot length of rice

Treatments		Germination percentage (%)			Speed of germination	Shoot length (cm)		
		5 DAS	10 DAS	15 DAS		5 DAS	10 DAS	15 DAS
T_1	Control (Dry seed)	72.9	82.4	90.2	3.98	2.4	6.2	8.3
T_2	Water	78.2	88.1	90.4	4.18	2.8	6.7	8.4
T_3	KCl 2%	84.8	90.9	94.3	4.42	4.3	9.8	13.2
T_4	NaCl 0.5%	78.9	90.2	92.1	4.23	3.1	7.5	9.6
T_5	KH_2PO_4 2%	84.7	90.8	92.9	4.38	3.4	7.4	9.8
T_6	$ZnSO_4$ 1%	78.5	90.4	90.4	4.20	2.8	6.7	8.7
T_7	Carbendazim 0.2%	78.7	90.6	92.3	4.23	3.5	7.5	10.3
T_8	Imidacloprid 0.05%	90.3	96.6	96.2	4.65	5.4	12.6	15.9
T_9	Cow dung 10%	78.8	86.9	90.6	4.17	3.0	6.9	9.4
T_{10}	Cow dung – Wood ash 10% each	78.9	90.7	92.4	4.23	3.2	6.8	10.3
T_{11}	Cow dung – SSP 10% and 1%	82.8	92.2	92.7	4.35	3.4	7.7	10.5
T_{12}	*Azospirillum* 2%	86.6	94.8	94.8	4.50	6.1	14.0	17.8
T_{13}	*Ungu* 1%	84.5	94.5	94.4	4.45	5.7	13.3	17.2
CD (0.05)		7.2	6.4	NS	0.22	0.6	0.6	0.6

Plate 3. Effect of seed hardening on seedling growth in the laboratory study



3a. 5 DAS



3b. 10 DAS

3c. 15 DAS

Table 3. Effect of seed hardening on root length, shoot dry weight and root dry weight of rice

Treatments		Root length (cm)			Shoot dry weight (mg)			Root dry weight (mg)		
		5 DAS	10 DAS	15 DAS	5 DAS	10 DAS	15 DAS	5 DAS	10 DAS	15 DAS
T_1	Control (Dry seed)	3.7	9.4	11.11	3.86	8.54	14.83	0.43	1.46	2.46
T_2	Water	3.4	9.5	11.2	3.94	8.83	14.97	0.46	1.53	2.54
T_3	KCl 2%	6.1	14.1	18.0	5.86	12.43	19.23	0.60	1.96	3.92
T_4	NaCl 0.5%	5.7	10.7	13.2	4.50	10.95	16.35	0.43	1.58	2.86
T_5	KH_2PO_4 2%	3.9	10.9	13.3	4.60	10.90	16.67	0.44	1.69	2.96
T_6	$ZnSO_4$ 1%	5.8	10.2	12.3	3.93	8.74	15.24	0.57	1.54	2.65
T_7	Carbendazim 0.2%	4.1	10.6	12.9	4.85	11.06	17.02	0.46	1.67	2.76
T_8	Imidacloprid 0.05%	10.3	15.5	20.2	6.34	15.34	21.25	0.77	2.06	4.32
T_9	Cow dung 10%	4.1	9.8	11.7	4.34	10.45	15.80	0.48	1.42	2.57
T_{10}	Cow dung – Wood ash 10% each	5.7	10.5	14.1	4.02	10.76	17.33	0.56	1.64	3.28
T_{11}	Cow dung – SSP 10% and 1%	6.0	10.5	13.9	4.91	11.26	17.44	0.59	1.72	3.26
T_{12}	*Azospirillum* 2%	13.6	17.2	23.0	7.24	16.14	23.33	0.83	2.16	4.63
T_{13}	*Ungu* 1%	10.2	12.3	15.8	7.03	15.86	22.72	0.74	1.86	4.01
CD (0.05)		0.52	0.69	0.58	0.64	0.62	0.62	0.07	0.55	0.64

4.1.3 **Shoot length** (Table 2)

The length of shoot was significantly influenced by the hardening treatments at all the periods of observation (Plates 3a, b and c). *Azospirillum* registered significantly higher shoot length at all the stages of observation except on the fifth day wherein it was comparable with the *Ungu* treatment. Dry seed invariably recorded the lowest value at the three stages. Among the hardening treatments, water and $ZnSO_4$ treatments recorded the lowest values.

4.1.4 **Root length** (Table 3)

Seedlings raised from seeds treated with different solutions/slurries produced appreciably longer roots at all the three stages of observation (Plates 3a, b and c). The longest roots were produced by *Azospirillum* treatment and it was significantly different from all other treatments at all the three stages of observation. The next best treatment was imidacloprid and it was superior to all other remaining treatments at all the three stages except *Ungu* on the fifth day. Among the hardening treatments, water recorded the lowest value and it was on par with control at all the three stages.

4.1.5 **Shoot weight** (Table 3)

Various seed treatments exerted favourable and significant influence on shoot dry weight. Hardening seeds with *Azospirillum* and *Ungu* recorded appreciably higher shoot weight followed by imidacloprid at all the stages of observation.

4.1.6 **Root weight** (Table 3)

Seedlings raised from seeds hardened with *Azospirillum* and imidacloprid registered the highest root weight value at all the three stages. It

Table 4. Effect of seed hardening on shoot: root ratio and vigour index of rice

Treatments		Shoot:Root ratio			Vigour index		
		5 DAS	10 DAS	15 DAS	5 DAS	10 DAS	15 DAS
T_1	Control (Dry seed)	9.10	5.97	6.11	444.7	1285.4	1751
T_2	Water	8.64	5.81	5.90	484.8	1427.2	1772
T_3	KCl 2%	9.77	6.39	4.93	881.9	2172.5	2942
T_4	NaCl 0.5%	10.46	7.03	5.74	694.3	1641.6	2100
T_5	KH_2PO_4 2%	10.49	6.48	5.68	618.3	1661.6	2146
T_6	$ZnSO_4$ 1%	6.89	5.71	5.79	675.1	1527.8	1898
T_7	Carbendazim 0.2%	10.67	6.65	6.20	598.1	1639.9	2141
T_8	Imidacloprid 0.05%	8.28	7.58	4.93	1417.7	2714.5	3473
T_9	Cow dung 10%	9.05	7.40	6.19	559.5	1451.2	1912
T_{10}	Cow dung – Wood ash 10% each	7.16	6.69	5.31	702.2	1569.1	2255
T_{11}	Cow dung – SSP 10% and 1%	8.35	6.66	5.35	778.3	1678.0	2262
T_{12}	*Azospirillum* 2%	8.77	7.54	5.06	1706.0	2957.8	3868
T_{13}	*Ungu* 1%	9.56	8.64	5.70	1343.6	2419.2	3115
CD (0.05)		1.35	NS	NS	375.9	539.4	429

Table 5. Effect of seed hardening on germination percentage

Treatment		Days to emergence	Germination percentage (%)						
			7 DAS	9 DAS	11 DAS	13 DAS	15 DAS	20 DAS	27 DAS
T_1	Control (Dry seed)	9	44.9	73.6	77.2	80.8	86.3	89.3	85.9
T_2	Water	9	41.3	71.7	77.2	80.8	86.8	81.3	85.3
T_3	KCl 2%	8	44.3	76.7	81.8	85.9	88.3	90.5	85.9
T_4	NaCl 0.5%	8	43.3	78.1	82.9	87.9	89.3	89.8	87.9
T_5	KH_2PO_4 2%	9	38.3	73.6	80.8	86.3	88.3	88.9	85.3
T_6	$ZnSO_4$ 1%	8	45.5	67.6	79.8	86.3	88.9	89.8	86.3
T_7	Carbendazim 0.2%	8	38.3	68.6	77.2	81.3	85.9	88.3	88.9
T_8	Imidacloprid 0.05%	7	47.8	80.8	85.3	95.9	98.5	97.4	95.9
	Cow dung 10%	9	40.3	80.8	85.3	87.4	89.8	89.3	85.3
T_{10}	Cow dung – Wood ash 10% each	8	41.8	77.7	80.8	84.8	88.3	90.9	90.9
T_{11}	Cow dung – SSP 10% and 1%	8	41.8	77.7	82.9	85.3	87.4	88.3	86.3
T_{12}	*Azospirillum* 2%	8	46.9	81.8	87.2	91.3	93.5	92.4	89.3
T_{13}	*Ungu* 1%	8	36.3	69.0	77.7	83.8	87.4	85.9	83.8
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

was closely followed by *Ungu* treatment at the fifth and 15th day, whereas at tenth day, it was followed by KCl treatment. Hardening with water did not improve the germination over dry seed.

4.1.7 **Shoot : root ratio** (Table 4)

On the fifth day hardening seeds with carbendazim recorded higher ratio and it was comparable with KH_2PO_4, NaCl, KCl and *Ungu*. The effect of seed hardening treatments on shoot : root ratio as compared to control was not significant at tenth and 15th day.

4.1.8 **Vigour Index** (Table 4)

Significant variations in vigour index was observed due to seed hardening at the three stages of observation. At fifth and tenth day, *Azospirillum* treatment resulted in maximum vigour index, which was on par with imidacloprid and *Ungu* treatments, whereas at 15th day *Azospirillum* and imidacloprid were on par and was followed by *Ungu* treatment. Control recorded the minimum value, but it was comparable with all other hardening treatments except *Azospirillum*, imidacloprid, *Ungu and* KCl treatment at fifth and tenth day.

4.2 Field experiment

4.2.1 Growth characters

4.2.1.1 **Germination percentage** (Table 5)

The impact of seed hardening treatments on germination percentage was not significant at any of the stages of observation. However seed hardening with imidacloprid recorded higher values followed by cow dung-wood ash and *Azospirillum*.

Table 6. Effect of seed hardening on number of seedlings m^{-2}

Treatment		7 DAS	9 DAS	11 DAS	13 DAS	15 DAS	20 DAS	27 DAS
T_1	Control (Dry seed))	157.6	216.3	231.6	261.7	300.0	287.3	253.7
T_2	Water	165.3	237.0	270.0	308.0	324.3	314.3	284.7
T_3	KCl 2%	173.6	239.3	291.0	341.3	362.7	353.7	327.0
T_4	NaCl 0.5%	186.0	246.6	295.7	334.0	371.3	359.0	322.3
T_5	KH_2PO_4 2%	149.6	217.0	268.3	306.3	339.0	335.7	297.7
T_6	$ZnSO_4$ 1%	175.3	248.7	297.0	326.7	358.7	334.7	320.3
T_7	Carbendazim 0.2%	168.6	236.7	285.0	307.3	325.3	317.7	286.0
T_8	Imidacloprid 0.05%	209.6	324.7	346.3	383.7	430.7	406.0	395.7
T_9	Cow dung 10%	168.6	234.0	250.0	247.3	272.3	268.7	241.3
T_{10}	Cow dung – Wood ash 10% each	186.0	243.3	281.3	306.0	326.3	334.7	267.3
T_{11}	Cow dung – SSP 10% and 1%	177.0	237.7	262.7	296.3	303.0	298.7	278.0
T_{12}	*Azospirillum* 2%	182.3	239.7	282.3	317.3	363.3	360.7	342.0
T_{13}	*Ungu* 1%	152.6	235.0	276.6	310.0	338.7	337.3	319.0
CD (0.05)		NS	NS	NS	49.7	60.7	58.4	61.4

At seven days after sowing, germination percentage was very low in all the treatments except in imidacloprid treatment i.e. less than 50 per cent. Germination percentage reached more than 80 per cent at nine DAS in treatments involving imidacloprid, *Azospirillum* and cow dung slurry. Maximum germination percentage was recorded at 15 DAS in case of treatments like imidacloprid, *Azospirillum*, *Ungu*, cow dung etc. No increase in germination percentage could be observed in treatments involving hardening of seeds with water, KH_2PO_4, carbendazim, cow dung slurry and cow dung-wood ash slurry, over dry seed, even at 27 DAS.

4.2.1.2 **Days to emergence** (Table 5)

The difference in the number of days to emergence among the treatments was not significant. However the data indicated that the number of days to emergence was less in the treatment involving seed hardening with imidacloprid.

4.2.1.3 **Seedling population** (Table 6)

There was no significant variation among the treatments during the first three dates of observation i.e. 7, 9 and 11 DAS. The treatment effect was however significant at all the subsequent dates of observation i.e. from 13 DAS to 27 DAS. Irrespective of the treatments, it was generally observed that the seedling population reached the peak at 15 DAS.

Maximum seedling population was observed in the imidacloprid treatment at all the dates of observation. Comparable values were recorded by NaCl at 13, 15 and 20 DAS, KCl at 13 and 20 DAS and *Azospirillum* at 20and 27 DAS.

Table 7. Effect of seed hardening on plant height (cm)

Treatment		15 DAS	30 DAS	ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	14.9	28.5	41.9	57.5	80.3	78.4
T_2	Water	13.2	24.6	42.8	57.7	79.9	79.2
T_3	KCl 2%	14.3	29.1	42.0	58.3	83.6	81.7
T_4	NaCl 0.5%	14.1	26.0	41.5	58.0	83.7	81.7
T_5	KH_2PO_4 2%	14.0	26.8	43.5	58.7	83.6	82.3
T_6	$ZnSO_4$ 1%	13.6	23.3	41.6	58.8	83.8	81.6
T_7	Carbendazim 0.2%	14.8	26.0	42.2	58.2	83.4	82.0
T_8	Imidacloprid 0.05%	15.3	30.5	44.9	59.9	85.5	83.0
T_9	Cow dung 10%	13.1	27.0	44.0	57.6	82.3	81.3
T_{10}	Cow dung – Wood ash 10% each	14.7	23.2	42.5	58.6	81.3	78.5
T_{11}	Cow dung – SSP 10% and 1%	13.1	27.3	43.6	58.6	80.8	79.9
T_{12}	*Azospirillum* 2%	14.6	25.3	43.3	59.1	83.8	81.3
T_{13}	*Ungu* 1%	13.3	26.9	43.2	59.0	84.9	81.7
CD (0.05)		0.6	1.4	1.8	1.1	2.0	2.3

Table 8. Effect of seed hardening on root length (cm)

Treatment		15 DAS	30 DAS	ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	2.2	7.2	11.1	15.1	21.1	23.8
T_2	Water	2.5	6.9	10.9	15.4	20.7	24.0
T_3	KCl 2%	2.2	7.1	11.6	15.8	21.8	24.4
T_4	NaCl 0.5%	2.3	5.5	11.1	15.2	21.7	23.7
T_5	KH_2PO_4 2%	2.3	6.9	11.2	17.2	22.0	24.4
T_6	$ZnSO_4$ 1%	2.4	6.6	10.8	16.1	21.2	23.8
T_7	Carbendazim 0.2%	1.9	6.5	11.0	15.3	21.6	24.1
T_8	Imidacloprid 0.05%	2.2	7.8	11.0	17.3	21.9	24.8
T_9	Cow dung 10%	1.9	6.6	10.4	14.7	21.4	23.7
T_{10}	Cow dung – Wood ash 10% each	2.1	6.8	10.8	15.0	22.1	24.1
T_{11}	Cow dung – SSP 10% and 1%	2.3	6.9	10.7	15.1	21.9	24.4
T_{12}	*Azospirillum* 2%	2.4	6.6	11.4	17.5	22.6	25.1
T_{13}	*Ungu* 1%	1.8	6.0	11.6	16.5	22.5	24.7
CD (0.05)		NS	0.3	0.6	NS	0.8	0.7

4.2.1.4 **Plant height** (Table 7)

The treatment effects led to significant variation in plant height at all the dates of observation. At 15 DAS, imidacloprid treatment recorded the maximum plant height of 15.3 cm and was on par with dry seed and carbendazim treatments. At 30 DAS, seed treatment with imidacloprid 0.05 per cent registered the maximum plant height of 30.5 cm and was on par with KCl treatment. At ATS hardening with imidacloprid registered the maximum plant height of 44.9 cm and it was comparable with cow dung, cow dung-SSP, KH_2PO_4, *Azospirillum* and *Ungu*. Maximum plant height was recorded by imidacloprid treatment followed by *Azospirillum*, *Ungu*, $ZnSO_4$ and KH_2PO_4 treatments and the latter four treatments were on par with imidacloprid at PIS. At flowering stage, imidacloprid recorded the highest value (85.5 cm) and *Ungu*, *Azospirillum*, carbendazim, $ZnSO_4$ and KH_2PO_4, NaCl and KCl recorded comparable values. At harvest, carbendazim, NaCl, *Ungu*, KCl, $ZnSO_4$, *Azospirillum* and cow dung were comparable with imidacloprid.

4.2.1.5 **Root length** (Table 8)

The effect of treatments did not cause any significant variation in root length at 15 DAS and PIS. However, at 30 DAS, active tillering, flowering and harvesting stages the root length varied significantly. At 30 DAS, imidacloprid recorded the longest root which was significantly larger than all other treatments. Though the longest root was produced by KCl at ATS, it was comparable with NaCl, KH_2PO_4, carbendazim, *Azospirillum*, *Ungu* and dry seed. The cow dung treatment recorded the lowest value at all stages.

Table 9. Effect of seed hardening on dry mater production (kg ha^{-1})

Treatment		15 DAS	30 DAS	ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	73.4	851	1240	3125	6659	7965
T_2	Water	64.2	853	1624	3109	6775	8085
T_3	KCl 2%	77.3	1186	1820	3508	7791	9099
T_4	NaCl 0.5%	83.0	971	1417	3642	7554	8857
T_5	KH_2PO_4 2%	77.3	927	1246	3555	7626	8929
T_6	$ZnSO_4$ 1%	93.1	856	1444	3502	7374	8680
T_7	Carbendazim 0.2%	85.1	842	1326	3677	7712	9011
T_8	Imidacloprid 0.05%	134.6	1376	1825	4144	9078	10400
T_9	Cow dung 10%	80.2	898	1523	3278	7287	8254
T_{10}	Cow dung – Wood ash 10% each	85.5	840	1451	3571	8182	9506
T_{11}	Cow dung – SSP 10% and 1%	67.1	944	1726	3545	7580	8884
T_{12}	*Azospirillum* 2%	104.2	1103	1662	3808	7810	9141
T_{13}	*Ungu* 1%	78.5	1088	1806	3803	7551	8864
CD (0.05)		25.7	225	192	538	1368	863

Table 10. Effect of seed hardening on root dry weight (gm^{-2})

Treatment		15 DAS	30 DAS	ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	0.40	16.8	28.7	116.9	133.4	127.6
T_2	Water	0.42	18.7	36.6	120.7	147.3	119.3
T_3	KCl 2%	0.54	27.2	43.0	134.3	197.4	144.6
T_4	NaCl 0.5%	0.50	19.0	31.8	135.7	173.9	139.6
T_5	KH_2PO_4 2%	0.48	23.9	31.0	122.1	225.2	148.8
T_6	$ZnSO_4$ 1%	0.61	17.3	35.3	124.5	153.5	127.9
T_7	Carbendazim 0.2%	0.52	18.7	30.7	133.9	194.1	134.2
T_8	Imidacloprid 0.05%	0.79	29.7	43.0	148.6	221.1	155.5
T_9	Cow dung 10%	0.46	19.3	32.4	111.6	138.1	124.1
T_{10}	Cow dung – Wood ash 10% each	0.41	20.5	32.3	110.8	191.7	131.9
T_{11}	Cow dung – SSP 10% and 1%	0.47	23.4	37.1	126.1	170.5	138.5
T_{12}	*Azospirillum* 2%	0.62	20.1	37.0	142.4	232.5	150.4
T_{13}	*Ungu* 1%	0.58	24.7	44.2	133.2	198.0	144.2
CD (0.05)		0.13	4.7	5.9	NS	33.9	18.5

Treating the seeds with two per cent *Azospirillum* recorded the highest value of 22.6 cm and 25.1 cm at flowering and harvesting stages respectively. It was comparable with KH_2PO_4, imidacloprid, cow dung-wood ash slurry, cow dung-SSP slurry and *Ungu* extract at flowering stage and with KCl, KH_2PO_4, imidacloprid and *Ungu* extract at harvest.

4.2.1.6 **Dry matter production** (Table 9)

Significant variation was observed in dry matter production due to treatments at all stages. Hardening seeds with imidacloprid invariably registered the maximum dry matter production at all stages. At 15 DAS, imidacloprid recorded the highest weight of 135 kg ha^{-1} followed by *Azospirillum* treatment. Whereas at 30 DAS, it was on par with KCl. At ATS, imidacloprid recorded the highest value of 1825 kg ha^{-1} and KCl, *Ungu*, cow dung-SSP and *Azospirillum* registered comparable values.

At PIS, *Azospirillum, Ungu,* carbendazim and NaCl were on par with imidacloprid. Maximum dry matter production was observed in the imidacloprid treatment at flowering stage and it was on par with cow dung-wood ash, *Azospirillum*, KCl and carbendazim. At harvest imidacloprid recorded the highest value as compared to other treatments followed by cow dung-wood ash.

4.2.1.7 **Root dry weight** (Table 10)

Treatment variation was conspicuous in root dry weight at all the stages of observation except at panicle initiation stage. At 15 DAS, 30 DAS and harvest stage imidacloprid treatment registered the highest values. At 15 DAS, imidacloprid was significantly superior to all other treatments. At 30 DAS, it

Table 11. Effect of seed hardening on shoot: root ratio

Treatment		15 DAS	30 DAS	ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	18.14	5.08	4.35	3.61	5.96	7.36
T_2	Water	15.60	4.50	4.81	3.59	5.51	8.09
T_3	KCl 2%	14.27	4.37	4.25	3.44	4.59	7.24
T_4	NaCl 0.5%	16.56	5.11	4.49	3.69	5.14	8.21
T_5	KH_2PO_4 2%	15.80	3.87	4.02	3.73	3.98	7.55
T_6	$ZnSO_4$ 1%	15.23	4.97	4.19	3.71	5.66	9.02
T_7	Carbendazim 0.2%	16.55	4.52	4.34	3.66	4.68	8.05
T_8	Imidacloprid 0.05%	17.00	4.66	4.25	3.49	4.70	8.34
T_9	Cow dung 10%	17.49	4.65	4.71	4.09	6.36	8.72
T_{10}	Cow dung – Wood ash 10% each	20.68	4.15	4.59	4.25	5.01	8.14
T_{11}	Cow dung – SSP 10% and 1%	14.42	4.06	4.71	3.63	5.21	7.95
T_{12}	*Azospirillum* 2%	17.02	5.50	4.59	3.45	3.95	8.31
T_{13}	*Ungu* 1%	13.56	4.45	4.10	3.85	4.47	8.11
CD (0.05)		NS	0.64	NS	NS	0.92	NS

Table 12. Effect of seed hardening on number of tillers m^{-2}

Treatment		ATS	PIS	FS	Harvest
T_1	Control (Dry seed)	439	713	659	412
T_2	Water	448	724	651	448
T_3	KCl 2%	592	868	763	491
T_4	NaCl 0.5%	517	801	667	442
T_5	KH_2PO_4 2%	563	774	667	445
T_6	$ZnSO_4$ 1%	520	733	629	443
T_7	Carbendazim 0.2%	492	720	623	501
T_8	Imidacloprid 0.05%	615	884	759	469
T_9	Cow dung 10%	446	737	655	460
T_{10}	Cow dung – Wood ash 10% each	548	840	724	474
T_{11}	Cow dung – SSP 10% and 1%	516	767	660	493
T_{12}	*Azospirillum* 2%	547	836	747	471
T_{13}	*Ungu* 1%	545	820	723	485
CD (0.05)		49	61	42	NS

was comparable with KCl. At harvest stage, *Ungu*, *Azospirillum*, cow dung-SSP, KH_2PO_4, NaCl and KCl were on par with imidacloprid. At ATS and FS *Ungu* and *Azospirillum* treatments recorded the highest value respectively. At ATS, imidacloprid and KCl were on par with *Ungu*. At flowering stage, *Ungu*, imidacloprid, KH_2PO_4 and KCl were comparable with *Azospirillum*.

4.2.1.8 **Shoot : root ratio** (Table 11)

The effect of treatments on shoot : root ratio was significant only at 30 DAS and FS. *Azospirillum* treatment registered the widest ratio at 30 DAS and comparable values were recorded by NaCl, dry seed and $ZnSO_4$. Cow dung slurry recorded the widest ratio at flowering stage but was on par with dry seed, water and $ZnSO_4$.

4.2.1.9 **Number of tillers m^{-2}** (Table 12)

Seed hardening favourably influenced the tiller number m^{-2} at all stages except at harvest. Control plots recorded the lowest tiller number at all stages. At ATS imidacloprid recorded the maximum tiller number (616) which was on par with KCl (592).

At panicle initiation stage, imidacloprid, KCl, cow dung-wood ash, *Azospirillum* and *Ungu* treatments were on par. At flowering stage KCl treatments recorded the highest value of 763, which was on par with seeds hardened with imidacloprid, cow dung-wood ash, *Azospirillum* and *Ungu*. The influence of treatments did not cause any significant variation in the number of tillers at harvest.

Table 13. Effect of seed hardening on leaf area index

Treatments		ATS	PIS	FS
T_1	Control (Dry seed)	3.2	5.8	7.0
T_2	Water	3.6	6.3	7.4
T_3	KCl 2%	4.4	8.1	9.2
T_4	NaCl 0.5%	4.0	7.6	8.5
T_5	KH_2PO_4 2%	4.3	7.8	8.7
T_6	$ZnSO_4$ 1%	3.9	6.6	7.6
T_7	Carbendazim 0.2%	3.7	6.4	7.7
T_8	Imidacloprid 0.05%	5.2	9.3	10.7
T_9	Cow dung 10%	3.5	6.1	7.3
T_{10}	Cow dung – Wood ash 10% each	3.8	6.5	7.8
T_{11}	Cow dung – SSP 10% and 1%	4.1	7.0	8.1
T_{12}	*Azospirillum* 2%	4.5	8.4	9.6
T_{13}	*Ungu* 1%	4.2	7.3	8.4
CD (0.05)		0.6	0.4	0.5

Table 14. Effect of seed hardening on yield and yield attributes

Treatments		Days to flowering	Days to 50% flowering	No. of panicles m^{-2}	No. of grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Chaff $panicle^{-1}$	% of filled grains	Panicle length (cm)	Panicle weight (g)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
T_1	Control (Dry seed)	73.0	90.7	376	91.5	75.3	16.2	82.3	20.0	1.76	28.32	3199	4766	0.41
T_2	Water	70.7	89.3	394	93.1	77.9	15.2	83.6	19.8	2.31	28.39	3782	4303	0.47
T_3	KCl 2%	71.0	89.7	456	102.2	86.9	15.3	85.0	20.8	2.38	29.52	4324	4774	0.48
T_4	NaCl 0.5%	72.0	90.3	437	101.8	85.3	16.5	83.8	20.6	2.30	28.87	3998	4859	0.45
T_5	KH_2PO_4 2%	70.7	88.3	418	96.2	82.2	13.9	85.5	20.6	2.38	28.97	4362	4567	0.49
T_6	$ZnSO_4$ 1%	71.0	89.7	405	95.2	79.9	15.3	83.9	19.9	1.99	28.77	3910	4770	0.45
T_7	Carbendazim 0.2%	71.3	89.7	389	99.5	83.6	15.9	84.1	21.0	2.39	29.05	3756	5255	0.42
T_8	Imidacloprid 0.05%	70.0	88.7	470	103.9	89.4	14.5	86.1	21.1	2.50	29.37	5335	5071	0.51
T_9	Cow dung 10%	73.7	90.7	392	94.9	80.9	14.1	85.2	20.7	2.11	29.72	3750	4504	0.45
T_{10}	Cow dung – Wood ash 10% each	70.7	89.3	436	99.0	83.3	15.7	84.2	20.2	2.13	28.82	3765	5741	0.39
T_{11}	Cow dung – SSP 10% and 1%	73.7	91.0	420	101.2	85.9	15.3	84.9	20.8	2.52	29.44	4125	4759	0.47
T_{12}	*Azospirillum* 2%	68.7	87.6	444	103.7	87.4	16.5	84.3	21.2	2.44	29.33	4638	4503	0.51
T_{13}	*Ungu* 1%	71.0	89.3	443	107.6	90.6	17.0	84.6	20.9	2.47	29.24	4306	4558	0.49
CD (0.05)		NS	NS	47	6.6	5.8	1.7	1.4	0.6	0.41	NS	810	NS	NS

4.2.1.10 Leaf area index (Table 13)

The leaf area index (LAI) increased progressively from the ATS to FS. The treatments showed significant variation in LAI at all growth stages. Imidacloprid treatment recorded the highest value followed by *Azospirillum* treatment at all stages. The LAI of imidacloprid was significantly higher than all the other treatments at all the three growth stages. The control exhibited the least leaf area index at all stages.

4.2.2 Yield and yield attributes (Table 14)

4.2.2.1 Days to flowering and 50 per cent flowering

The treatments did not show variation in the number of days to flowering and 50 per cent flowering. The number of days to 50 per cent flowering ranged from 87.6 (T_{12}) to 91.0 (T_3). Most of the seed hardening treatments showed a general reduction, though of low magnitude in the number of days to flowering and 50 per cent flowering as compared to control. The reduction was to the tune of two to five days.

4.2.2.2 Number of panicles m^{-2}

Seed hardening caused significant variation in the number of panicles m^{-2}. Plants raised from seeds hardened with imidacloprid produced appreciably higher number of panicles m^{-2} (470) followed by KCl treatment. The treatments involving hardening seeds with KCl, *Azospirillum*, *Ungu*, NaCl, KH_2PO_4, cow dung-wood ash and cow dung-SSP treatments recorded comparable values with that of imidacloprid. Unhardened seeds produced the lowest number of panicles of 376 m^{-2}.

4.2.2.3 Number of grains panicle^{-1}

The variation in the number of grains per panicle among treatments was statistically significant. The highest number (107.6) was recorded by *Ungu* treatment. This was on par with imidacloprid, *Azospirillum*, KCl, cow dung-SSP and NaCl treatments. The least value of 91.5 grains per panicle was obtained in the control.

4.2.2.4 Number of filled grains panicle^{-1}

Number of filled grains varied from 75.3 to 90.6 per panicle for different treatments and the variation was found to be significant. Among the treatments hardening with *Ungu* has registered the maximum number of filled grains per panicle. The next best was imidacloprid and it along with KCl, NaCl, cow dung-SSP and *Azospirillum* recorded comparable values with that of *Ungu*. Control plots recorded the lowest value of 75.3 grains panicle^{-1}.

4.2.2.5 Chaff panicle^{-1}

Significant variation was observed in number of chaff per panicle. The KH_2PO_4 treatment recorded the lowest value of 13.9 closely followed by cow dung and imidacloprid treatments. *Ungu*, NaCl and *Azospirillum* recorded comparatively higher values.

4.2.2.6 Percentage of filled grains

A significantly higher percentage of filled grains was observed in imidacloprid treatment (86.1). It was on par with KH_2PO_4, cow dung, KCl, cow dung-SSP and *Ungu*. Control recorded significantly lower percentage of filled grains.

4.2.2.7 Panicle length

The perusal of the data revealed that the treatments had significant influence on panicle length. Hardening the seed with *Azospirillum* two per cent recorded the highest value (21.2 cm). The treatments which recorded comparable values with *Azospirillum* were imidacloprid, *Ungu*, cow dung-SSP, cow dung, carbendazin, KH_2PO_4, NaCl and KCl.

4.2.2.8 Panicle weight

Seed hardening led to significant fluctuation in panicle weight. Seed hardening with cow dung-SSP, imidacloprid and *Ungu* produced heavier panicles (2.52 g) and were comparable with *Azospirillum*, cow dung-wood ash, cow dung, carbendazim, KH_2PO_4, NaCl, KCl and water. Control plots recorded the lowest panicle weight (1.76 g).

4.2.2.9 Test weight of grains

The effect of treatment was not significant on 1000 grains weight. Thousand grain weight ranged from 28.3 g to 29.7 g among the different treatments.

4.2.2.10 Grain yield

Statistical analysis of the grain yield data indicated the significant effect of seed hardening treatments. The yield increase due to seed hardening over control ranged from 551 kg ha^{-1} to 2136 kg ha^{-1}. Hardening with imidacloprid has registered the highest grain yield of 5335 kg ha^{-1} and was comparable with *Azospirillum* treatment (4638 kg ha^{-1}). Both these treatments were significantly superior in yield over the other treatments. Seed hardening increased the yield over the dry seed by 2136 kg ha^{-1} with respect to imidacloprid and 1439 kg ha^{-1} with respect to *Azospirillum*. This worked out to an increase of 67 per cent and 45 per cent, respectively over the dry seed control. In addition to imidacloprid and *Azospirillum*, treatments involving hardening with KH_2PO_4, KCl, *Ungu* and cow dung-SSP also enhanced the grain yield significantly, over the dry seed control.Though not appreciable in terms of statistical significance, hardening with water recorded an yield increase of 583 kg ha^{-1} which was worked out to 18 per cent. The lowest yield was recorded in control (3199 kg ha^{-1}).

4.2.2.11 Straw yield

Though not statistically significant, a perusal of the mean data revealed that the highest straw yield of 5741 kg ha^{-1} was recorded by cow dung-wood ash treatment. Hardening with carbendazim produced the next highest yield of 5255 kg ha^{-1}. These treatments recorded yield increase of 975 and 489 kg ha^{-1} respectively over the dry seed. They worked out to 20 and 10 per cent respectively, over the dry seed control. Hardening with water recorded the lowest straw yield of 4303 kg ha^{-1}.

4.2.2.12 Harvest index

Significant variation was not observed in the case of harvest index among the different seed hardening treatments. However, imidacloprid recorded the highest value of 0.51. *Azospirillum* stands second with a value of 0.50.

Table 15.Effect of seed hardening on chlorophyll content (mg g^{-1} fresh weight of leaf)

Treatments		Chlorophyll 'a'			Chlorophyll 'b'			Total chlorophyll		
		ATS	PIS	FS	ATS	PIS	FS	ATS	PIS	FS
T_1	Control (Dry seed)	2.35	2.26	2.37	0.78	0.92	0.81	3.13	3.18	3.17
T_2	Water	2.32	2.09	2.17	0.78	0.82	0.81	3.10	2.91	2.98
T_3	KCl 2%	2.38	2.18	1.31	0.86	0.89	0.88	3.24	3.07	3.19
T_4	NaCl 0.5%	2.43	2.33	2.37	0.93	0.96	0.91	3.36	3.30	3.28
T_5	KH_2PO_4 2%	2.36	2.08	2.33	0.83	0.89	0.82	3.18	2.97	3.15
T_6	$ZnSO_4$ 1%	2.41	2.36	2.42	0.91	0.95	0.86	3.32	3.31	3.28
T_7	Carbendazim 0.2%	2.40	2.24	2.33	0.81	0.87	0.85	3.21	3.10	3.18
T_8	Imidacloprid 0.05%	2.32	2.26	2.31	0.85	0.87	0.83	3.16	3.13	3.14
T_9	Cow dung 10%	2.37	2.29	2.72	0.89	0.93	0.87	3.28	3.21	3.26
T_{10}	Cow dung – Wood ash 10% each	2.44	2.31	2.35	0.83	0.89	0.85	3.27	3.21	3.21
T_{11}	Cow dung – SSP 10% and 1%	2.23	2.12	2.21	0.78	0.88	0.82	3.01	3.00	3.02
T_{12}	*Azospirillum* 2%	2.43	2.27	2.25	0.90	0.93	0.83	3.33	3.19	3.08
T_{13}	*Ungu* 1%	2.47	2.38	2.44	0.85	0.97	0.95	3.32	3.36	3.39
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 16. Effect of seed hardening on RLWC and cell sap pH

Treatment		RLWC (%)				Cell sap pH		
		30 DAS	ATS	PIS	FS	ATS	PIS	FS
T_1	Control (Dry seed)	85.3	89.4	93.4	94.3	6.48	6.65	6.48
T_2	Water	85.3	88.5	94.3	95.7	6.38	6.58	6.42
T_3	KCl 2%	87.9	92.1	94.4	96.6	6.38	6.55	6.45
T_4	NaCl 0.5%	87.3	92.0	93.9	95.3	6.45	6.57	6.47
T_5	KH_2PO_4 2%	88.2	92.9	95.7	96.6	6.43	6.58	6.48
T_6	$ZnSO_4$ 1%	86.3	92.2	93.4	95.6	6.43	6.63	6.48
T_7	Carbendazim 0.2%	86.0	90.0	94.4	95.6	6.48	6.63	6.50
T_8	Imidacloprid 0.05%	87.9	92.7	94.4	96.2	6.46	6.60	6.42
T_9	Cow dung 10%	87.0	89.7	94.8	96.2	6.48	6.63	6.48
T_{10}	Cow dung – Wood ash 10% each	87.6	91.7	94.4	95.7	6.42	6.58	6.42
T_{11}	Cow dung – SSP 10% and 1%	85.7	92.7	93.4	95.2	6.42	6.63	6.47
T_{12}	*Azospirillum* 2%	86.9	91.2	93.8	95.6	6.45	6.62	6.42
T_{13}	*Ungu* 1%	85.8	93.4	95.1	96.1	6.40	6.58	6.47
CD (0.05)		1.7	2.4	NS	NS	NS	NS	NS

Table 17. Effect of seed hardening on pest and disease incidence in per cent

Treatment		Panicle initiation stage			15 days before harvest
		Stem borer	Leaf folder	Gall Midge	Sheath blight
T_1		0.90	54.3	1.17	96.3
T_2	Water	0.80	51.7	0.97	97.0
T_3	KCl 2%	0.40	40.3	0.77	89.3
T_4	NaCl 0.5%	0.77	51.7	0.93	96.0
T_5	KH_2PO_4 2%	0.50	40.0	0.80	90.3
T_6	$ZnSO_4$ 1%	0.70	50.3	1.03	94.7
T_7	Carbendazim 0.2%	0.80	48.0	1.00	87.0
T_8	Imidacloprid 0.05%	0.20	38.3	0.63	93.0
T_9	Cow dung 10%	0.80	48.3	1.07	92.3
T_{10}	Cow dung – Wood ash 10% each	0.57	48.3	0.93	94.0
T_{11}	Cow dung – SSP 10% and 1%	0.70	49.0	1.03	95.0
T_{12}	*Azospirillum* 2%	0.50	42.0	0.83	91.0
T_{13}	*Ungu* 1%	0.27	39.3	0.70	88.3
CD (0.05)		0.32	4.5	NS	3.5

4.2.3 Physiological parameters

4.2.3.1 Chlorophyll content (Table 15)

The influence of seed hardening treatments on content of chlorophyll 'a' and 'b' and total chlorophyll in leaves were not statistically significant.

Seed hardening with *Ungu* recorded relatively higher content of chlorophyll 'a' at active tillering and panicle initiation stages, whereas, at flowering stage cow dung extract registered the highest value.

With regard to chlorophyll 'b' hardening with *Ungu* registered the highest content at panicle initiation and flowering stages whereas at active tillering NaCl recorded the highest values.

Seed treatment with *Ungu* extract recorded the maximum total chlorophyll content at panicle initiation and flowering stages, whereas at active tillering NaCl recorded the highest value. Control plots recorded relatively lower values.

4.2.3.2 Relative leaf water content (RLWC) (Table 16)

RLWC was recorded at 30 DAS, ATS, PIS and FS. Statistically significant effect due to seed hardening was noted only at 30 DAS and ATS. Among the different treatments significantly higher RLWC was recorded by KH_2PO_4 at 30 DAS and *Ungu at* ATS. KCl, NaCl, $ZnSO_4$, imidacloprid, cow dung, cow dung-wood ash and *Azospirillum* were on par with KH_2PO_4 at 30 DAS. At ATS, in addition to the above treatments, cow dung-SSP also recorded comparable values with that of *Ungu* and KH_2PO_4.

4.2.3.3 Cell sap pH (Table 16)

The impact of seed hardening on cell sap pH was negligible. In general relatively higher values were recorded at panicle initiation stage, as compared to other growth stages, irrespective of the treatments.

4.2.4 Pest and disease incidence (Table 17)

Effect of treatments on pest incidence at panicle initiation stage was monitored. In general treatments involving hardening reduced the incidence of leaf folder and stem borer. The treatment involving imidacloprid recorded significantly lower incidence of stem borer and leaf folder.

In respect of leaf folder, significantly higher incidence was observed in control treatment but it was statistically on par with water, NaCl and $ZnSO_4$. Imidacloprid recorded the least incidence which was on par with *Ungu*, KH_2PO_4, KCl and *Azospirillum*.

In respect of incidence of stem borer significant variation was observed among treatments. In the control plot (dry seed), the percentage incidence was the highest. Least incidence of stem borer was noted in imidacloprid, *Ungu*, *Azospirillum*, KH_2PO_4 and KCl.

The incidence of gall midge did not vary significantly among the treatments. The incidence was in general very low ranging from 0.63 per cent to 1.17 per cent. However, the damage was the highest in untreated control.

Observation on the incidence of sheath blight disease was recorded 15 days before harvest and it showed remarkable variation among the treatments. The disease incidence was found to be the lowest in carbendazim

Table 18. Effect of seed hardening on nitrogen content and uptake of rice

Treatments		Content (%)					Uptake (kg ha^{-1})					
		ATS	PIS	FS	Harvest		ATS	PIS	FS	Harvest		
					Straw	Grain				Straw	Grain	Total
T_1	Control (Dry seed)	1.74	1.25	0.77	0.49	0.88	21.50	39.06	51.08	23.14	28.50	51.64
T_2	Water	1.77	1.29	0.84	0.50	0.86	28.81	40.14	56.90	21.64	32.61	54.25
T_3	KCl 2%	1.87	1.38	0.93	0.64	1.03	33.97	48.54	73.40	30.27	44.43	74.70
T_4	NaCl 0.5%	1.77	1.33	0.78	0.54	0.93	25.12	48.12	59.64	26.33	37.07	63.41
T_5	KH_2PO_4 2%	1.85	1.34	0.90	0.65	0.92	23.08	47.92	68.19	29.82	39.87	69.69
T_6	$ZnSO_4$ 1%	1.81	1.29	0.86	0.56	0.88	26.12	45.12	63.22	26.76	34.43	61.19
T_7	Carbendazim 0.2%	1.77	1.31	0.88	0.60	0.92	23.55	48.25	67.54	31.39	34.11	65.50
T_8	Imidacloprid 0.05%	1.92	1.42	1.01	0.73	1.08	35.12	58.66	91.42	36.89	57.35	94.23
T_9	Cow dung 10%	1.81	1.29	0.88	0.58	0.95	27.56	42.11	64.69	26.03	35.43	61.46
T_{10}	Cow dung – Wood ash 10% each	1.83	1.33	0.90	0.62	0.93	26.54	47.38	73.46	35.41	35.11	70.52
T_{11}	Cow dung – SSP 10% and 1%	1.83	1.36	0.92	0.65	1.01	31.58	48.11	69.77	31.11	41.58	72.68
T_{12}	*Azospirillum* 2%	1.90	1.46	0.97	0.71	1.05	31.64	55.51	75.91	31.93	48.47	80.39
T_{13}	*Ungu* 1%	1.87	1.36	0.92	0.52	0.97	33.72	51.90	69.38	23.83	41.88	65.71
	CD (0.05)	NS	NS	NS	NS	NS	4.20	9.03	19.00	8.48	9.86	13.13

with a mean value of 87.0. *Ungu*, KCl and KH_2PO_4 were also effective in minimizing the disease incidence.

4.2.5 Nutrient content and uptake

4.2.5.1 Nitrogen

4.2.5.1.1 Content (Table 18)

Nitrogen content declined successively from ATS to maturity irrespective of treatments. Accordingly, the highest N content was recorded at ATS and least in straw at harvest.

There was no significant variation among the treatments in N content at any of the stages as well as in the grain and straw at harvest. Overall perusal of the data indicated higher N content in imidacloprid followed by *Azospirillum* at all the stages. However the variation was minimal towards the harvest stage. Control recorded the lowest N content at all stages except in grain at harvest. Least N content in grain was observed in the treatment involving hardening with water.

4.2.5.1.2 Uptake (Table 18)

Nitrogen uptake by rice among treatments was significantly different at all growth stages including grain and straw at harvest. The highest uptake of N was recorded by imidacloprid treatment. This was comparable with *Azospirillum* and KCl treatments in almost all the stages. At ATS, imidacloprid was significantly superior to the remaining treatments except *Ungu*. At PIS, it was comparable with *Azospirillum, Ungu* and KCl. At flowering stage, *Azospirillum*, cow dung-wood ash and KCl were on par with imidacloprid. An exception was observed at harvest stage (straw) where KCl treatment was

Table 19. Effect of seed hardening on phosphorus content and uptake of rice

Treatments		Content (%)					Uptake (kg ha^{-1})					
		ATS	PIS	FS	Harvest		ATS	PIS	FS	Harvest		
					Straw	Grain				Straw	Grain	Total
T_1	Control (Dry seed)	0.14	0.16	0.17	0.034	0.187	1.73	5.00	11.10	1.63	5.98	7.61
T_2	Water	0.13	0.15	0.19	0.333	0.193	2.13	4.70	12.77	1.43	7.27	8.70
T_3	KCl2%	0.15	0.17	0.21	0.046	0.195	2.79	5.98	16.51	2.19	8.40	10.60
T_4	NaCl 0.5%	0.13	0.14	0.17	0.039	0.177	1.85	5.09	13.01	1.88	7.01	8.88
T_5	KH_2PO_4 2%	0.16	0.17	0.19	0.052	0.198	1.95	6.08	14.79	2.36	8.63	10.98
T_6	$ZnSO_4$ 1%	0.14	0.16	0.17	0.043	0.193	2.08	5.48	12.21	2.05	7.55	9.59
T_7	Carbendazim 0.2%	0.15	0.16	0.20	0.046	0.200	2.02	6.00	15.32	2.39	7.50	9.90
T_8	Imidacloprid 0.05%	0.17	0.18	0.20	0.052	0.201	3.02	7.28	18.70	2.66	10.67	13.33
T_9	Cow dung 10%	0.15	0.16	0.19	0.045	0.199	2.31	5.29	13.93	2.02	7.48	9.50
T_{10}	Cow dung – Wood ash 10% each	0.14	0.15	0.17	0.048	0.189	2.05	5.20	14.30	2.76	7.14	9.90
T_{11}	Cow dung – SSP 10% and 1%	0.13	0.15	0.17	0.041	0.192	2.30	5.34	13.25	1.97	7.91	9.88
T_{12}	*Azospirillum* 2%	0.16	0.17	0.21	0.052	0.204	2.65	6.59	16.56	2.34	9.44	11.78
T_{13}	*Ungu* 1%	0.18	0.18	0.20	0.046	0.202	3.16	7.00	14.84	2.09	8.71	10.80
CD (0.05)		NS	NS	0.01	NS	NS	0.88	1.49	3.24	NS	1.57	2.06

significantly lower than the above mentioned treatments. Imidacloprid recorded the highest uptake of 57.35 kg ha^{-1} inrespect of uptake by grain at harvest, which was comparable with *Azospirillum*.

4.2.5.2 Phosphorus

4.2.5.2.1 Content (Table 19)

The content of P showed an increase from ATS to FS and there after declined. The content did not show appreciable variation at ATS, PIS and harvest (grain and straw). The variation was however, significant at flowering stage.

Though not significant, *Ungu* and imidacloprid treatment recorded the highest P content at ATS. The next best was *Azospirillum* treatment. Lower P contents were recorded by NaCl, water and cow dung-SSP treatments. At flowering stage, the highest P content was recorded by *Azospirillum* treatment. It was significantly superior to all other treatments. Control and $ZnSO_4$ recorded the lowest values which were comparable with NaCl, cow dung-wood ash and cow dung-SSP treatments.

At the harvest stage, the highest content of P in straw and grain were observed in *Azospirillum* and imidacloprid treatments. Control recorded the lowest P content in grain at harvest.

4.2.5.2.2 Uptake (Table 19)

The impact of seed hardening on P uptake was appreciable at all stages except in the case of uptake by straw at harvest.

Hardening with imidacloprid recorded the highest uptake of P at almost all the stages. However, at ATS *Ungu* extract recorded the highest

Table 20. Effect of seed hardening on potassium content and uptake of rice

Treatments		Content (%)					Uptake (kg ha^{-1})					
		ATS	PIS	FS	Harvest		ATS	PIS	FS	Harvest		
					Straw	Grain				Straw	Grain	Total
T_1	Control (Dry seed)	2.92	2.95	2.00	1.67	0.43	36.21	92.2	133.7	79.47	13.90	93.37
T_2	Water	3.07	2.90	2.02	1.72	0.45	49.81	90.3	136.4	73.91	17.06	90.98
T_3	KCl2%	3.17	3.05	2.10	1.75	0.45	57.63	107.1	163.7	83.55	19.49	103.00
T_4	NaCl 0.5%	3.03	2.95	2.02	1.73	0.45	43.17	107.2	152.5	84.21	18.13	102.30
T_5	KH_2PO_4 2%	3.10	2.98	2.08	1.82	0.45	38.61	106.4	159.5	82.94	19.63	102.60
T_6	$ZnSO_4$ 1%	3.05	2.92	2.05	1.78	0.40	43.99	102.1	151.1	85.04	15.64	100.70
T_7	Carbendazim 0.2%	3.07	2.95	2.05	1.72	0.43	40.67	108.7	158.0	90.24	16.25	106.50
T_8	Imidacloprid 0.05%	3.12	3.00	2.17	1.80	0.47	56.88	124.5	196.7	91.28	24.74	116.00
T_9	Cow dung 10%	3.02	2.97	1.98	1.72	0.45	45.93	97.28	144.6	77.31	16.80	94.11
T_{10}	Cow dung – Wood ash 10% each	3.02	2.92	2.03	1.58	0.43	43.81	104.1	166.3	90.89	16.29	107.20
T_{11}	Cow dung – SSP 10% and 1%	3.00	2.92	2.05	1.72	0.40	51.80	103.2	155.3	81.74	16.50	98.24
T_{12}	*Azospirillum* 2%	3.12	3.02	2.07	1.72	0.43	51.79	114.8	161.3	77.30	20.08	97.38
T_{13}	*Ungu* 1%	3.07	3.00	2.08	1.77	0.47	55.37	114.2	156.4	80.59	20.03	100.60
CD (0.05)		NS	NS	NS	NS	NS	6.57	17.1	29.9	8.91	4.55	11.02

uptake followed by imidacloprid, KCl, *Azospirillum*, cow dung and cow dung-SSP. Control and NaCl recorded the lowest values.

At PIS, the P uptake was the maximum in imidacloprid. Comparable values were recorded by *Ungu*, *Azospirillum*, KH_2PO_4, carbendazim and KCl. The lowest uptake was recorded by the water treatment and it was comparable with control, NaCl and cow dung treatments.

Imidacloprid continued to record the maximum uptake at flowering stage also. It was however, comparable with *Azospirillum* and KCl treatments. The lowest value recorded by $ZnSO_4$ was comparable with control. At harvest, there was remarkable variation in the case of uptake by grain whereas the variation was statistically non-significant in the case of uptake by straw. Imidacloprid recorded the highest uptake of 10.7 kg ha^{-1} in respect of uptake by grain and it was comparable with *Azospirillum*.

Though not significant, P uptake by straw at harvest was the highest in cow dung-wood ash treatment followed by imidacloprid treatment. The uptake was least in control at harvest stage (both in respect of grain and straw).

4.2.5.3 Potassium

4.2.5.3.1 Content (Table 20)

The variation due to treatments in the content of K was not significant at any of the growth stages. The content of K was in general high in treatments involving KCl, *Azospirillum* and imidacloprid at early stages (ATS, PIS and FS).

At harvest the content of K in grain and straw were not significantly influenced by the treatments. However, the variation among the treatments was

Table 21. Effect of seed hardening on post harvest soil NPK status (kg ha^{-1})

Treatment		Available N	Available P	Available K
T_1	Control (Dry seed)	190.3	13.23	115.73
T_2	Water	196.5	11.77	110.13
T_3	KCl 2%	204.9	13.03	108.27
T_4	NaCl 0.5%	209.1	11.13	112.00
T_5	KH_2PO_4 2%	202.8	12.70	115.73
T_6	$ZnSO_4$ 1%	219.5	12.17	102.27
T_7	Carbendazim 0.2%	211.2	13.83	117.60
T_8	Imidacloprid 0.05%	198.6	12.93	113.87
T_9	Cow dung 10%	200.7	12.43	119.47
T_{10}	Cow dung – Wood ash 10% each	206.9	13.47	121.33
T_{11}	Cow dung – SSP 10% and 1%	215.3	14.17	125.07
T_{12}	*Azospirillum* 2%	192.3	11.63	110.13
T_{13}	*Ungu* 1%	207.0	13.43	112.00
CD (0.05)		16.0	1.46	NS
Initial status		257.6	11.40	98.80

comparatively higher in straw than in grain. The highest content of 1.82 per cent in straw was recorded by KH_2PO_4 followed by imidacloprid treatment. In the case of grain at harvest, imidacloprid and *Azospirillum* treatments tended to increase the K content.

4.2.5.3.2 Uptake (Table 20)

Data pertaining to the uptake of K showed significant difference among treatments at all stages. At ATS, KCl recorded the highest uptake and it was comparable with imidacloprid, *Ungu* and *Azospirillum* treatments. The lowest uptake was observed in dry seed, KH_2PO_4 and carbendazim treatments.

Imidacloprid recorded the highest uptake of 124.5 kg ha^{-1} at PIS, which was comparable to *Azospirillum*, *Ungu* and carbendazim. The uptake was least in respect of hardening with water and control. At flowering and harvest (both grain and straw) stages the highest uptake of K was recorded by imidacloprid. At flowering stage it was comparable with *Azospirillum*, KH_2PO_4, KCl, cow dung-wood ash, carbendazim, cow dung-SSP and NaCl. In case of uptake by straw at harvest carbendazim, $ZnSO_4$, NaCl, KCl and KH_2PO_4 were on par with imidacloprid, but in flowering stage *Ungu* treatment recorded the lowest value.

4.2.6 Post harvest soil NPK status (Table 21)

Significant variation among the treatments was observed in the content of N and P in the post harvest soil samples, whereas the variation was not appreciable in respect of K.

Available N content of the soil after harvest was lower than the pre-experiment soil (257.6 kg ha^{-1}) in all the treatments. Zinc sulphate recorded the

Table 22. Economics of the treatments

Treatments	Cost of production excluding treatments (Rs. ha^{-1})	Cost of treatments (Rs. ha^{-1})	Total cost of cultivation (Rs. ha^{-1})	Mean yield (kg ha^{-1})		Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	Benefit: cost ratio
				Grain	Straw			
T_1	20783	-	20783	3199	4766	29065	8282	1.40
T_2	20783	80	20863	3782	4303	32498	11635	1.56
T_3	20783	88	20871	4324	4774	36952	16081	1.77
T_4	20783	82	20865	3998	4859	34789	13924	1.67
T_5	20783	848	21631	4362	4567	36928	15297	1.71
T_6	20783	150	20933	3910	4770	34048	13115	1.63
T_7	20783	256	21039	3756	5255	33649	12610	1.60
T_8	20783	920	21703	5335	5071	44444	22741	2.05
T_9	20783	85	20868	3750	4504	32556	11688	1.56
T_{10}	20783	95	20878	3765	5741	34392	13514	1.65
T_{11}	20783	89	20872	4125	4759	35538	14666	1.70
T_{12}	20783	130	20913	4638	4503	38770	17857	1.85
T_{13}	20783	120	20903	4306	4558	36523	15620	1.75

Cost of inputs :

KCl (Rs. kg^{-1}) = 4.48
NaCl (Rs. kg^{-1}) = 4.00
KH_2PO_4 (Rs. kg^{-1}) = 384.00
$ZnSO_4$ (Rs. kg^{-1}) = 70.00
Carbendazim (Rs. kg^{-1})= 880.00

Imidacloprid (Rs. kg^{-1}) = 3000.00
Cow dung (Rs. kg^{-1}) = 0.50
Wood ash (Rs. kg^{-1}) = 1.00
Single Super Phosphate (Rs kg^{-1})= 4.00
Azospirillum (Rs. kg^{-1}) = 25.00

Price of produce :

Grain (Rs. kg^{-1}) = 7.00
Straw (Rs. kg^{-1}) = 1.40

Data not statistically analysed

highest available N content (219.5 kg ha^{-1}) among the treatments. It was on par with cow dung-SSP, carbendazim, NaCl, *Ungu*, cow dung-Wood ash and KCl treatments. Control plot recorded the lowest value.

Content of available P in soil after harvest was slightly higher than the pre-experiment soil (11.4 kg ha^{-1}) in all treatments except NaCl treatment. The highest value was recorded by cow dung-SSP treatment. Carbendazim, cow dung-wood ash, *Ungu*, dry seed, KCl, imidacloprid and KH_2PO_4 recorded comparable values.

Available K content of the soil after harvest was higher in all the treatments compared to the pre-experiment soil (98.8 kg ha^{-1}). Though not significant, cow dung-SSP and cow dung-wood ash recorded the highest available K content among the treatments.

4.2.7 **Economics of the treatments** (Table 22)

Among the seed hardening treatments, imidacloprid and KH_2PO_4 required more costs for adoption. The highest gross and net incomes were derived from imidacloprid followed by *Azospirillum*. Other hardening treatments were slightly better than control in net income but considerably higher in gross income. The benefit cost ratio was the highest for imidacloprid treatment (2.05) closely followed by *Azospirillum* (1.85). The benefit cost ratio was the least for dry seed control. This was followed by water and cow dung treatments.

Discussion

5. DISCUSSION

Dry seeded lowland (semi-dry) rice is the major cultural system in Kerala during first crop season, necessitating increased research efforts to make this system more viable and economical. This chapter encompasses the discussion on the results of the investigations conducted at Agricultural Research Station, Mannuthy to evaluate the effect of seed hardening treatments on establishment, growth and productivity of semi-dry rice under moisture stress situations.

Semi-dry rice is established through sowing dry seeds of rice in well prepared unpuddled lowland soils when the soil moisture condition is favourable with the receipt of few pre-monsoon showers. Field submergence is not practiced until the crop reaches 3-4 leaf stage, i.e. upto around six weeks after sowing, and upto this period the crop is grown just like any other upland crop. During the initial stages, the water requirement of the crop is met through the few pre-monsoon showers it receives. Such showers are often inadequate in quantity or are ill distributed, exposing the crop to moisture stress of varying degree. Even though the moisture stress is limited to the initial growth stages of the crop i.e. until the onset of regular monsoon, it can cause permanent strain to the crop leading to drastic yield reduction (Sahu and Rao, 1974; Sudhakar *et al.*, 1989 and Fussel *et al.*, 1991). Several reports suggest that alleviation of the moisture stress during early stages can improve the germination, ensure adequate plant population, enhance the seedling vigour and finally contribute to increased growth and yield (Turner *et al.*, 1986 and Ramakrishnayya and Murty, 1991).

Pre-sowing hardening of seeds is one of the low cost and effective technology suggested for incorporating characters that are favourable for drought tolerance in rainfed crops through modification of the physiological and bio-chemical nature of the seed (Joseph and Nair, 1989 and Rangasamy *et al.*, 1993). Water, solutions of growth regulating compounds and salts, plant extracts, organic materials etc. have been employed for hardening of seeds in different crops. The efficacy of different materials for hardening of rice seeds has been tested in the present study.

During hardening, quantity of water or solution used should be such that it would just be enough for imbibition during a stipulated period and not in excess. Excess water may cause leaching out of seed constituents (Sinha, 1969). Accordingly, 1000 ml solution per kg of seed was used for hardening the seeds in the present study and the hardening was done for a period of 18/24 h. Sinha (1969) recommended a period of 24 h for hardening rice seeds.

5.1 Germination and seedling population

Maintenance of adequate plant population is an essential pre-requisite for achieving high productivity in any rice culture. However the occurrence of moisture stress often leads to inadequate plant population in rainfed rice, particularly in dry seeded rainfed rice. The influence of seed hardening in ensuring adequate plant population through improved germination and survival of seedlings in dry seeded rainfed rice was very clearly brought out from the study.

The variation in germination percentage among treatments was very evident in the laboratory study undertaken under controlled condition (Table 2 and Fig.3). Though the field study also showed almost a similar trend, it was of low magnitude (Table 5 and Fig.4). The variation in soil moisture content, depth of sowing etc. under field situation might be the reason for the failure of the treatments to fully manifest the effects in the field study.

As compared to unhardened seeds, hardened seeds showed significant improvement in germination, particularly on five and ten DAS in respect of laboratory study, but the treatment variation become non-significant at 15 DAS. At five DAS, hardening with imidacloprid, *Azospirillum*, *Ungu*, KH_2PO_4 and KCl recorded appreciably high germination percentage. At ten DAS, almost all the treatments involving hardening (except water and cow dung) recorded remarkably high germination percentage over control.

The data shows that the variation in the germination percentage at different dates of observation is owing to the variation in the effect of treatments in inducing earliness in germination. While hardening with imidacloprid recorded germination percentage of 90 per cent even on five DAS, the control treatment (dry seed as well as hardening with water), took 15 days to reach the same percentage of germination. Data on the speed of germination (Table 2) also shows that hardened seeds germinated quicker. Several authors reported early and better germination due to seed hardening (Urs *et al.*, 1970; Singh and Chatterjee, 1980 and Joseph and Nair, 1989).

Germination involves hydration and inbibition as the first step and during soaking of the seed for inducing hardening, seeds would become physiologically advanced by carrying out some of the initial steps of germination. Subsequent improvement in germinability of the hardened seed

Fig. 3. Effect of seed hardening on germination percentage under laboratory condition

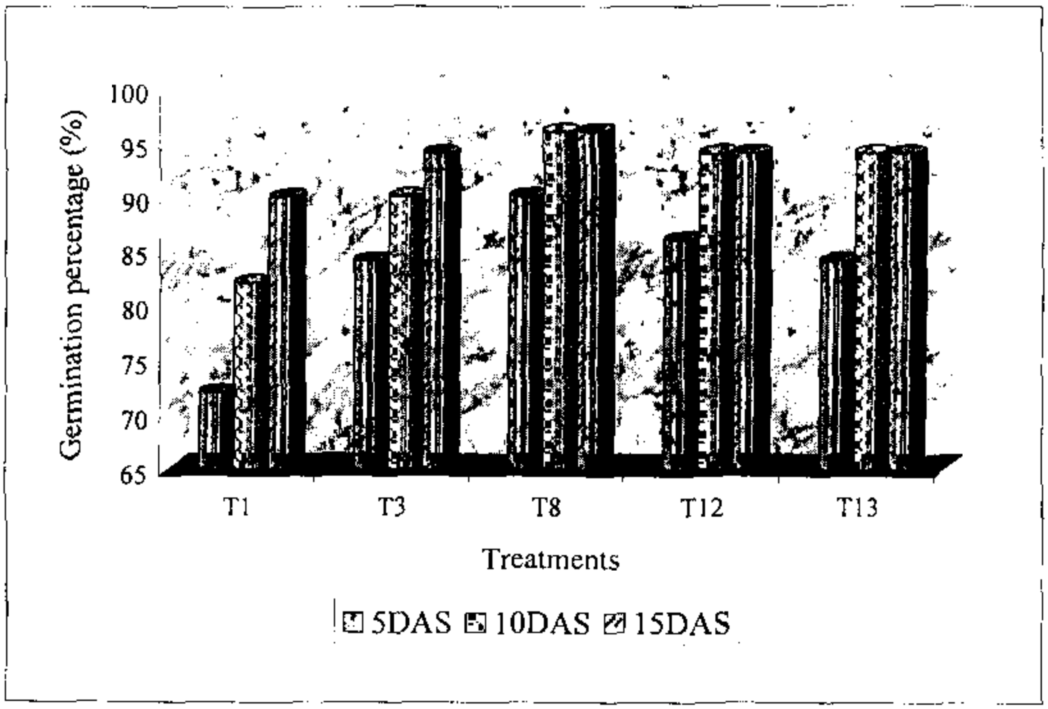
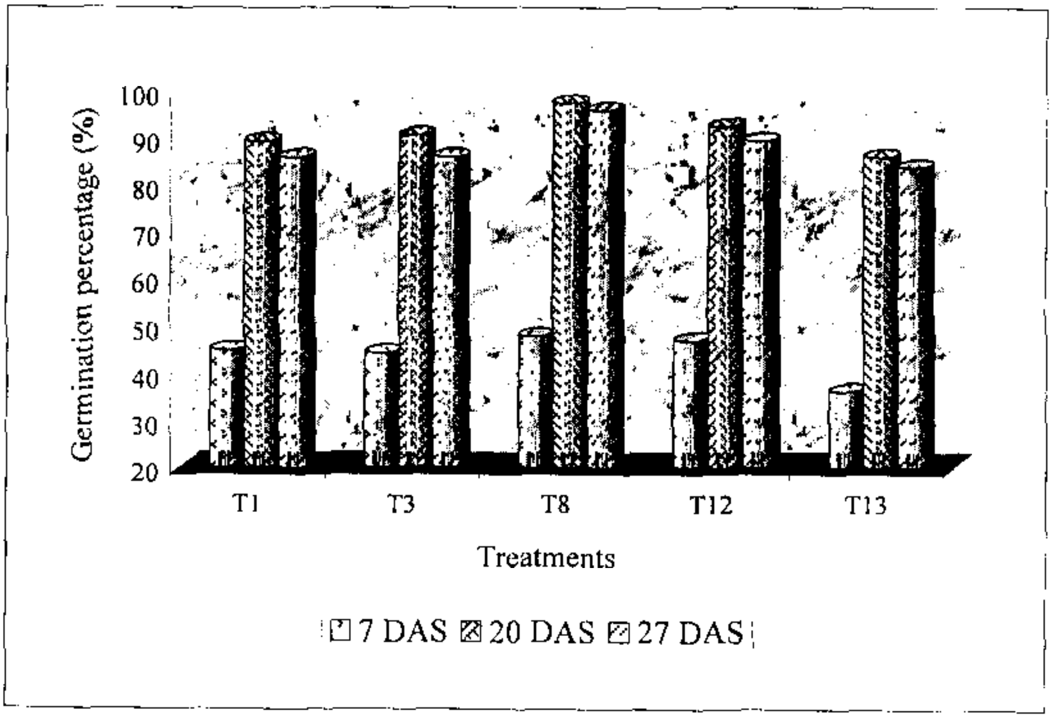


Fig. 4. Effect of seed hardening on germination percentage under field condition



could be due to the fact that such advanced seed would retain viability to carry on where they left upon germination (Joseph and Nair, 1989). According to Bradford (1986), early germination due to seed hardening could be attributed to the reduction in time lag for pre-germinative metabolic activity which it had already undergone during the hardening process.

The data on the density of seedlings (Table 6 and Fig.8) gives a clear picture about the earliness in germination and survival of the seedlings as influenced by different treatments. It took around 15 days for the treatment involving dry seed to reach a seedling density of 300 seedlings m^{-2}, while imidacloprid recorded more than 300 seedlings m^{-2} even on 9 DAS. After reaching the peak population during 13 to 20 DAS, depending upon the treatments, there was a decline in seedling number in almost all the treatments due to seedling mortality. It can be seen that the mortality of seedlings was the highest in dry seeds leading to the lowest seedling population of 253.7 seedlings m^{-2} on 27 DAS. The seedling density was the highest in the treatments hardened with imidacloprid, followed by hardened treatments like *Azospirillum*, KCl, $ZnSO_4$, *Ungu*, NaCl, KH_2PO_4 carbendazim, cow dung - wood ash and cow dung - SSP. This indicates that hardening of seeds could bring down the mortality of seedlings in moisture stress situation experienced under dry seeding in the field.

The induction of early germination and improved survival of seedlings play a significant role in the crop performance. Early germinated seedlings can compete with weeds for moisture, nutrients and light and can putforth increased vegetative growth. Early and quick germination can ensure a

Fig. 5. Effect of seed hardening on number of seedlings m^{-2}

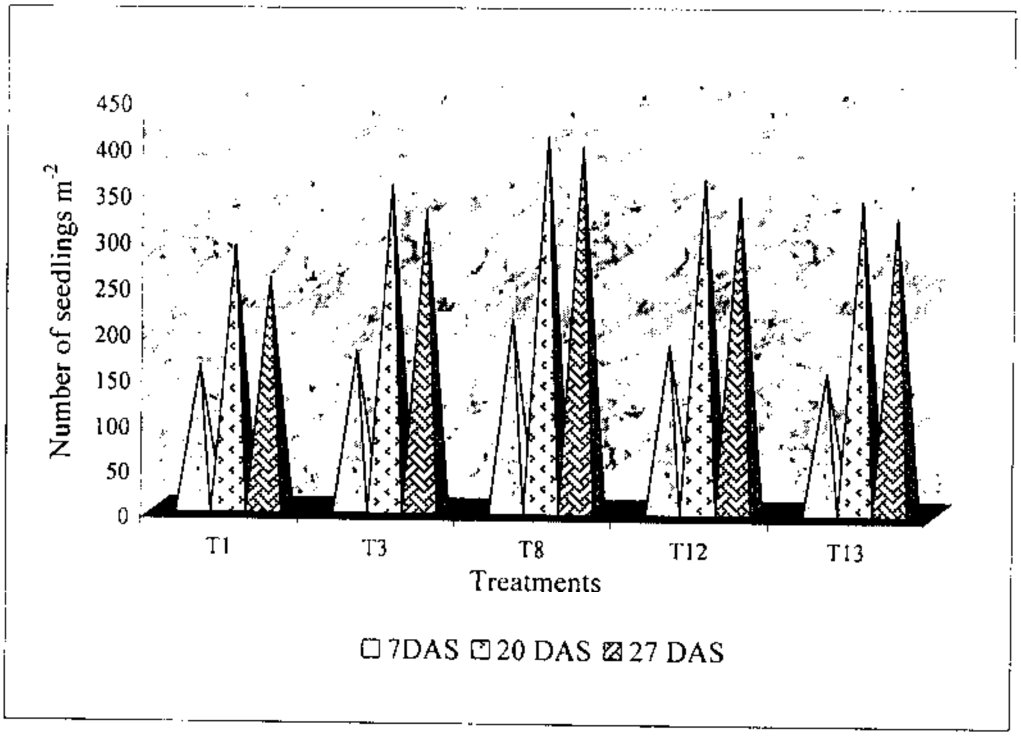
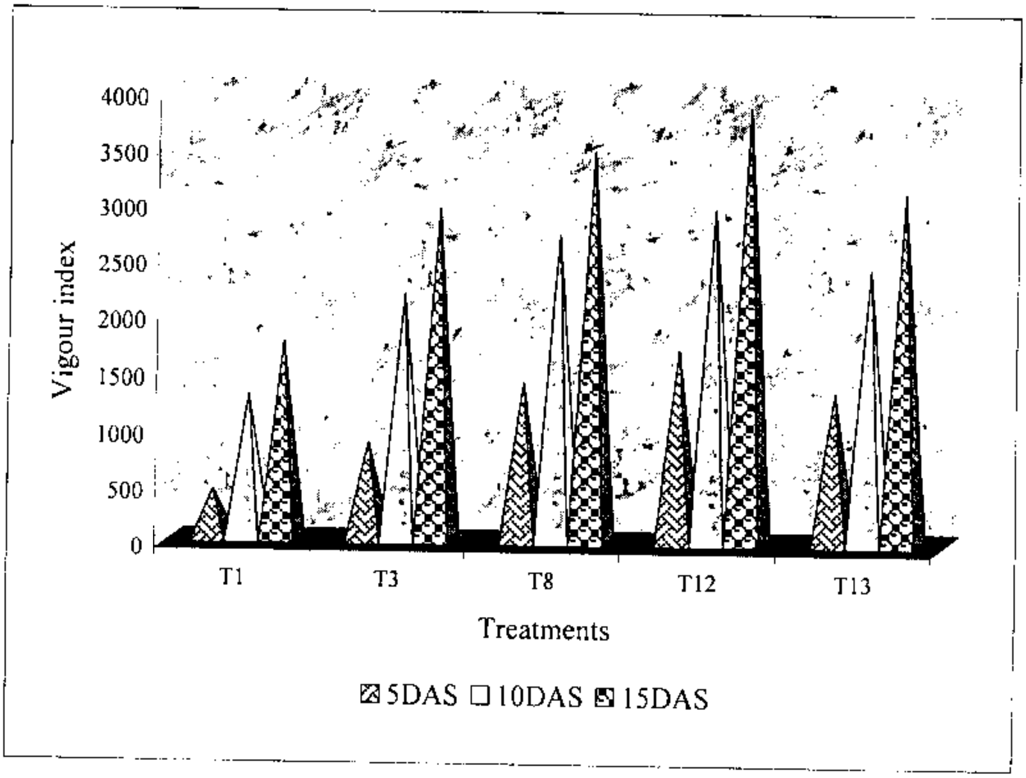


Fig. 6. Effect of seed hardening on vigour index



uniform crop stand. A uniform crop stand with optimum plant population is a very critical factor deciding the yield of the crop.

While considering the data on germination percentage, seedling population and speed of germination at different periods of observation, it could be seen that imidacloprid, followed by *Azospirillum* consistently showed good results. KH_2PO_4, KCl, *Ungu* and cow dung-SSP were the other superior treatments. Imidacloprid is a new systemic insecticide, belonging again to a new group of active ingredients, the nitroguanidines. Because of the excellent systemic activity and relatively low rate of application it is recommended as a seed dressing chemical, particularly against sucking pests. The effectiveness of imidacloprid solution for seed hardening is reported for the first time from the present study. However, phytotonic effect in imidacloprid treated plots, particularly when applied as seed treatment was reported earlier by Gupta *et al.* (1995) in cotton. Phytotonic effect due to priming with imidacloprid was noted in rice from the present study, which is discussed in details elsewhere. Improved germination percentage and reduced mortality of seedlings in treatments involving hardening with imidacloprid indicate that the same chemical can be used to serve two purposes i.e. for hardening and seed dressing, which is advantageous to the farmer.

Apart from the beneficial effect due to seed hardening *per se*, seed biofortification with *Azospirillum* increased amylase activity (Ramamoorthy *et al.*, 2000), which also might have encouraged the early emergence of seedlings in this treatment. Increased rate of germination due to seed biofortification with *Azospirillum* has been reported by Ramamoorthy *et al.* (2000). KH_2PO_4 and

KCl has been reported by several authors as very effective salts for inducing hardening in different crops (Kuppusamy *et al.*, 1992; Sujatha, 1994; Palanisamy and Punithavathi, 1998 and Salakinkop *et al.*, 1998) with advantages of improved germination and reduced seedling mortality.

Use of organics, including botanicals, is off late encouraged in crop production due to several reasons. If locally available materials are identified as suitable for the seed hardening process, it will be of immense help to farmers for its immediate adoption at low cost. In the present study, seed hardening with leaf extract of *Ungu* showed improved performance over control, in terms of germination percentage, speed of germination and seedling survival. Sabir Ahmed (1989), Saraswathi (1994) and Nurghis (1995) also employed leaf extract of *Ungu* for seed hardening. Nagaraj (1996) reported that plant products could correct or improve the soil moisture potential, soil moisture diffusivity, water diffusivity of seeds and seed-soil interface characteristics, influencing the germination of seeds favourably. According to Nurghis (1995), coating with leaf powder of *Ungu* could act as a wick in absorbing, regulating and correcting the soil moisture availability in the root zone favouring better seed-soil relationship.

Among the three treatments involving cow dung extract, performance was in the order of cow dung-SSP, cow dung-wood ash and cow dung in that order, and cow dung-SSP was appreciably superior in most of the cases. Apart from the beneficial effect of cow dung, nutrient enrichment may be one reason for the variation in the effect. The beneficial effect of cow dung extract treatment in increasing seed germination was attributed to the presence of physiologically active substance in it (Joseph and Nair, 1989).

5.2 Seedling growth

The growth attributes of seedlings viz., shoot length and dry matter (Tables 2, 3, 7 and 9 and Fig.7) showed significant variation among treatments both in the laboratory and field study (observation on 15 DAS in respect of field study). In respect of laboratory study, almost all the treatments appreciably increased the shoot length and shoot weight (except water, NaCl, cow dung, codung-wood ash and $ZnSO_4$ at different stages) over the dry seed. However, *Azospirillum* and *Ungu* performed remarkably better among the hardening treatments. In respect of field study, imidacloprid and *Azospirillum* exhibited improved growth characters.

The physiological advancement of seeds during seed hardening might have improved the seedling growth in the treatments involving hardening. Joseph and Nair (1989) attributed enhanced metabolic activity and earliness in germination for the improved seedling growth in hardened treatments. According to Cutler *et al.* (1980), drought hardening enhances the capacity to maintain turgor and turgor mediated processes in the seeds, resulting in better survival of seedlings. Beneficial effect of seed hardening on seedling growth was reported by Hafeex (1969) in sorghum and Sheela *et al.* (1998), Andoh and Kobata (2000), Ramamoorthy *et al.* (2000) and Slaton *et al.* (2001) in rice.

Vigour index was significantly improved by seed hardening (Table 4 and Fig.6). Use of *Azospirillum* and *Ungu* extract were found to be the best in

Fig. 7. Effect of seed hardening on shoot length

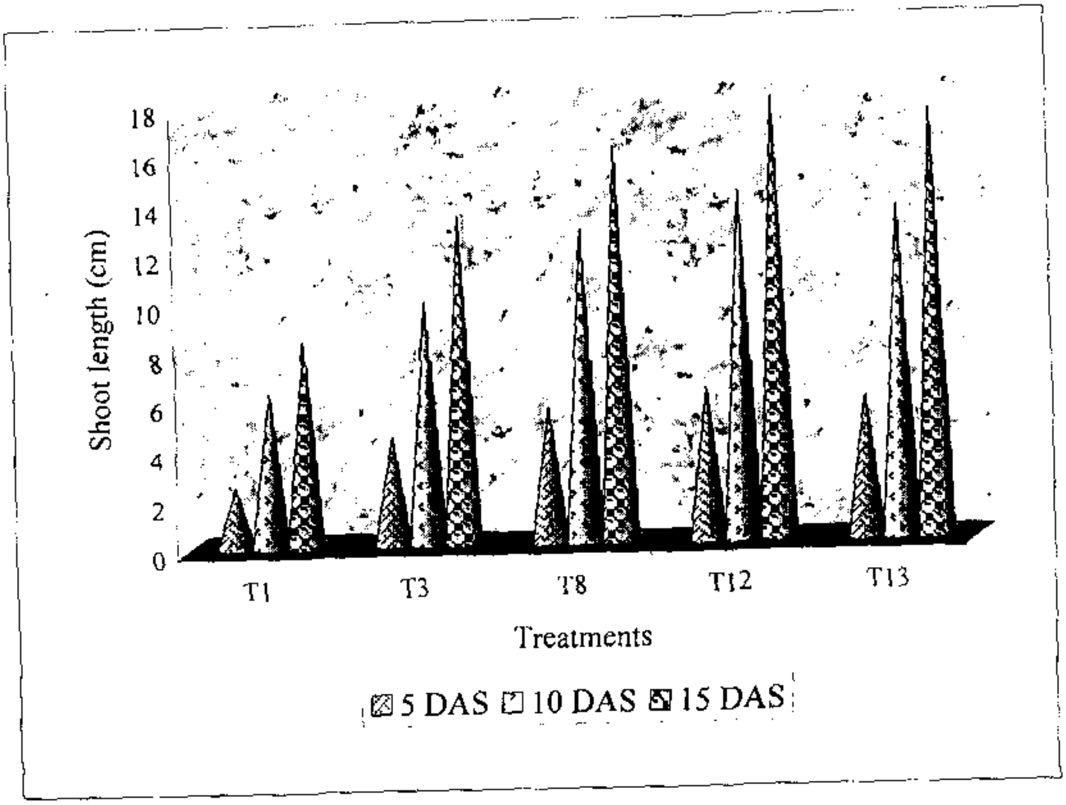
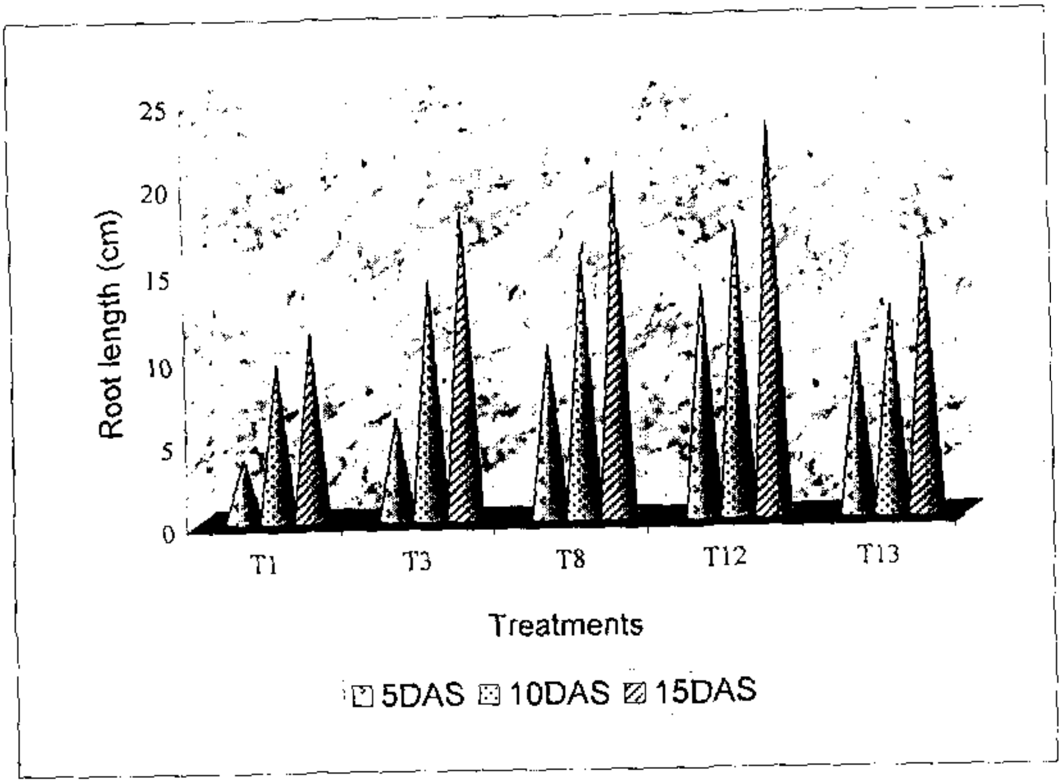


Fig. 8. Effect of seed hardening on root lengh



the laboratory trial. This was attributed to the enhanced germination percentage and seedling growth recorded in these treatments. Abdulbaki and Anderson (1973) found that the vigour index served as a reliable criterion for the assessment of seed vigour. Basu *et al.* (1974) and Singh and Chatterjee (1981) reported that seed hardening increased the vigour of upland rice in the early stages.

5.3 Growth and growth characters

Significant improvement in growth components such as plant height, tiller number and leaf area index, due to seed hardening was observed at different growth stages. Imidacloprid, *Azospirillum* and *Ungu* were found to be the best treatments while comparing the different growth attributes at different stages. KCl, KH_2PO_4 and cow dung-wood ash were other promising treatments.

The early vigour of the seedlings in hardened treatments enables them to withstand adverse situation in the field and putforth good vegetative growth. As discussed earlier, the treatments exhibiting increased vegetative growth were superior in respect of seedling growth and vigour index.

A well developed root system observed in the study in the treated plants enabled them to improve their foraging ability leading to higher RLWC and nutrient uptake and subsequently the vegetative growth. According to Aspinall *et al.* (1964), drought hardening reduced the rate at which critical levels of RWLC declined and thereby maintained the growth.

Positive influence of seed hardening on the improvement of growth characters such as plant height (Sinha, 1969; Urs *et al.*, 1970 and Narayanasamy, 1985), tiller number (Chockalingam, 1986; Mathew, 1989 and

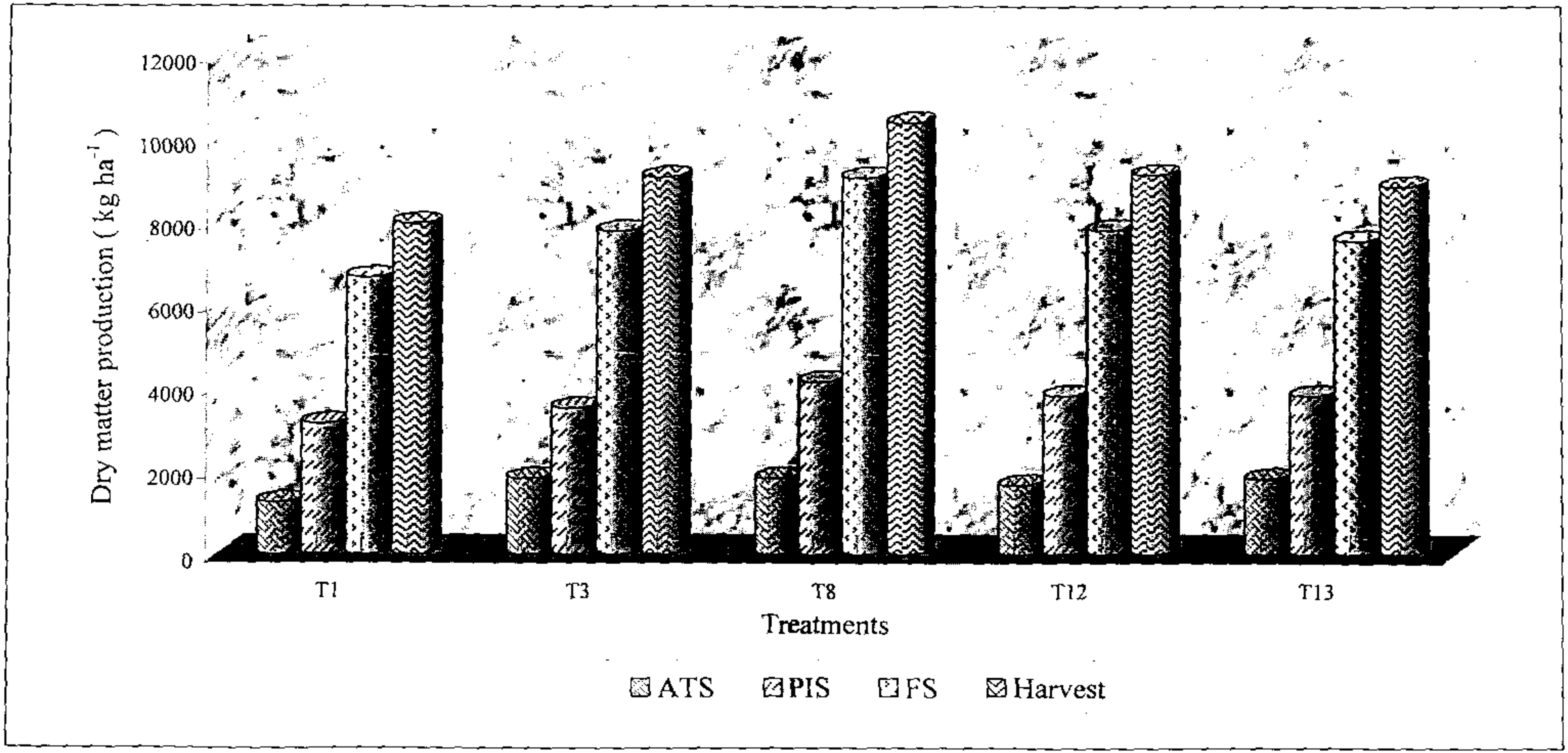
Paul and Choudhury, 1991) and leaf area index (Dakshinamoorthy and Sivaprakasam, 1989 and Basu *et al.*, 1974) were reported by several authors.

Considerable variation in dry matter production was observed among treatments due to hardening. Though the difference was significant only at the initial stages, the trend continued in the latter stages also. A perusal of the overall data on DMP at different growth stages showed that imidacloprid followed by *Azospirillum* were the superior treatments (Fig.9). Other treatments, which showed impressive increase in DMP as compared to control, were cow dung-SSP, *Ungu* and KCl. Increase in DMP due to seed hardening were also reported by Narayanasamy (1985), Chockalingam (1986), Mathew (1989) and Sheela (1993).

Early emergence, vigourous seedlings and tolerance to stress under adverse soil moisture conditions are the major contributing factors that enabled the hardened plants to putforth increased vegetative growth. Well developed root system of the treated plants improved the nutrient uptake (Tables 18, 19 and 20), favoring vegetative growth and subsequent improvement in DMP. Assimilation of photosynthates was favoured in hardened plants due to increased LAI (Table 13) and relatively high RLWC (Table 16).

According to Jayaraj (1977) increase in dry weight in hardened treatments is attributed to greater vigour reflected in early germination and higher percentage of germination of the seeds that had reached auto-trophic stage well in advance of others. Increase in dry weight might also be due to enhanced lipid utilization through glyoxalate cycle, a primitive metabolic pathway (Vanni and Vincenzini, 1972) thereby facilitating the conversion of

Fig. 9. Effect of seed hardening on dry matter production (kg/ha)



acetate into nucleic acid as quoted by Weiss (1971) leading to faster growth and development of seedlings to reach auto-trophic stage well in advance of others and enabling them to produce relatively more quantity of dry matter.

5.4 Root characters and shoot : root ratio

Improvement in root characters by seed hardening was observed in laboratory and field trials (Tables 3, 8, and 10 and Fig.8). Among the seed treatments, imidacloprid and *Azospirillum* treatments were observed to be better than the others in improving the root characters. KCl, *Ungu*, cow dung- wood ash, cow dung-SSP and KH_2PO_4 were other promising treatments. The primary changes occurring in the physico-chemical properties of the cytoplasm due to pre-sowing seed hardening determined a series of changes including a more efficient root system (Singh and Chatterjee, 1981). Similar results were also reported by Narayanasamy (1985), Mathew (1989) and Sheela (1993). Dewan and Rao (1979) reported that root biomass of rice seedlings was increased due to inoculation with *Azospirillum brasilense*. The increase in root biomass can be attributed to plant growth promoting substances, thus providing maximum surface area for the absorption of nutrients. This, when coupled with the fixation of nitrogen *in vivo*, may result in the increased performance of the inoculants. Clements and Jones (1978) noted that modification of root system in response to 'sublethal drought' might confer a more permanent advantage on the plant.

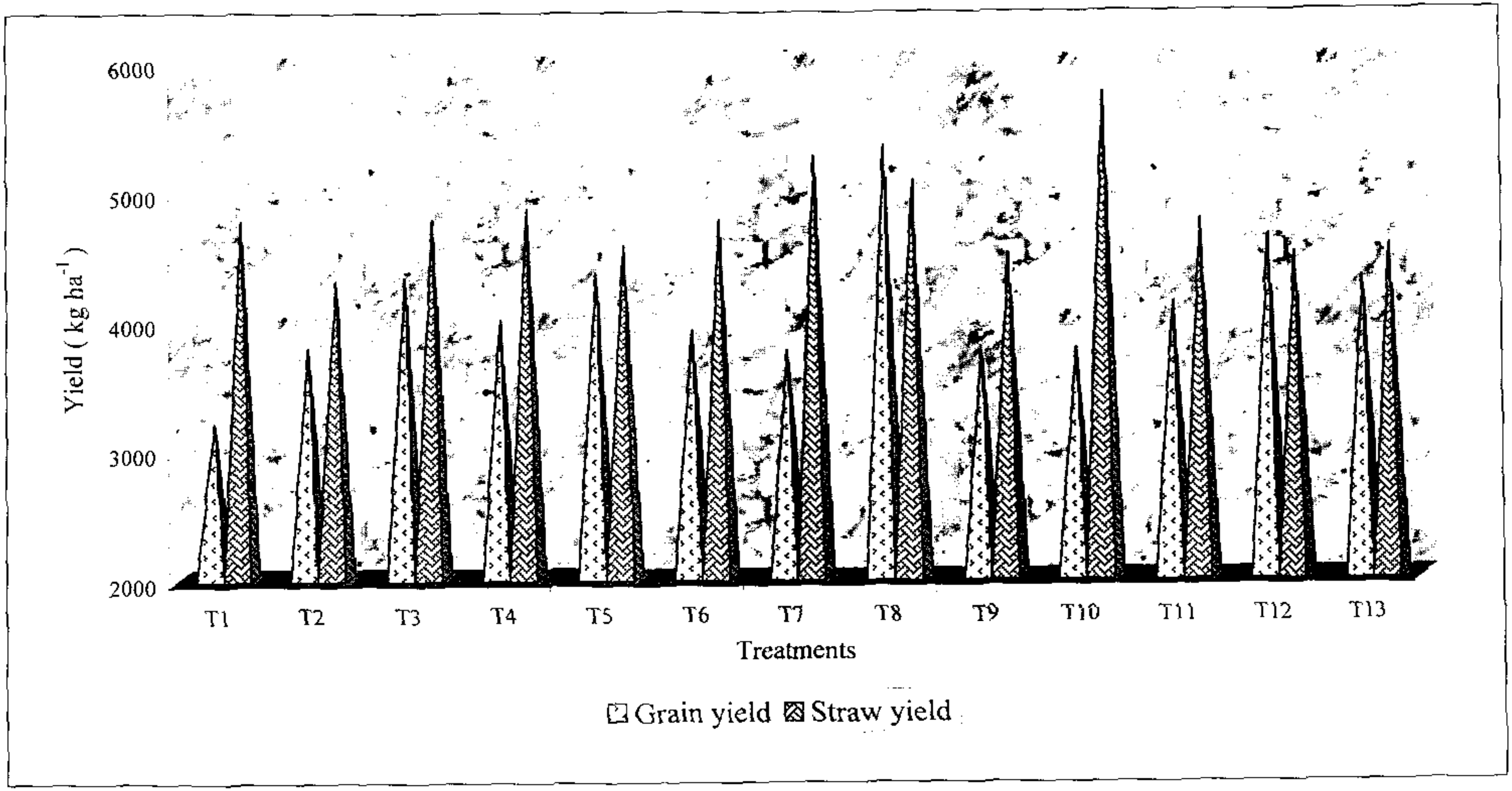
In the laboratory trial, shoot : root ratio was influenced significantly by seed hardening treatments only on the fifth day (Table 4). Though significant only at 30 DAS and FS, shoot : root ratio showed an increasing trend in hardened plants in the field trial. Seed treatment with carbendazim increased the shoot : root ratio as compared to other treatments. KH_2PO_4, NaCl, KCl and *Ungu* were other promising treatments. This can be attributed to the increased contribution of roots towards total dry matter, revealing the effect of seed hardening on root proliferation, which in turn increased the root weight. Similar results were also recorded by Narayanasamy (1985), Fletcher and Hofstra (1990) and Sheela (1993).

5.5 Yield and yield attributes

The grain yield and most of the yield related parameters, except 1000 grain weight, were significantly influenced by the seed hardening treatments. An overall perusal of the data clearly shows constantly superior performance by imidacloprid and *Azospirillum* in respect of yield and yield attributes. KCl, KH_2PO_4 and *Ungu* also recorded significantly higher grain yield over control, but was inferior to imidacloprid. However, variation in straw yield due to treatments, did not reach the level of significance.

The yield increase due to seed hardening over control ranged from 551 to 2136 kg ha^{-1}. Hardening with imidacloprid has registered the highest grain yield of 5335 kg ha^{-1} and was comparable with *Azospirillum* treatment (4638 kg ha^{-1}). Both these treatments were significantly superior in yield over the other treatments. Significantly higher yields, over control, were also obtained in KCl, KH_2PO_4 and *Ungu*. Seed hardening increased the yield over the dry seed by 2136 kg ha^{-1} in respect of imidacloprid and 1439 kg ha^{-1} in respect of *Azospirillum*. This worked out to an increase of 67 per cent and 45 per cent, respectively over the dry seed control (Table 14 and Fig. 10).

Fig. 10. Effect of seed hardening on yield of rice (kg ha^{-1})



The increase in grain yield in high yield treatments can mainly be attributed to the increase in number of panicles m^{-2} and number of filled grains per panicle. Increase in plant population and tiller production per m^2, through improved germination and reduced seedling mortality, has contributed largely to the increased number of panicles. Increased percentage of filled grains favoured the production of more number of grains per panicle.

Seed hardening enabled the plants to withstand moisture stress, as observed by high RLWC. Enhanced root growth was another important character favoured by hardening. These improvements in plant characters reflected in increased nutrient uptake in the high yielding treatments. Consequent improvement in vegetative growth and photosynthate production led to improved yield attributes and finally yield.

Increased number of panicles (Ramanathan, 1980; Singh and Chatterjee, 1980 and Kundu and Biswas, 1985) and percentage of filled grains (Singh and Chatterjee, 1981; Devika, 1983 and Chockalingam, 1986) were reported by several authors due to seed hardening. Improvement in grain yield by seed hardening have been reported by Sheela *et al.* (1998), Tang *et al.* (1991) and Pathak et al. (1999)

5.6 Physiological parameters

In respect of physiological parameters, the variation was not significant in the case of chlorophyll content, whereas RLWC differed significantly among treatments at 30 DAS and ATS. However seed hardening facilitated an increasing trend in chlorophyll synthesis in hardened plants. Among the different treatments, *Ungu* treatment recorded the maximum content of chlorophyll (Table 15). Improvement in nutrient uptake (Tables 18, 19 and 20) in hardened plants might have facilitated increased chlorophyll synthesis in these treatments.

Hardened plants maintained higher RLWC than control (Table 16). Among the different treatments, KH_2PO_4 and *Ungu* treatment recorded maximum value of RLWC followed by imidacloprid and KCl (Table 16). Cow dung-wood ash and cow dung-SSP were the other promising treatments. The result indicated the ability of these treatments to hold water better than others, under stress. Levitt (1972) reported that hardened seeds showed better ability to hold water against dehydrating forces since the adapted protoplasm did not become rigid and brittle as quickly as in the unadapted plants. The development of better root system by the hardened plants enabled better moisture absorption from the soil which in turn, increased the RLWC. This result was in agreement with the findings of Singh and Chatterjee (1981) and Sheela (1993). The moisture stress in the field study was relieved in the latter stages with the receipt of south-west monsoon due to which no variation in RLWC was observed in the latter stages.

5.7 Nutrient uptake by crop and soil nutrient status

The NPK uptake by the crop was significantly influenced by seed hardening treatments at almost all the growth stages. The post-harvest nutrient status showed appreciable variation among treatments only in respect of nitrogen and phosphorus.

The total nutrient uptake by a crop is affected by the percentage of nutrients in the dry matter and the quantum of dry matter production. Though the nutrient content did not show significant variation among the treatments at different growth stages, dry matter production showed appreciable variation among the treatments. This led to significant variation among the treatments in respect of NPK uptake at different growth stages. Increase in nutrient uptake by seed hardening was earlier reported by Chockalingam (1986) and Sheela (1993).

Nitrogen uptake varied significantly at all the growth stages with imidacloprid recording the highest value (Table 18 Fig.11). The highest P and K uptake were recorded by imidacloprid followed by *Azospirillum* treatment at all stages except at ATS wherein *Ungu* recorded the highest value of P uptake and KCl recorded the highest value of K uptake (Tables 19 and 20 and Fig.12 and 13). Amelioration of moisture stress in hardened plants enabled them to facilitate enhanced nutrient absorption. Reduction in NPK uptake of rice due to moisture stress was reported by Reddy and Kuladaivelu (1992) and Sheela (1993). Exploitation of larger volume of soil by viture of more root length and volume, as revealed by the data on root characters, facilitated increased nutrient uptake. Imidacloprid and *Azospirillum*, in particular, and the hardened treatments in general increased the root proliferation, in terms of root length and weight, thereby facilitating higher uptake of all nutrients. In respect of *Azospirillum* treatment, improved nitrogen availability in the rhizosphere and the solublization of unavailable form of phosphorus to available form also contributed towards increased N and P uptake, respectively.

Fig. 11. Effect of seed hardening on nitrogen uptake at harvest (kg/ha).

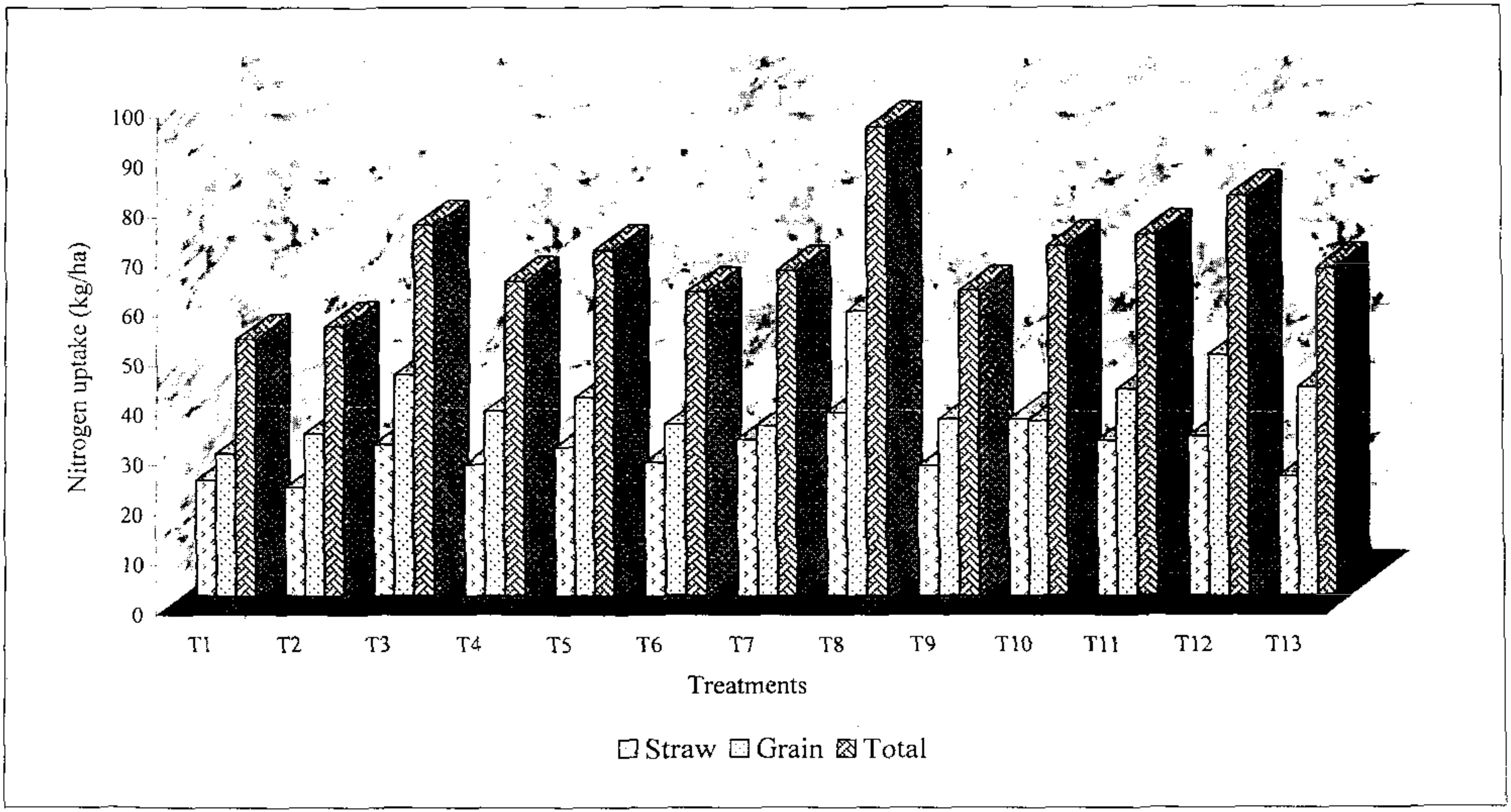


Fig. 12. Effect of seed hardening on phosphorus uptake at harvest (kg/ha)

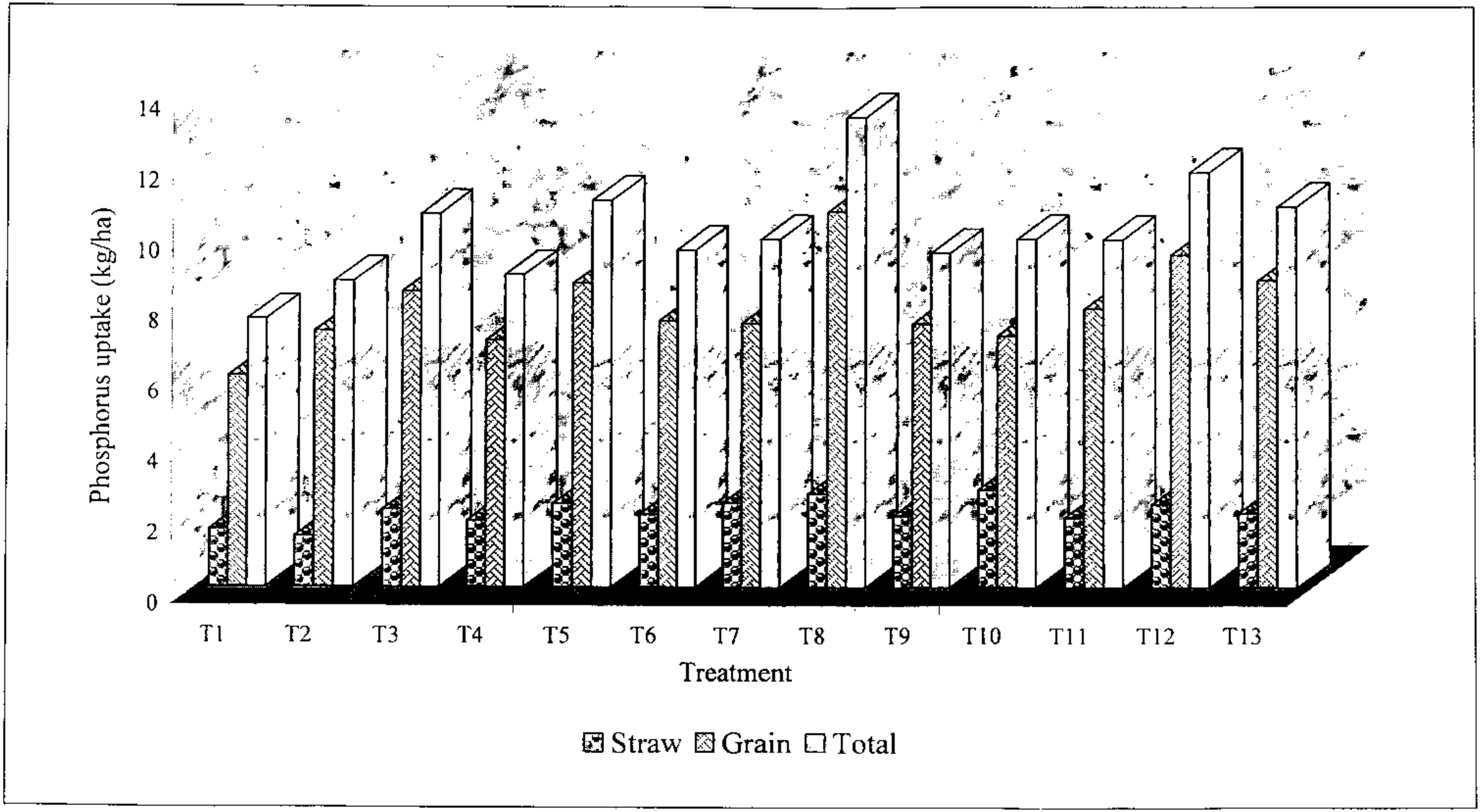
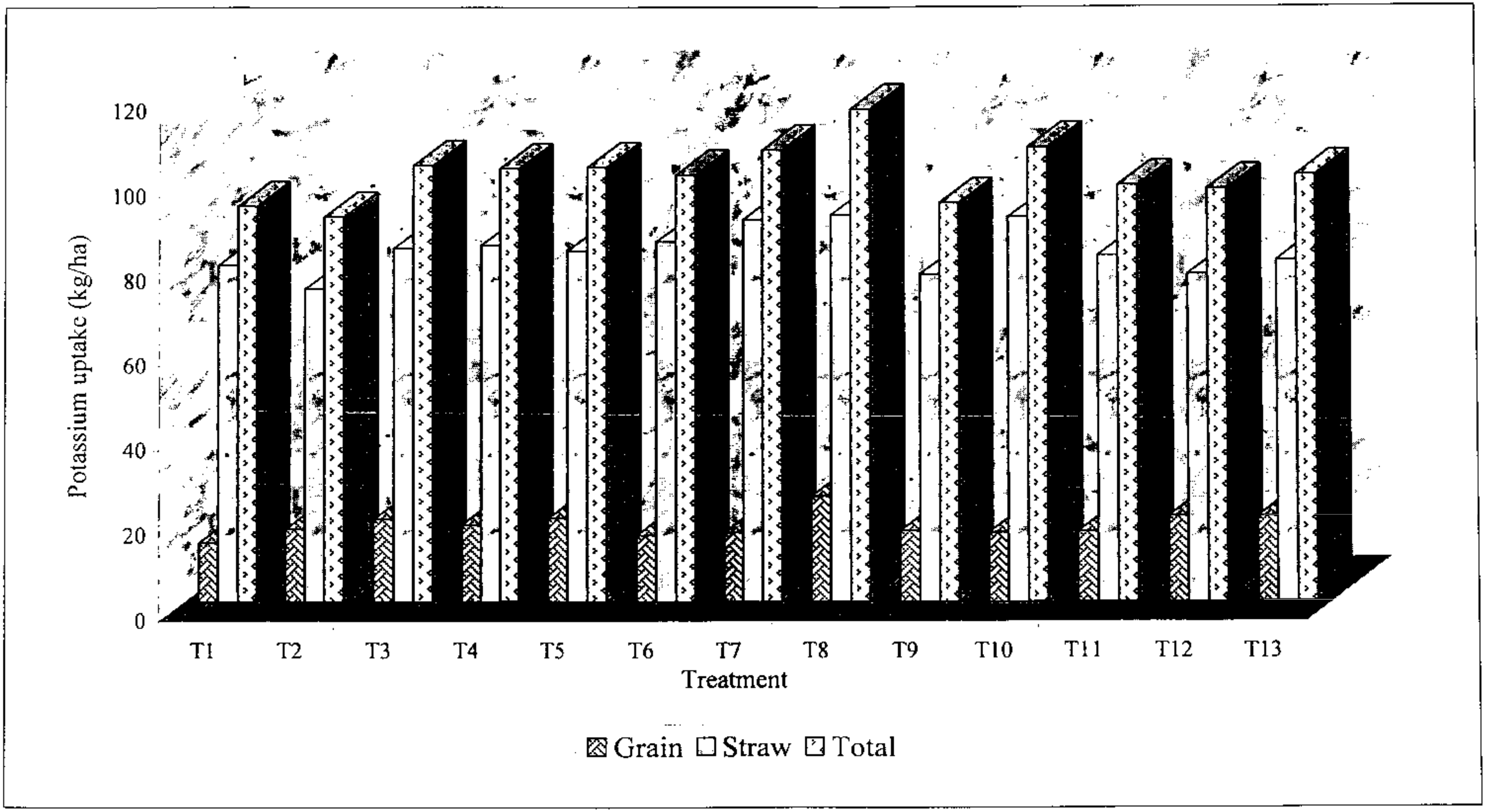


Fig. 13. Effect of seed hardening on potassium uptake at harvest (kg/ha)



5.8 Phytotonic effect of treatments

A critical perusal of the data on crop performance have revealed the distinct superiority of imidacloprid, over control as well as other seed hardening chemicals, in improving growth and productivity of rice. This superiority had been comparable with *Azospirillum*, which is known to have effects other than those attributed to seed hardening. This comparison implied that imidacloprid has affected the growth and productivity of rice through ways other than those attributed to seed hardening. The validity of this conclusion is supported by the sustained superiority of the invigorated growth manifested in the early stages by the treatment to the end. This resulted in an yield improvement of the order of 1000 kg ha^{-1}. This yield improvement has not been due to the effect of attributed to the process of seed hardening alone is further confirmed by the significantly higher level of absorption of major nutrients as well as the improved grain : straw ratio. These effects of imidacloprid was found to exert additional positive effects on growth and productivity other than the original objective. Thus the additional improvement in growth and yield termed as lateral positive effect, which was due to an invigorated metabolic process, is referred here as phytotonic effect. Phytotonic effect can be defined as the additional positive advantages in growth and development other than the direct effect for which the input process has been used.

So phytotonic effect is a lateral effect other than the expected positive effect of the chemical in the sense that it is an unexpected effect of the input used. Conversely, it can also be stated that phytotonic effect is the net effect or it is the net additional derivative of removing the persistent inhibition on realizable productivity which could not be removed through use of conventional management inputs. Not realized yield in a given situation can be designated as the product at rate of reactions. Therefore phytotonic effect is the resultant removal of inhibition of metabolic rate.

A comparison of the growth of rice under imidacloprid and azopsirillum treatments shows that both of them have acted in similar lines. The positive effects of *Azospirillum* stems not merely from the increased nitrogen availability, but also from its effects on regulation of hormones and auxins in the plant. The fact that the germination phase do not require any additional inputs of nutrients, points out to the fact that increased growth in this phase has resulted from the direct effects through auxins and hormones. Thus phytotonic effect, in terms of net advantages in growth and productivity, appears to result from the indirect effect of the inputs on Auxin and hormonal regulation of the metabolic systems of the plant.

A perusal of the data on growth biometrics like root length, plant height and DMP of shoot and root have shown that the tonic effect has been expressed more on DMP and height of plant or length of root. Increased height of plant and length of root as a result from cell expansion, which is a physical effect, but a significant improvement in DMP of both shoot and root which was manifested through out the growth cycle have pointed out that the phytotonic effect has resulted from increased photosynthetic activity and net photosynthetic accumulation which were bestowed by the persistant metabolic advantages derived from the seed treatment with the particular chemical.

The data on shoot : root ratio have shown that the improvement in quantitative production of shoot and root has been merely through increased DMP and that the chemical has not modified the natural pattern of use of photosynthates.

Yoshida and Hasengawa (1982) have stated that ideal shoot : root ratio of rice at active tillering is 10:1. However in the present study the ratio was around 4.0, indicating excessive root production during this growth stage. Excessive consistent root production is a reflection of root damaged to root production, which in tern is direct effects of soil; Bridgit (1999) have reported excessive root production and damage in laterite soils due to the extraordinary Fe content in soil. Incidentally these results would imply that the yield advantages, would have been far more higher had the soil not been suffering from excess Fe content. The possibility of realization of still higher yield levels by combining the use of imidacloprid with ameliorative management for containing the excess Fe content can not be roled out. A scrutiny of the number of tillers m^{-2} at active tillering phase and moving pattern of tiller count, there after will show that imidacloprid treatment has produced the maximum number of tiller (615 m^{-2}) which was 15 per cent more than that of *Azospirillum*. This excess tiller production is further 33 per cent increase in PIS, would be normally unexpected in ideal cropping situations. A 45 per cent increase in tiller count after active tillering is normally an unexpected behaviour in rice and these tillers subsequently declined. Musthafa (1995) and Bridgit (1999) have reported that this non productive growth, which tells upon the realized productivity at harvest, is the direct influence of excess Fe absorption of plant.

This observation further confirm the earlier statement, that the yield would have been for higher had the Fe effect were ameliorated early. It also would mean that the phytotonic effect now expressed by imidacloprid is over and above the negative impact of excess Fe on productivity. Seed treatment with imidacloprid could not possibly contain the effect of excess Fe in the soil and that these positive and negative effects were independent.

The data on the progressive changes in LAI as well as yield attributes have brought to light the mechanism of yield improvement by imidacloprid, which was the partially of the phytotonic improvement. Imidacloprid has contributed to increased LAI and sustained them to the end. The increased LAI should be seen in the context of comparatively higher tiller decline in the post PIS. This results probably suggested a higher Leaf area duration (LAD) as well, leading to larger photosynthetic surface and increased net photosynthetic accumulation contributing to improved productivity through improved number of panicles m^{-2}, number of grains panicle^{-1} and number of filled grains panicle^{-1}. Number of panicles m^{-2} are decided at PIS whereas the number of filled grains in decided in the post flowering phase until harvest. Thus the phytotonic effect due to imidacloprid has been steady and continuous up to the harvest, though the treatment was given to the seed before germination. The advantages of *Azospirillum* on the other hand probably got dissipated after PIS as is evident in increased number of chats panicle^{-1}.

The increased grain yield due to imidacloprid has been associated with increased uptake of N, P and K. The mechanism of influence of imidacloprid in respect of nutrient use has been evidenced in the data on content and uptake of rice in Tables 18, 19 and 20. The data showed that the increased vigour bestowed on the plant by the chemical has led to increased content on the one side as well as uptake. The most significant results has been that the seed printing chemical has increased profoundly the use efficiency of K on marginally the use efficiency of P whereas N use efficiency has tended to declined. Thus it can be said that increased vigour brought about increased N uptake which was less efficiency utilized by the plant, but on the other hand increased vigour increased P and K absorption as well as their use efficiency. Thus the phytotonic effect in the present study shall be attributed to increased use efficiency of K especially because K absorption is comparatively passive in nature. The most important function of K in plant is considered to be in its water relations in plants. A seed treatment chemical to confer resistant against drought should naturally be modifying the water relations of the plant. As such phytotonic effect of the chemical would appear to be a continuation of the induced effect on water relations persisting to the final stages of crop growth. This phytotonic effect is specific to the chemical concerned which is evident from the results on modified water relations.

Summary

6. SUMMARY

An investigation to study the effect of seed hardening on establishment, growth and productivity of semi-dry rice, which consisted of a laboratory study and a field experiment was conducted during early Virippu season of 2000 at the College of Horticulture, Vellanikkara and Agricultural Research Station, Mannuthy, respectively.

The salient findings of the study are summarised below: -

Laboratory study

1. Germination percentage varied significantly among treatments on five and ten DAS but not on 15 DAS. Imidacloprid recorded the maximum germination percentage both on five and ten DAS. Speed of germination was also appreciably influenced by the treatments and the maximum value was recorded by imidacloprid.
2. Significant improvement in shoot and root lengths of rice seedlings was observed due to seed hardening, with *Azospirillum* recording the maximum value.
3. Hardening seeds with *Azospirillum* and *Ungu* recorded appreciably higher shoot weight followed by imidacloprid at all stages of observation. In respect of vigour index, *Azospirillum, Ungu* extract and imidacloprid were found to be the best treatments.

Field experiment

4. The variation in germination percentage due to treatments did not reach the level of significance at any of the stages of observation. The seedling

density was consistently highest in the treatment involving imidacloprid and comparable values were recorded by NaCl, *Azospirillum* and KCl, at different dates of observation.

5. Significant difference in plant height was observed at all the dates of observation, with imidacloprid recording the maximum value. Other promising treatments which recorded comparable values with imidacloprid on different dates of observation were KCl, KH_2PO_4, $ZnSO_4$, *Azospirillum*, *Ungu* and carbendazim.
6. Regarding root length, imidacloprid and KCl recorded significantly higher root length at 30 DAS and ATS respectively. But at flowering and harvesting stages *Azospirillum* recorded the highest values.
7. Significant variation was observed in dry matter production due to treatments at all stages. Hardening seeds with imidacloprid invariably registered the maximum dry matter production at all stages. Comparable values were recorded by *Azospirillum* at 15 DAS and PIS, KCl at 30 DAS and ATS, cow dung – wood ash at flowering and harvesting stages.
8. Among the seed priming treatments, imidacloprid and *Azospirillum* were significantly superior to all other treatments in improving the root weight.
9. Seed priming treatment with carbendazim increased the shoot : root ratio as compared to other treatments. KH_2PO_4, NaCl, KCl and *Ungu* were other comparable treatments.
10. The different treatments did not have an appreciable effect on the chlorophyll content.

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11. In respect of relative leaf water content, significant variation was observed at 30 DAS and ATS. KH_2PO_4 and *Ungu* treatment recorded maximum value followed by imidacloprid and KCl.

12. Yield and yield attributing characters such as number of panicles m^{-2}, number of filled grains panicle^{-1}, percentage of filled grains, panicle length and panicle weight were superior in imidacloprid and *Azospirillum* while *Ungu* recorded the highest number of grains per panicle. Apart from imidacloprid and *Azospirillum*, KH_2PO_4, KCl and *Ungu* recorded significantly higher grain yield over control. The effect of treatments on straw yield was non significant.

13. Nitrogen uptake varied significantly at all the growth stages, with imidacloprid recording the highest value. The highest P and K uptake were also recorded by imidacloprid followed by *Azospirillum* treatment at all the stages except at ATS. At ATS *Ungu* recorded the highest uptake value of P while KCl recorded the highest uptake value of K.

14. Available nitrogen content of the soil after the harvest of the experiment was lower than the pre-experiment status in all the treatments. Available P and K content of the soil after the harvest was higher than the pre-experiment soil.

15. The net income and benefit:cost ratio were higher in imidacloprid and *Azospirillum* treatments.

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* Originals not seen

Appendices

APPENDIX I

Average weekly weather data during the cropping period (from 16-4-2000 to 2-9-2000)

Meteorological week	Temperature (^{0} C)			Relative humidity (%)		Wind speed (km/hr)	Sunshine hours	Total Rainfall (mm)	No. of Rainy Days	Evaporation mm day^{-1}
	Maximum	Minimum	Mean	Morning	Afternoon					
16	34.1	24.5	29.30	88	58	2.4	8.4	0.0	0	4.6
17	34.2	25.1	29.65	88	54	3.2	6.9	2.9	0	4.8
18	34.4	25.0	29.70	86	55	2.9	8.4	4.5	1	4.9
19	34.9	25.0	29.95	85	51	3.0	9.3	0.0	0	5.5
20	31.0	24.5	27.75	89	53	3.0	9.1	46.4	4	4.7
21	32.8	24.2	28.50	91	63	3.0	7.2	60.2	2	4.0
22	31.6	23.5	27.55	91	69	2.7	5.9	38.1	3	3.5
23	28.9	22.4	25.65	96	83	3.6	2.0	319.7	6	2.5
24	29.9	22.8	26.35	94	75	2.9	3.3	106.9	6	3.7
25	29.6	23.2	26.40	95	74	3.8	3.1	55.9	3	3.3
26	29.4	22.5	25.95	94	74	3.4	4.1	104.3	5	2.8
27	28.9	22.0	25.45	93	76	3.8	1.5	87.8	6	2.5
28	29.2	21.5	25.35	94	74	3.8	3.5	170.0	5	3.1
29	30.1	22.8	26.45	93	66	4.0	5.7	48.9	2	3.6
30	30.9	23.2	27.05	92	62	3.7	8.5	5.9	1	4.3
31	31.1	23.6	27.35	92	69	3.2	6.4	9.0	1	3.6
32	29.0	22.8	25.90	94	80	3.6	2.5	93.3	4	3.7
33	29.4	22.6	26.00	93	78	2.7	4.1	139.5	4	2.9
34	27.7	22.0	24.85	95	88	3.8	0.3	232.8	7	2.3
35	29.4	22.1	25.75	94	73	3.6	4.6	44.2	3	3.2

APPENDIX II

Average weekly weather data during the previous ten years (1990 to 1999)

Meteorological week	Temperature (^{0} C)			Relative humidity (%)		Wind speed (km/hr)	Sunshine hours	Total Rainfall (mm)	No. of Rainy Days	Evaporation mm day^{-1}
	Maximum	Minimum	Mean	Morning	Afternoon					
16	35.13	25.18	30.16	85.5	56.1	4.00	8.23	21.14	1	5.32
17	35.21	25.15	30.18	85.7	56.2	3.99	8.34	19.19	2	5.26
18	34.63	25.25	29.94	86.2	58.3	3.59	7.84	23.68	1	5.10
19	33.70	25.00	29.35	88.5	61.2	3.88	6.66	66.46	2	4.75
20	32.98	24.60	28.79	88.8	65.9	3.83	6.00	36.16	2	4.29
21	33.04	24.63	28.84	89.7	64.0	3.69	6.88	50.93	2	4.27
22	32.60	24.17	28.39	90.7	67.6	3.77	5.98	74.99	3	3.90
23	30.50	23.43	26.97	92.8	76.5	3.86	3.87	168.11	5	3.21
24	29.51	23.18	26.35	94.3	80.6	3.89	2.55	200.90	6	2.91
25	29.91	23.25	26.58	94.7	77.9	3.89	3.95	124.15	6	3.08
26	29.50	23.27	26.39	94.1	79.1	3.30	3.62	204.95	5	3.12
27	29.29	22.93	26.11	94.6	79.9	3.30	2.84	167.90	6	2.83
28	28.88	22.77	25.83	94.8	82.1	3.31	2.36	165.22	6	2.58
29	28.72	22.73	25.73	95.7	82.9	3.25	1.88	221.22	7	2.51
30	28.70	22.84	25.77	94.9	82.2	3.36	2.16	192.17	6	2.66
31	28.99	23.23	26.11	95.6	80.1	3.47	2.77	158.30	6	2.76
32	29.19	23.33	26.26	94.7	78.1	3.08	3.09	97.75	6	2.89
33	29.62	23.39	26.51	94.2	75.8	3.23	3.97	93.39	4	3.20
34	29.72	23.28	26.50	94.4	75.4	3.27	4.27	87.11	4	3.15
35	29.63	23.36	26.50	94.3	74.7	3.39	4.29	83.12	4	3.30

EFFECT OF SEED HARDENING ON ESTABLISHMENT, GROWTH AND PRODUCTIVITY OF SEMI-DRY RICE

By

K. MOHANASARIDA

ABSTRACT OF THE THESIS

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Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA
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ABSTRACT

Studies involving laboratory and field experiments were conducted during *kharif* 2000 at the College of Horticulture, Vellanikkara to investigate the effect of seed hardening treatments on imparting moisture stress tolerance in semi-dry rice and its subsequent effect on germination, establishment, seedling vigour, growth, yield attributes and yield of the crop.

The treatments, thirteen in number, consisted of hardening the seeds with aqueous solutions/slurries or combination of both, of different materials such as salts, plant protection chemicals, botanicals, organic manures, biofertilizers etc.

The effect of the treatments was more conspicuous in the laboratory study, showing significant variation in respect of most of the parameters studied. Hardening with imidacloprid (0.05%), *Azospirillum* (2.0%) and leaf extract of *Ungu* (1.0%) generally recorded the best results in respect of germination percentage and seedling parameters.

In the field study hardening with imidacloprid (0.05%) and *Azospirillum* (2.0%) were found to be consistently superior in hastening germination, maintaining adequate seedling population, reducing seedling mortality and producing healthy seedlings. Growth components and root characters showed significant improvement due to seed hardening, with imidacloprid and *Azosprillum* recording the best results.

The yield increase due to seed hardening, over control, ranged from 0.6 to 2.1 t ha^{-1}. Imidacloprid and *Azosprillum* continued to record superior

performance in respect of yield and yield attributes, also. KCl, KH_2PO_4 and *Ungu* recorded significantly higher grain yield, over control, but was inferior to imidacloprid.

The NPK uptake by the crop was significantly influenced by seed hardening treatments at almost all the growth stages, with imidacloprid and *Azosprillum* recording highest values in most of the cases.

The study clearly revealed the effectiveness of seed hardening in realizing high yields in rainfed semi-dry rice through amelioration of moisture stress during the early growth stages.