Research Bulletin 53

Application of Bio-Drainage for Reclamation of Waterlogged Situations in Deltaic Orissa

S. Roy Chowdhury, Ashwani Kumar, P.S. Brahmanand, S. Ghosh, R.K. Mohanty, S.K. Jena, N. Sahoo and G.C. Panda

D.W.M

DWM

Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar- 751 023, India
2011

Research Bulletin

APPLICATION OF BIO-DRAINAGE FOR RECLAMATION OF WATERLOGGED SITUATIONS IN DELTAIC ORISSA

S Roy Chowdhury, Ashwani Kumar
P S Brahmanand, S Ghosh, R K Mohanty
S K Jena, N Sahoo and G C Panda

Directorate of Water Management
(*Indian Council of Agricultural Research*)
Bhubaneswar – 751023

2011

Roy Chowdhury, S.; Kumar, Ashwani.; Brahmanand, P.S.; Ghosh, S.; Mohanty, R.K.; Jena, S.K.; Sahoo, N. and Panda, G.C. (2011). Application of Biodrainage for Reclamation of Waterlogged Situations in Deltaic Orissa. Research Bulletin no. 53. Directorate of Water Management (Indian Council of Agricultural Research). Chandrasekharpur, Bhubaneswar-751023, India. Page : 32

Published by

Director, Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar - 751 023, India

Printed at

Capital Business Service & Consultancy
B-51, Saheed Nagar, Bhubaneswar - 751 007
capital_a1press@yahoo.com

PREFACE

Management of excess water in agricultural field is a major challenge globally as well as in India, in particular, where about 8.5 million ha area is waterlogged. The extent of water logging and associated soil salinity has already thrown a serious challenge for sustainability of irrigated agriculture in irrigation commands. Flat and saucer shaped topography of land, high rainfall, and inadequate drainage often lead to waterlogging in irrigation commands. To combat drainage problem of such an extent, the technology needed to be less expensive and environment friendly for its sustenance. Reliance on capability of vegetation to reduce water table has been reported promising both in India as well as in other countries. The main physiological feature of such vegetation is profuse transpiration whenever the root system comes in contact with groundwater. As physical drainage measures, several engineering approaches like tube well, surface, sub-surface drainage have been adopted to deal with the problem of waterlogging. But they have limitations like high cost of construction and subsequent maintenance cost, etc. Moreover, large scale engineering intervention altering topography could be a source of environmental concern. In this context use of vegetation for drainage appears promising. It is reported that trees could be used to manage rising water table and salinity problem. The clear impact of lowering of water table is reported to be evident even within 10 years of establishment of vegetation. The approach is relatively cheaper, sustainable and ecologically compatible relying on natural capability of vegetation to transpire water. Introduction of suitable intercrops in bio-drained area is also an issue for strategic application of bio-drainage as a tool for reclamation of waterlogged area for agricultural production. It is perceived that combination of bio-drainage with conventional drainage might make drainage planning in irrigation commands socio-economically more relevant and environmentally sustainable. This conjecture warranted present investigation for better understanding of the problems, issues and opportunities for fitting in bio-drainage into an integrated framework of agricultural drainage management on sustainable basis. An account of research accomplishments is reported in this bulletin.

We take this opportunity to extend our deep sense of gratitude and indebtedness to Dr. A.K. Singh, DDG (NRM), Dr. P.S. Minhas, ADG (Soil and Water Management), ICAR, New Delhi for their encouragement and guidance for carrying out the study. The support and help provided by Er. J. Sahoo (Ex. Director) CADA, Govt. of Orissa is gratefully acknowledged. The funding support received from the INCID, Ministry of Water Resources, Govt. of India, New Delhi is also thankfully acknowledged. Authors sincerely thank the farmers for their participation in this study. Thanks are also due to the research associates involved in this study and other staff members of Directorate of Water Management for providing support from time to time during the course of the work.

AUTHORS

CONTENTS

1. INTRODUCTION

In naturally existing ecology, the various components of hydrological systems like rainfall, evapotranspiration by above-ground vegetation, storage of water in soil profile as well as drainage etc. exist in equilibrium. High rainfall scenarios results in short-term increase in surface run-off or drainage flow with rise in ground water table and increased storage of water in soil profile. However above-ground vegetation has an important role in controlling moisture storage in soil profile due to evapotranspiration. It is reported that trees could be used to manage rise in water table. The root systems of trees could intercept saturated zone or unsaturated capillary fringe above water table to control shallow water table. These plants are known as **phreatophytes.** The unsaturated top soil zones are intercepted by the trees by root systems of plants mainly following rainfall or irrigation to remove water from soil profile controlling recharge. The clear impact of lowering of water table is evident even within 10 years of establishment of vegetation. Reliance on capability of vegetation to reduce water table has been reported promising both in India (Chhabra and Thakur 1998, Naik and Manjunath 1999, Kapoor 1998) as well as in other countries (Bhutta and Choudhry 2000, Zang *et al* 1999, Stirzaker *et al* 1999). Several plants species are used for this purpose from salt bush (*Atriplex*) to tall trees like *Eucalyptus, Casuarinas*, *Tamarix* etc. The main physiological feature of such vegetation is profuse transpiration whenever the root system comes in contact with ground water. However compared to shorter vegetations, tall tree species have greater advantages like high aerodynamic roughness resulting into increased water loss through transpiration. This effect is more pronounced when trees are planted in a row to give clothesline effect (Chorley and Barry 1971). Moreover deeper root systems of trees could reach out for soil water more extensively at a greater depth for draining out waterlogged soils.

Even though availability of water is essential for better productivity, but the excess water situation in agricultural field is a serious challenge to agricultural productivity in addition to negative ecological implications like green house gas emission from waterlogged areas and marshy lands. The seepage losses from the conveyance and along distribution system, excess water application in the crop field and recharge of ground water table, inadequate drainage etc. are among reasons for waterlogged condition in agricultural fields. The diversion of flood waters through existing canal systems to low lying areas causes large scale inundation of agricultural fields rendering them unproductive for agriculture. Sub-himalayan plateau, Indo-Gangetic plains, deltaic Orissa are among major areas plagued with such type of problems due to waterlogging and sub-optimal agricultural productivity due to waterlogged situation. In India out of 8.4 m ha waterlogged area, about 2.46 m ha is waterlogged due to over irrigation and rest is due to run-off congestion. In Orissa about 85000 ha area is affected by waterlogged condition. Nearly 58 per cent of Mahanadi command is under influence of waterlogging (MOWR, 1991) mainly in deltaic region. The deltaic region of Orissa suffers from waterlogging mainly due to following three reasons:

1. high and unusual rainfall within short span coupled with insufficient drainage leading to flood like situation in wider areas
2. localized brief or prolonged water accumulation in the topographic depressions and
3. sea water intrusion in deltaic areas.

The influence of above-ground vegetation for soil moisture storage in underlain profile is well appreciated. The vegetation mainly controls soil moisture profile through evapo-transpiration in the process has potential to remove excess water from field including agricultural land. The vegetations with profuse transpiration ability appear to be a promising tool for improvement of drainage situation through removal of excess water. The biodraining ability of vegetation can also be utilized in rainfed systems mainly for interception of ground water flow and recharge control through increasing discharge. Whereas in irrigated areas it can be useful for control of rise in water table, intercepting seepage water from channels etc. Under above three given scenarios prevailing in deltaic region of Orissa, use of bio-drainage vegetation to control excess water situation in this region appears feasible only in 'type **2'** scenario where accumulation of water or waterlogged situation occurs in topographical depressions which lacks adequate drainage facilities and 'type **3'** scenario where the natural drainage is incapacitated by ingression of sea water. The rate of drainage might be slower compared to discharge rate following engineering drainage measures. Unlike engineering method, slow but continuous drainage is another feature of bio-drainage and is influenced by the moisture absorption ability from soil profile and its transpiration efficacy. Moreover resultant biomass due to growth of vegetation is additional benefit over reclaimed field. Therefore vegetation has potential to complement engineering methods for removal of excess water from soil profile and can be utilized to reduce the extent of waterlogging.

With this backdrop, an attempt was made to raise biodrainage vegetation in waterlogged area and to evaluate their potential for reclamation of agricultural field affected by excess water situation. Scope for integration of agronomic silvi-cultural practice as well as aquaculture was also tried to enhance overall productivity of the system.

2. METHODOLOGY

Selection of site

The two sites in coastal deltaic Orissa were selected at Patna and Baghadi villages in Erasama block, Jagatsinghpur district with problem of waterlogging due to sea water intrusion. The two other sites, at Alisibindha village in Balipatna block, Khurda district and Ambapada village in Brahmagiri block, Puri district were also selected where waterlogging was due to topographical depression.

Table 1. Socioeconomic profile of the farmers of selected sites for bio-drainage intervention

Sl. No.	Variables	Characteristics
1.	Education level	High school and above
2.	Caste	General and OBC
3.	Annual income (Rs.)	Varied from 10000 to 100000
4.	Main occupation	Agriculture
5.	Farm size (acres)	Varied from 1.5 to 10
6.	Household	Small (1-3 members) to very large (9 members and above)
7.	Socio-political participation	No participation to active participation
8.	Extension orientation	Poor to average
9.	Mass media participation	Above average to high
10.	Land utilization pattern	Mostly fallow due to excess moisture situation in low lying areas and areas close to creek. Otherwise, paddy in medium land. Plantations under social forestry (cashew, *Eucalyptus, Casuarina*)
11.	Perceived constraints	Most of the areas suffer from waterlogging (period of water logging June to December; depth of standing water up to 75 cm).Poor performance of rice crop (average yield 1t/ha) with occasional crop failure.Difficulty in carrying out required agricultural operations.Delayed agricultural operation in *rabi* season till land is dry enough.

12.	Knowledge/ experience of farmers in plantation	Type of trees planted: cashew, *Casuarinas*, *Eucalyptus*, *Acacia*, fruit trees under social forestry.Years of experience: 3 to 5Type of land of plantations: backyard, farm bund, waste land, scattered plantationSources of knowledge/awareness and saplings: Block office, OUAT, NATP project personnelBenefits: extra income with minimal care, meet fuel wood, fodder requirements, economic use of land where crops cultivation is non-remunerative

Selection of Farmers

To understand the existing socio-economic situation as well as strength-weakness-opportunity-threat (SWOT) of bio-drainage intervention, sample of farmers representing four sites were surveyed. An overview of the profile of the selected farmers is presented in following table (Table 1)

Farmers who took keen interest to carry out plantation of *Casuarina* or *Eucalyptus* in the field affected by waterlogging, were identified. The selected farmers were Sri Vikas Maity of Baghadi, Shri Madhab Mondal of Patna from Ersama block, dist. Jagatsinghpur, Sri Subala Bhatta, Sri Ramachandra Bhatta & group (four farmers) vill. Alishibindha, dist Khurda and Sri Bichitrananda Biswal & group (four farmers), vill Ambapada, dist Puri.

SWOT analysis of bio-drainage interventions was carried out through focus group discussion with the farmers during the reconnaissance survey. Some of the strengths, weaknesses, opportunities and threats as perceived by the farmers are mentioned below:

Strengths

- ❖ In addition to traditional income from agriculture, biodrainage plantations can provide extra income and products like fuelwood, fodder, timber and other forestry products.
- ❖ As a vegetation based drainage system the operation and maintenance requirements of biodrainage vegetation are less than conventional drainage (horizontal/vertical) methods. Demand for seasonal labour requirement can be dispensed with.
- ❖ Bio-drainage plantations make the wasteland/low productive land more productive and enhance economic utilization of problem areas.

- Bio-drainage plantations might be a viable option and low cost measure to tackle water logging and salinity problems.

Weaknesses

- Efficacy of bio-drainage plantations need to be tested in the waterlogged areas of high rainfall zones where stagnant water is real weakness.
- The plantations would need one time or periodical up-keep and care all the times depending on types of vegetation.
- Lack of proper knowledge, motivation and expertise for planning and development of plantations among the farmers.
- Limited distance up to which benefit of bio-drainage plantations will be felt.

Opportunities

- Bio-drainage has two stage implications i.e. prevention or remediation of water logging and means of resource generation.
- Tree plantations can provide returns that are at least equal to agriculture if not more and besides that it helps to improve environment and solves many problems like water congestion, salinity, wind hazards (shelter belt), etc.
- Integration of bio-drainage with conventional drainage measures is an open option.
- Exploring possibility of integration of silviculture and aquaculture with conventional agriculture to improve land and water productivity.

Threats

- With age there would be gradual decrease in capacities of trees for consuming and transpiring water thereby reducing extent of bio-drainage.
- Competition of foliage and roots between trees and crops for light, moisture, nutrient, etc and its effects on co-existing vegetation.
- Lack of availability of land for raising plantations may be a problem. It may be difficult to persuade small and marginal farmers to part with their lands or to change its use from agriculture to forestry.
- Destruction/damage of plantations may happen in the event of natural disasters like cyclone, flood, etc.

Selection of bio-drainage species and preparation of plant materials

There are several species which has biodraining ability from soil moist with excess water like *Eucalyptus*, *Casuarina*, *Bambusa arundinacea* , *Tamarix*, *Lucerne* etc. (Chhabra and Thakur 1998, Zang *et al* 1999, Stirzaker *et al* 1999, Bhutta and Choudhry 2000). In our study *Eucalyptus* was selected for plantation at Alisibindha and Ambapada where the topographical depression of the area is main cause of water logging. At other two sites *i.e.* Patna and Baghadi, where the experimental areas were influenced by intrusion of sea water, *Casuarina* was selected for raising plantation. In salinity affected area, comparative performance of *Casuarina glauca* and *Eucalyptus camaldulensis* (Cramer *et al* 1999) showed that former species intercepted deep ground water while later species relied on shallower unsaturated zone. Thus Casuarina was found to be more efficient in discharging saline ground water and was used for bio-drainage plantation at Patna and Baghadi.

Seedlings of *Casuarina equisetifolia* Forst were collected from farmers' nursery at Brahmagiri. The seedlings were raised on nursery bed. About half kg seed is sufficient to produce about 10,000 healthy seedlings. Raised beds are made of 5x2m size with mixture of sandy soil and farm yard manure in 10:1 ratio. After sowing in November, mixture of a thin layer of sand mixed with wood dust is sprinkled over seeds to check evaporation from nursery bed. Adequate water is applied for germination of seeds. Seeds germinate within ten days and within one and half month seedlings attain 10-15cm height. At this stage seedlings are taken out of bed and are placed in polythene bags of 7cm diameter and 15cm height filled with sand and FYM mixture as that of nursery bed. Seedlings are ready for transplantation after they attain about 40 cm length after another month. The seedlings of *Casuarina* were collected from farmers' nursery.

The *Eucalyptus* seedlings named 'JK Super clone' developed by JK Paper Ltd., Raygada, Orissa were collected from their nursery located at Bhubaneswar. The eight to ten leaved seedlings of 25-30 cm height were raised in molded polythene trays. Each tray had 35 chambers of 125cm^3 volume each and has a perforated base for drainage of excess water from the chamber. Each chamber was filled with soil and FYM mixture at 1:1 ratio.

Installation of observation bores and monitoring of hydrological parameters

Shallow observation bores were installed in the four plantation sites. The bores constructed were of size 40 mm diameter of PVC pipes, installed in 100 mm diameter size auger hole up to depth of 3 m slotted below 1 m from surface. The space between

40 mm PVC pipes and 100 mm auger hole was back filled with coarse sand over the slotted section of the pipe. The top 1 m section of the pipe was back filled with mixture of clay and bentonite to prevent vertical leakage from the surface along the pipe to the screen.

The water levels in side the observation bore were monitored initially with measuring tape. Thereafter, water level inside observation bore was recorded with water level indicator with a sensor and sound device (KL-010 Dip meter, M/s Messtechnik, GmBH, Germany). Whenever the sensor came in contact with water level inside bore as sensed by sound device, the water level was recorded. The ponding depth of water or level of water above ground was measured with a measuring scale.

Measurement of plant growth parameters

The height of the tree was measured at regular interval with the help of an altimeter (Ravi Altimeter, M/S. Ravi Vaigyanik Yantra Nirmata, Dehradun, India). The diameter at breast height (DBH) and collar diameter was measured with slide calliper following standard procedure.

3. FINDINGS AND DISCUSSION

Effect of bio-drainage plantation on hydrological changes in experimental sites

Measurement of efficacy of transpiration potential of biodrainage tree species and to establish its correlation with change in underlain water table is not always straight forward. Particularly when discharge rates are low and aquifer transmissivity is high, it becomes difficult to segregate contribution of tree water use and that of different hydrological process influencing the changes in water table underneath biodrainage vegetation. The main objective of use of biodrainage vegetation is to lower the water table beyond root zone of cultivating crop in a waterlogged field so that co-existing crops do not experience stress due to excess soil moisture. However vegetation has been used to manage rising water table mainly through drainage (Alexendra 1991, Kapoor 1998). It is reported that trees could be used to manage shallow water table and salinity problem (Alexendra 1991). The clear impact of lowering of water table is evident even within 10 years of establishment of vegetation (Silberstein *et al* 1999). Moreover under present experimental condition the deltaic Orissa on an average experience annual rainfall more than 1400mm, during monsoon. As a result, for about 10-12 weeks period, the plantation experience above ground waterlogged condition (Fig 1-4) and remain so till end of monsoon. Therefore in present scenario the scope for assessment of efficacy of biodrainage plantation has been limited to only in post

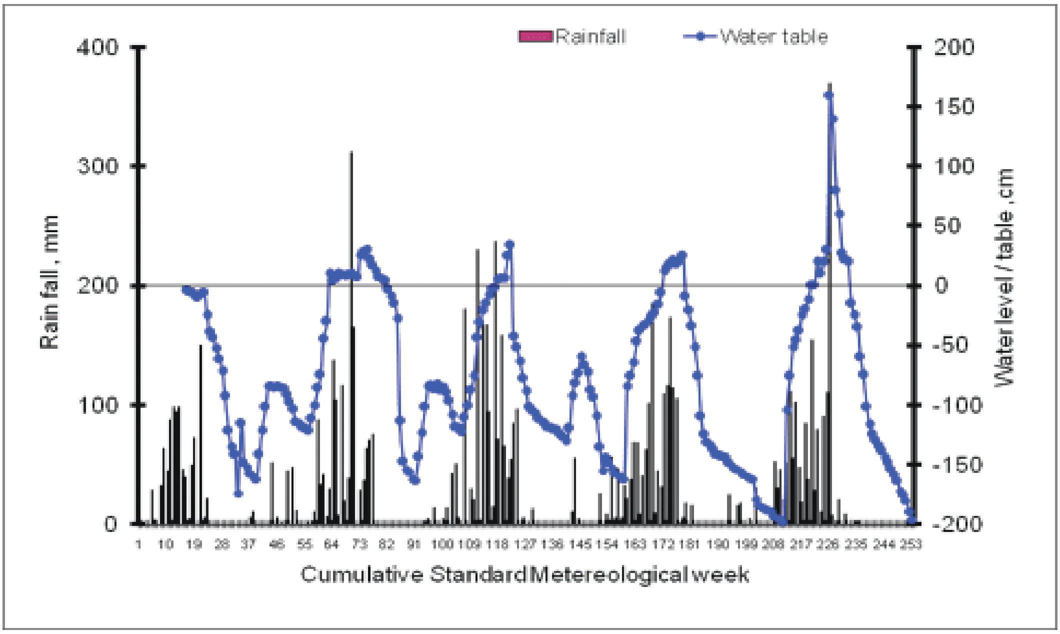


Fig. 1. The changes in level of water inside observation bore during experimental period and weekly rainfall underneath *Casuarina* vegetation at Baghadi from 2004-05 to 2009-10 (March).

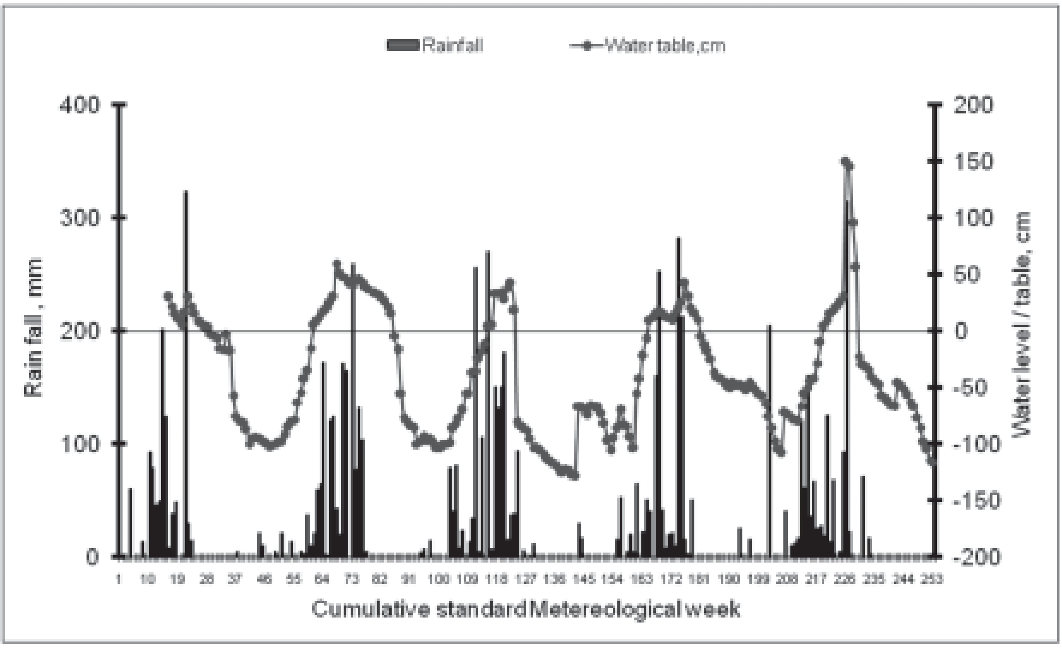


Fig. 2. The changes in level of water inside observation bore during experimental period and weekly rainfall underneath *Casuarina* vegetation at Patna from 2004-05 to 2009-10 (March).

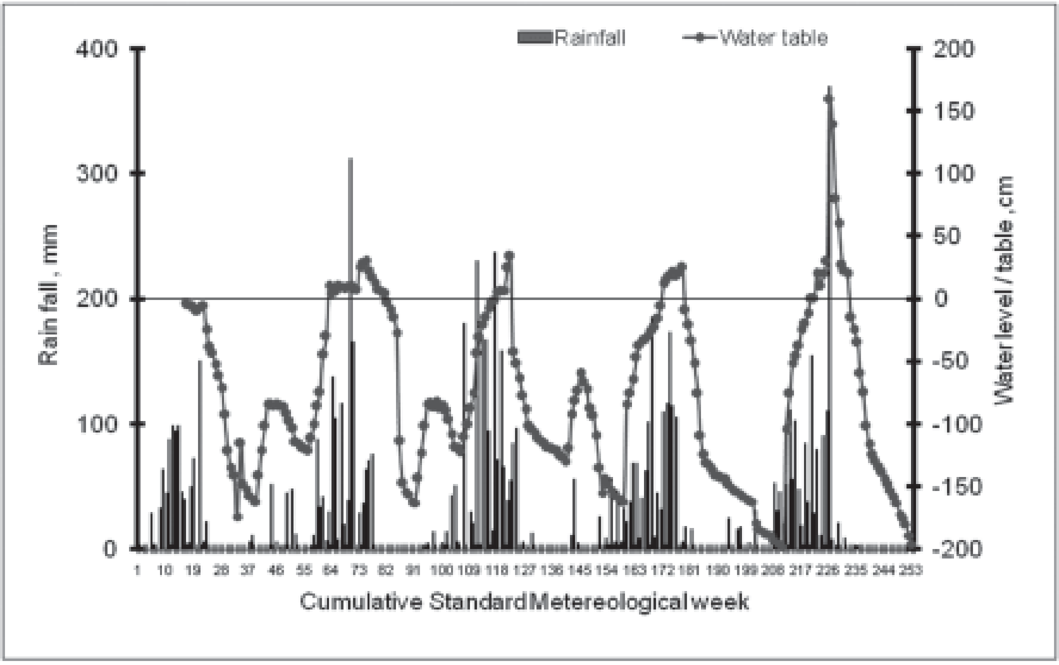


Fig.3. The changes in level of water inside observation bore during experimental period and weekly rainfall underneath *Eucalyptus* vegetation at Alishibindha from 2004-05 to 2009-10 (March)

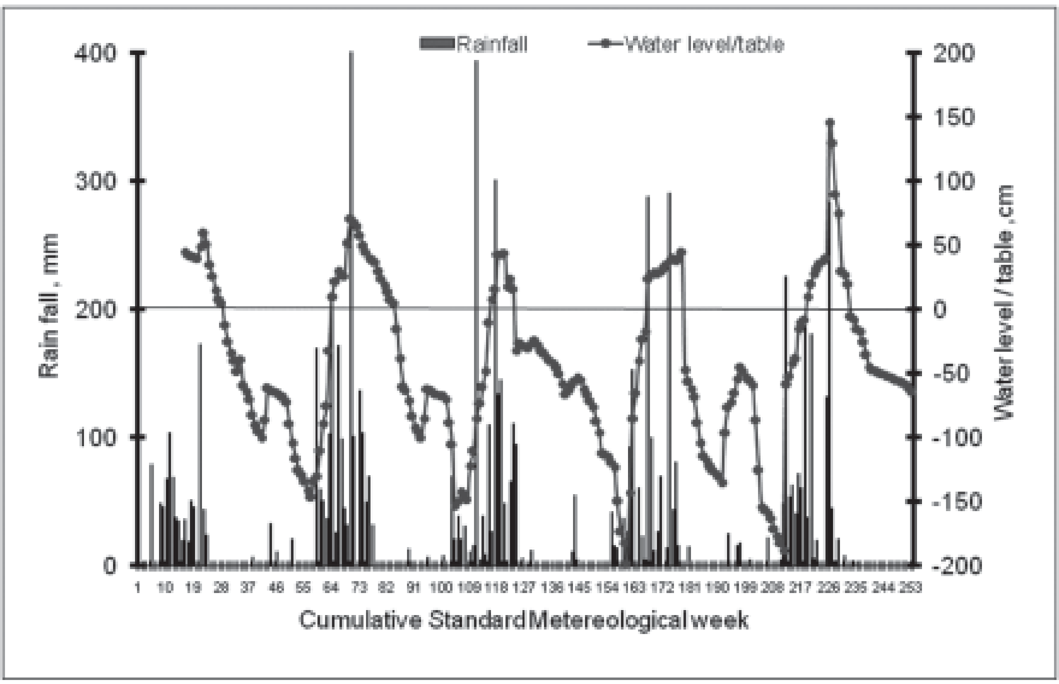


Fig. 4 The changes in level of water inside observation bore during experimental period and weekly rainfall underneath *Eucalyptus* vegetation at Ambapada from 2004-05 to 2009-10 (March).

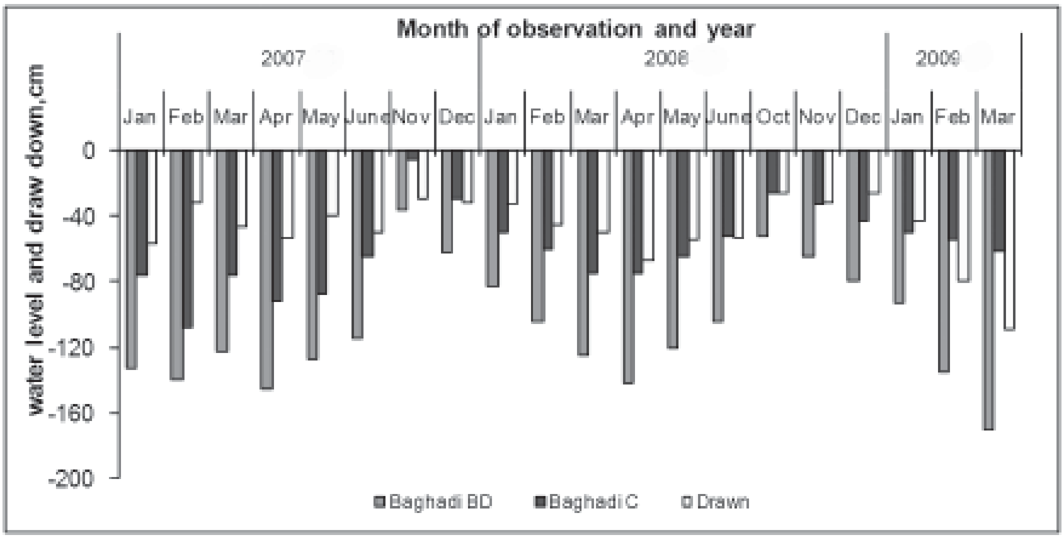
monsoon season. It is worthwhile to assess how fast the plantation is able to bring the field to cultivable condition so that a rabi crop can be raised as early as possible. The effect of planted tree species on underlain water table was monitored through observation well monitoring systems. Underneath biodrainage vegetation a clear cut draw down effect had already been reported (Heuperman 1999, 2000).

The progressive draw down of water level at phreatic surface monitored through shallow observation bore showed significant lowering in successive years (Fig.1-4). The mean of first two years (April-March; 2004-05 and 2005-06) lowest water level at Patna was -102cm which declined to -117.67cm (mean of last three years i.e.2006-07 and 2007-08 and 2008-09, Fig 1.). Similarly decline at Baghadi was from -127cm to -152.33cm (Fig 2), at Alishibindha from -168.5cm to -185.33cm (Fig.3) and similarly at Ambapada average decline was -150 cm (Fig.4). Thus from the data it is evident that at phreatic surface there has been a clear draw down in level of water table underneath bio-drainage vegetation. The decline was maximum under Eucalyptus vegetation at Alishibindha and under Casuarina vegetation at Baghadi. When the draw down in water level in observation bore well underneath bio-drainage vegetation was compared with that of an observation bore well in non vegetated area 300m away from experimental site (serving as a control), the effect of draw down was more pronounced at all the four sites (Fig. 5 and 6).

Therefore, as far as efficiency of drainage by plantation or tree water use *per se* is concerned, *Eucalyptus* was found more efficient than *Casuarina*. In addition, greater decline of water table in observation well underneath *Eucalyptus* vegetation (Fig.3) suggested better tree water use by *Eucalyptus* plantation. Therefore *Eucalyptus* plantation was superior in providing drainage relief through interception water from deeper soil profile, compared to that under *Casuarina* plantation (Fig.1 and 3).

The maximum decline in water level in observation bore well was noted at Baghadi under *Casuarina* whereas under *Eucalyptus* vegetation maximum lowering od water level in observation well was found at Alishibindha. The growth status of the vegetation also showed similar trend. The growth of plantation at Baghadi and Alishibindha was better than at Patna and Ambapada as was reflected through plant height and diameter of stem at breast height (Fig.7). Therefore in real time scale, quicker establishment and better growth of bio-drainage vegetation is critical for providing better drainage relief to a new treatment area

More importantly, the beneficial effect of maintaining water table beyond root zone is reflected through advancing the *rabi* cultivation activity by about 2-3 weeks earlier



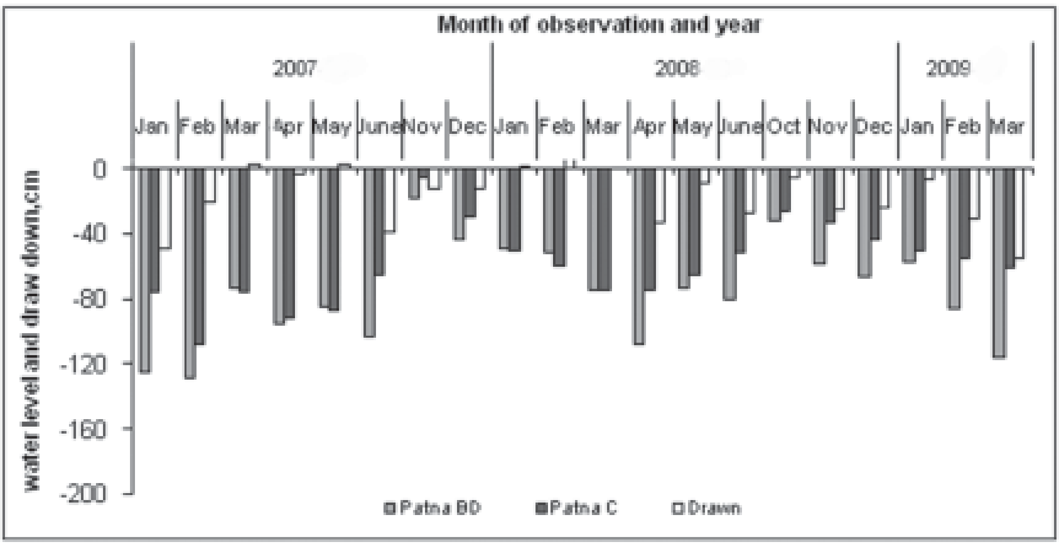
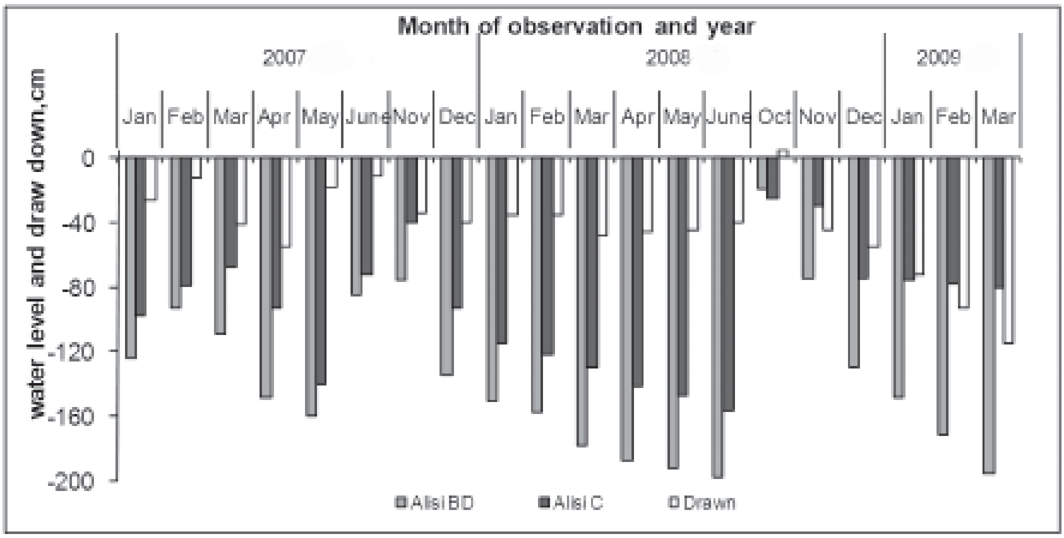


Fig. 5. The monthly changes in water level in observation bore well inside *Casuarina* plantation (BD) and in observation bore well out side plantation (C) and the difference in water level (BD-C, Drawn) at Baghadi and Patna.

than the field without bio-drainage vegetation. This accelerated drainage has helped the farmer to advance rabi cultivation by a period of 15-20 days. Through this process the cultivation of watermelon as intercrop inside *Casuarina* vegetation could get additional benefit of about Rs.15,000/- per ha for the farmer due to better market price of the crop as well as avoiding the market glut.



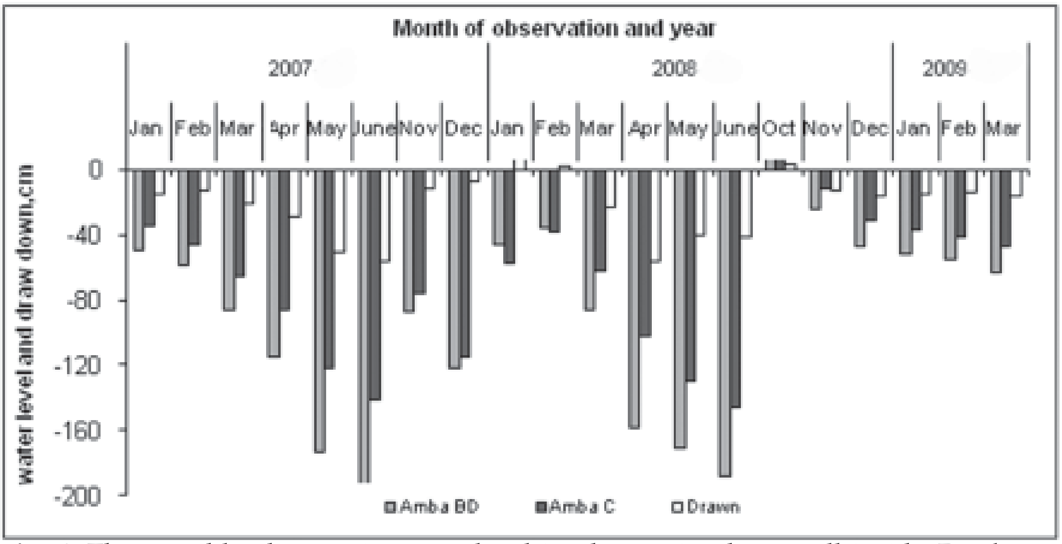
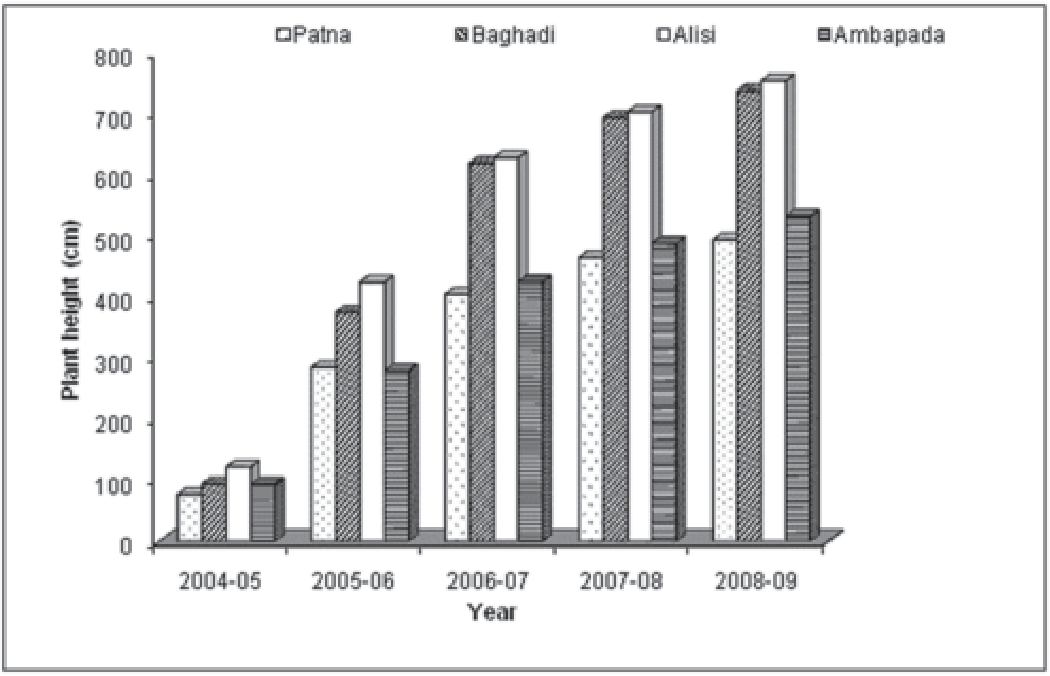


Fig. 6. The monthly changes in water level in observation bore well inside *Eucalyptus* plantation (BD) and in observation bore well out side plantation (C) and the difference in water level (BD-C, Drawn) at Alisibindha and Ambapada .

Package of agronomic practices for establishment and optimal growth of trees

For plantation in waterlogged areas like the present experimental sites, the soil is generally compact. Pits of 30 cm^3 size were made in 4 x 4m spacing. The bottom of each pit was filled with one kg farm yard manure (FYM) and 30g single super phosphate and granular Carbofuran 10G @ 7kg/ha. The seedlings were planted at a spacing of 4 x 4m with a population density of 625 plants per ha. Seedlings were placed at a depth



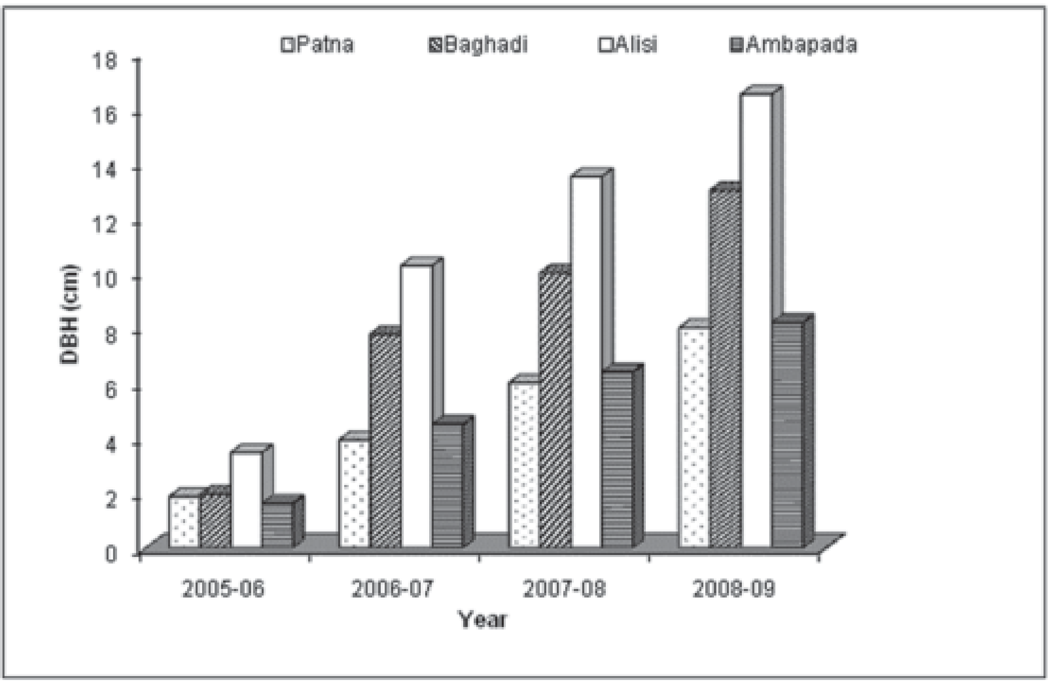


Fig.7. The changes in plant height, (cm) and diameter at breast height (DBH, cm) of *Casuarina* at Patna & Baghadi and of *Eucalyptus* at Alisibindha &Ambapada.

of 6cm in the pit. The *Casuarina* plants raised in polythene bags were placed gently over the layer of FYM. Care was taken so that root systems were not disturbed and were not subjected to planting shock. After planting in post monsoon dry period in January (except for February in case of Ambapada), the soil was repeatedly loosened so that root growth and penetration to soil is promoted. At Ambapada and Alishibindha to raise Eucalyptus vegetation, the N:P:K were applied @ 75:30:15 kg/ha respectively after one month of planting before onset of monsoon. At Patna and Baghadi where *Casuarina* was grown, the N:P:K were applied @ 70:20:35 kg/ha respectively after one month of planting before onset of monsoon.

Phorate granules (10G) were given @ 10 gm/plant whenever there was attack of pest at the base of *Casuarina* plant. Depending upon the area prone to waterlogging, after planting, the seedlings get about five to six months for establishment before experiencing inundation. Before onset of monsoon at the base of each seedling, raised mound of 45cm height was prepared so that inundation at the base of the stem is delayed. Moreover, adventitious roots also develop at the interface between accumulated water and base of the stem particularly in *Eucalyptus* and are important for their survival under waterlogged condition particularly at seedling stage. Once the plants are established, both *Eucalyptus* and *Casuarina* seedlings have capacity to withstand water logging for even two to three month, even though this growth is affected. During prolonged water logging, the leaf turns red or yellow in *Eucalyptus* and *Casuarina* and the colour is reversible to green whenever the waterlogged condition is over. Thus it suits well for cultivation in areas prone to water logging. However, in comparison to *Casuarina*, at other experimental sites Alishibindha, due to soft sandy wet soil, the *Eucalyptus* plants showed tendency to lodging particularly during post monsoon cyclone period which is common on coastal region of deltaic Orissa. The plants were given mechanical support at the base of stem to prevent such lodging. Such tendency of lodging might however be prevented with closer spacing like 2m x 2m or by avoiding tillage operation in areas around the stem, for intercrop cultivation , minimizing damage to the spreading roots of plantation.

Growth performance of bio-draining tree species

The experience from our project suggested that in topographically depressed areas like Alisibindha and Ambapada, *Eucalyptus* plantations tolerated water logging satisfactorily. Even under severe water logging scenario at Ambapada where the above ground stagnation of water condition continued for more than 3-4months in a year (Fig.4), the Eucalyptus plants tolerated water logging. However the growth of the plants proportionately reduced due to prolonged water logging at Ambapada compared to that at Alishibindha. The height of the plant, girth of stem represented by DBH (diameter at breast height) was lower at Ambapada than at Alishibindha. The slower growth trend continued from 2005-06 to 2009-10 period (Fig.7). Therefore, even though the *Eucalyptus* plants could survive extreme water logged environment, the extended period of water logged condition retarded the growth of the plantation.

In the areas affected by ingress of sea water *Casuarina* was planted as biodrainage vegetation at Baghadi and Patna. Because of proximity to sea, the site at Patna was more saline. The pH of the soil varied from 6.52 to 6.88 and initial soil $EC_{(1:2)}$ was upto 1.18 dS/m. Existing literature suggested that *Casuarina* could continue to discharge soil water efficiently even under saline environment (Cramer *et al* 1999). But under similar condition *Eucalyptus* showed significant reduction of leaf area even when exposed to moderately saline environment compared to that under non saline environment (Benyon *et al* 1999). In our study we noticed that under saline environment at Patna, the soil $EC_{(1:2)}$ reached from 1.18 to up to 2.15 $dS.m^{-1}$ and EC of bore well water was recorded up to 2.5 $dS.m^{-1}$. Under this saline environment the growth of *Casuarina* plants was slower (Fig.7) as was evident with shorter plant height and slender stem girth. However at Baghadi where the salinity was less, the plant growth was significantly better as was evident through greater plant height, collar diameter and higher DBH (Fig 7).

Therefore, so far as establishment and subsequent growth of biodrainage vegetation is concerned, in topographically depressed area, *Eucalyptus* can be suitably grown as it survives even several water logging albeit affecting its growth. Similarly *Casuarina* can be grown effectively in area influenced by sea water ingression. However prolonged exposure to higher soil and water electrical conductivity (EC) may retard growth potential of *Casuarina* plants and could lead to overall growth reduction of plantation as was evident at Patna.

Performance of co-existing crops inside biodrainage vegetation

Performance of inter crop inside Casuarina plantation

In kharif season, rice was taken as intercrop inside *Casuarina* vegetation at Baghadi and Patna. The final yield in (t/ha) of the paddy obtained was 1.73 t/ha in 2005-06, 2.20 t/ha in 2006-07, 1.5 t/ha in 2007-08 and it was 1.6 t/ha in 2008-09. Thus under *Casuarina*, yield of paddy increased marginally over the years at Baghadi. Even though the growth of plantation was vigorous at Baghadi, it did not cause yield reduction of intercrop. Even at Patna where level of soil and water EC was more, the kharif paddy yield improved from 0.89 t/ha in 2004-05 to 1.53 t/ha in 2005-06. The needle shaped leaves of *Casuarina* and lesser interference by canopy for light interception by intercrops is one of the main reason, for the same. In comparison to 22-26% reduction in light interception in *Eucalyptus*, canopy of *Casuarina* showed only 11-16% reduction in light interception on intercrop. The needle shaped leaves caused less hindrance for incident radiation. Moreover the leaf litter fall was also lesser under *Casuarina* compared to *Eucalyptus*. The mature leaves along with branches were periodically removed by the farmer for use as fuel wood, resulting in to less deposition of leaf litter on the field.

During *rabi* season of 2005-2006 at Baghadi, as a intercrop of *Casuarina,* watermelon was cultivated. As field remained uncultivable due to excess moisture till the end of December, an intervention was made to hasten the cultivation of water melon by raising watermelon seedlings in nursery in the polythene bags.

Raising of watermelon nursery in polybag and watermelon cultivation

Due to excess soil moisture till the end of December it is difficult to cultivate the field for at least 25-30 days before soil dries up. As field remained uncultivable, to avoid time delay, measures were taken for establishment of watermelon nursery in the polythene bags. When the field was cultivable by the mid-January, the seedlings at 2-4 leaf-stage were ready in the polythene bags in nursery for planting. Thus the entire crop growth cycle as well as harvest could be brought forward by 20-25 days. The effect of nursery grown seedlings was compared with traditionally direct seeded treatments of all the varieties. The establishment and growth of nursery raised plants were found significantly superior compared to direct seeded plants in terms of vine growth, canopy development and fruit appearance. Thus, raising of watermelon seedlings in the polythene bags hastened the plant establishment by 20-25 days ahead as compared to the local practice of direct seeded crop in the water-logged area. This intervention helped farmers to avoid market glut and produce fetched better price as well.

In 2005-06, performance of three cultivars of watermelon Suravi, Sugar Baby and a local cultivar was evaluated as intercrop inside *Casuarina* plantation at Baghadi. The average yield of watermelon was 19.2 t/ha. However, during initial year of plantation, the effect of biodrainage plantation *per se* was presumably minimum on intercrop. However, next year during 2006-07, performance of five varieties of watermelon (Suravi, Mukassa, Sitara, Arka Manik including Sugar Baby as a local check), was evaluated. The pooled average yield of watermelon intercrop was 24.16 t/ha.The growth of Mukassa and Arka Manik were comparable and were significantly better than Sitara, Suravi and Sugar Baby under *Casuarina* vegetation. The variety Mukassa performed significantly better than other cultivars. Thus drainage significantly improved watermelon yield and advanced cultivation period by three weeks. In 2007-08 season, performance of three varieties of watermelon viz. Mukassa, Arka Manik and Sugar

Baby was again tested and inter crop cultivation was advanced by 20 days using nursery raised seedling. The growth of crop was good but untimely rain during February, 2007 and a pest attack affected flowering of watermelon. Even then average yield of watermelon was 9.32 t/ha and crop harvest started two weeks earlier than other farmers field without biodrainage vegetation. In 2007-08 and 2008-09, cowpea was also taken as intercrop inside *Casuarina* plantation and yield was 2.5 q/ha and 2.3 q/ha in respective years.

Performance of inter crop inside Eucalyptus plantation

In *kharif* season inside *Eucalyptus* vegetation at Alishibindha rice was taken as intercrop. Paddy variety Swarnamasuri was used every year to assess its performance inside *Eucalyptus* plantation. The final yield of paddy at Alishibindha, was 3.51t/ha in 2005-06, 3.37 t/ha in 2006-07, 2.25 t/ha in 2007-08 and it was 2.12 t/ha in 2008-09. The performance of intercrop is result of complex interaction, both positive and negative effects between biodrainage plantation and intercrops. Whenever impact of negative factors dominated it caused reduction of crop growth and yield. Vigorous growth of *Eucalyptus* plantation and resultant shade could be one of the reasons for reduced yield and competed with intercrop for nutrients and other resources. Similar reduction in yield of intercrop under *Eucalyptus* vegetation has been reported in literature (Sasikumar *et al* 2001) particularly with age of the tree (Singh *et al* 1998). The reduction of intercrop yield was due to release of range of allelocheminals like coumaric acid, gallic acid, gentisic acid, syringic acid, hydroxy benzoic acid, vanillic acid, catechol etc. from leaf litter and root exudates reducing yield of intercrop (Sasikumar *et al* 2001, Blum *et al* 1999). Moreover, the leaf litter deposition from *Eucalyptus* vegetation and resultant soil acidity might also affected intercrop yield. Owing to these negative effects, the positive effects like increased organic matter content from leaf litter decomposition was less felt in this scenario. Even though plantation had little effect on water regime during monsoon period, however under *Eucalyptus* plantation, there was decline in yield of kharif paddy. But at Ambapada, in kharif, no crop was taken due to high water level and in rabi paddy was cultivated. After two years of plantation of *Eucalyptus*, paddy cultivation was initiated in reclaimed area. The yield of paddy did not decline as was evident at Alishibindha. The paddy yield at Ambapada was 1.4 t/ha in 2007-08 to 1.5 t/ha in 2008-09. In addition to better drainage scenario provided by plantation, lesser interference of shade of leaf area, lesser tree-crop competition (by smaller trees) and increased soil organic matter content might have resulted in yield improvement in rabi paddy. The better drainage by the bio drainage plantation might have resulted in reduced sulphide toxicity, improved soil aeration, nutrient use efficiency as was reflected in better tillering in both the years in rabi paddy and was not evident in nearby field without plantation.

At Alishibindha, in *rabi* season groundnut was cultivated as intercrop in first two years i.e. 2004-05 and 2005-06. In both the years the yield of groundnut was 1.4 and.1.2 t/ha respectively. In both the years the crop growth was satisfactory, compared to nearby farmers' field. Thus in rabi season in topographically depressed waterlogged area like Alishibindha, inside *Eucalyptus* plantation, groundnut could be a viable intercrop.

In 2006-07, due to market demand of pulses and lesser price of ground nut, farmer shifted to green gram cultivation from groundnut inside *Eucalyptus* plantation at Alishibindha. The initial growth of the inter crop was good but due to shade there was about 22-26% decline in incident radiation in side *Eucalyptus* plantation and might had affected pod formation in green gram which was reflected in lower yield of 1.25 q/ha. The incidence of yellow mosaic virus was also another reason for yield decline in green gram. In 2007-08, black gram was cultivated inside *Eucalyptus* plantation. This year farmer noted difficulties in ploughing operations due to proliferation of roots in the interspaces between trees. However, a yield of 1.75 q/ha black gram was obtained by the farmer in side *Eucalyptus* vegetation. Higher levels of allelochemicals from root exudates and leaf leachate from older trees might be reason for more inhibitory effect on intercrop with age of the *Eucalyptus* plantation (Singh *et al* 1998). However, the inhibitory role of allelochemicals is also expected to be more in *rabi* than that in *kharif* when the impact of inhibitory chemicals might be diluted due to high water regime and rainfall. But during *rabi* season depletion of soil moisture by the plantation and simultaneous release of these inhibitory chemicals affected performance of intercrop. Less reduction of yield of *kharif* paddy might be due to rain and high water regime, minimizing inhibitory effect of allelochemicals.

Integration of aquaculture along with bio-drainage vegetation

As the target area in this project has been mainly two scenarios like waterlogged areas affected by sea water intrusion and topographically depressed areas, both the scenarios had a common feature i.e. abundance of water. As availability of water is not a limitation, it was prudent to envisage that value addition to already available water would not only increase productivity of land it would also increase productivity of water in such water logged environment. It was designed to append intervention of aquaculture in the prevalent situation under bio-drainage vegetation. Aquaculture intervention in the bio-drainage field was initiated during first week of June 2007 using a dug out pond of 400m^2 of water surface area at Baghadi along with *Casuarina* plantation. The dug out pond was made in the lower reach of the experimental area where excess water from the field will take refuge. The depth of the pond was made 2m and surface area 400m$^{2.}$ After carrying out standard pond preparation protocol, air breathing fishes like Magur (*Clarius batrachus*) and Koi (*Anabas testudeneous*) were stocked@3000 fingerling/ha with MBW of 15-20g (Magur) and 5-8g (Koi). After six month of rearing, IMC and grass carp @2000 fingerlings/ha with MBW of 200g were further stocked in the pond along with the previous stock .Advanced fingerlings of IMCs were stocked just to avoid cannibalism and to minimize the rearing duration before getting table sized fish within 10 months . Periodic liming @150 kg/ha manuring @500kg raw cow dung/ha fortnightly was done for maintenance of the Plankton bloom. At the end of March, 2008 the average mean body weight of cultured species was up to 110gm, 90gm, 255gm and 270gm for Magur, Koi, IMCs and grass carp respectively. and 1.25 t/ha composite yield of air breathing fish (*C. batrachus*, *A. testudeneous*), grass carp and IMC was obtained within 10 months. The aquaculture intervention at Baghadi 400m^2 pond with yield of 1.25t/ha fish gave a profit of Rs. 1500/- with a B:C ratio of 2.5. The total yield of fish from the same water body in the year 2008-09 was 1.35 t/ha and was comprised Indian major carp, grass carp and air breathing fish.

Economics of intercrop

In 2005-06 under *Casuarina* plantation in *rabi* season, from watermelon, net return was Rs 30000.00, with a profit of Rs 16,000/- and B:C ratio of 2.14. Similarly under *Eucalyptus* from groundnut, net return and profit was Rs.21000/- and Rs.11000/- respectively with a B:C ratio 2.10. In 2006-07, from watermelon, net return was Rs.62,500/- and profit was Rs.45,500/- with B:C ratio of 3.67. Whereas under *Eucalyptus* from groundnut, the net return was Rs.20,000/- and a profit was Rs. 10,000/- with B:C ratio of 2.0. In 2006, under *Eucalyptus* in *kharif* paddy gave a profit of Rs.10,175/- with B:C ratio of 2.43 whereas under *Casuarina*, 1.5 t/ha paddy yield gave profit of Rs.4750/- with a B:C ratio of 1.95. In 2007-08 *rabi* season the watermelon gave a profit of Rs. 20,500/- with a B:C ratio of 1.64. The green gram under *Eucalyptus* gave a net profit of Rs.3400/- with a B:C ratio of 3.12. The rabi rice under *Eucalyptus* plantation which yielded 1.5 t/ha, also gave a net return of Rs. 8250/- with a profit of Rs.5250/- and a B:C ratio 2.75. The pruning of *Casuarina* plantation at Baghadi, gave additional yield of 1 t/ha of twig biomass after 39 months of planting which was sold by farmers as fuel wood and generated Rs.2100/- as additional income which in the year 2008-09 gave a additional yield of 2.3 t/ha of twig biomass after 51 months of planting which was sold by farmers as fuel wood and generated Rs.5500/- as additional income.

4. APPLICABILITY OF BIODRAINAGE IN WATERLOGGED AREA DEVELOPMENT

Excess water situation is a major problem to augment agricultural productivity. The condition of water logging in command areas arises due to various reasons like seepage losses from the conveyance and distribution system, excess water accumulation in low land, recharge of ground water table, inadequate drainage etc. The 'command area development and water management programme' in Orissa is under process of implementation in 14 irrigation project of the state with a cultivable command area of 7,86,449 ha spread over 94 blocks in 19 districts of the state. In addition to over irrigation and seepage from distribution system, there are two major reasons for existing waterlogged condition in deltaic Orissa. Firstly, the intense rainfall within short period leading to flood like situation in wider areas, secondly accumulation of water in topographic depressions due to saucer shaped land form and/or saline water ingression. The use of bio-drainage vegetation to reduce rising water table appears promising. Since long physical drainage measures like installation of tube well, surface, sub-surface drainage have been taken to deal with the problem of water logging. But these measures has its own limitations like cost intensive, difficulties in getting outfall areas for discharge of effluent, maintenance of the systems etc. As a new sustainable approach use of vegetation for drainage appears promising. It is reported that trees could be used to arrest the rising water table in soil profile. The intervention is relatively less expensive and eco-friendly. The clear effect of decline in level of water table is percieved within 10 years of establishment of vegetation. Present study also suggests that aforesaid strategy could be useful in keeping shallow ground water beyond the root zone of intercrops. Use of bio-drainage tree species like *Casuarina* in coastal areas and *Eucalyptus* in inland topographically depressed areas could keep the water table beyond the root zone of several cultivable crops like rice, groundnut, pulses, watermelon etc. The beneficial effect of reducing the water table beyond root zone is further reflected through advancing the rabi cultivation activity by about 2-3 weeks earlier than the field without bio-drainage vegetation. This accelerated drainage has helped the farmer to advance their rabi cultivation by a period of 15-20 days.

The use of 4x4m spacing for growing plantation has facilitated intercultural operations like tillage with conventional bullock operated ploughing or power tillers and was found useful in accommodating intercrops. The elasticity of wood of *Casuarina* plantation in coastal areas provided resilience to plantation against constant strong wind. But in *Eucalyptus* wider spacing and shallow root depth in soft waterlogged affected soil made it vulnerable to strong wind and causes lodging particularly during post-monsoon period when cyclone and storm is very common in deltaic Orissa during October-November period every year. However, narrower spacing of Eucalyptus might facilitate faster fall in water level providing better stability to vegetation preventing lodging, but would reduce convenience of intercrop cultivation. A clear cut draw down of ground water up to 109 cm underneath *Casuarina* vegetation and up to 115 cm beneath *Eucalyptus* vegetation in comparison to non-vegetated area, without bio-drainage vegetation was evident at the end of the season underneath four year old vegetation. This fact suggested that such ability can be used successfully for reducing water table in waterlogged areas. The ability of *Eucalyptus* and *Casuarina* to survive under prolonged period of 'above ground level water' condition also corroborated sustainability of the system in high rainfall low lying areas. The co-existence of intercrops like pulses, groundnut, watermelon etc. could made farming under bio-drainage more remunerative. With average drainage rate of 16.5-22.19 lit/day (measured with sap flow system in the experiment) it is about 1.03-1.38 ha mm per day accelerated drainage from soil profile which could be achieved from the system. The aggregation of effective functional absorbing root system of bio-drainage plantations within first 60 cm of the soil profile would provide favourable regime for intercrop cultivation. Maintenance of desirable soil water balance within root zone would facilitate cultivation of many common rabi crops as their root systems generally remain confined to said zone in the soil profile.

The integration of pisciculture is also a profitable intervention which significantly increased the productivity of water and economic return of the whole system. This approach shall play an important role in enhancing the productivity of water logged areas.

The decision-making attitude of farmers depends upon their perceptions besides agronomic, economic criteria and attributes of technology to arrive at their own conclusions about the suitability and adoption of any technology in specific farming system. Differential need perception of farmers is often evident as resource-rich farmers mostly express the need to maximize production while resource-poor farmers want to ensure their bare survival. In this context, a farmers' feedback survey was carried out covering sample of farmers growing plantations with bio-drainage potential.

Bio-drainage plantations have reduced the duration of waterlogging through accelerated drainage as opined by the farmers. Socio-economic situation of the farmers during pre intervention period was depended on mono-cropping of rice with poor productivity and low income. Waterlogging with sub-optimal performance of rice crop in kharif, inconvenience for timely rabi cultivation, production loss and low income characterized the farming system, which has been combated through bio-drainage intervention. Bio-drainage plantations have made positive impact on livelihood of farmers as it allowed intercrops cultivation both in wet and dry season, with increased production and income to farmers. In addition, growing plantation was an additional asset for the farmers.

As mentioned earlier, after the super cyclone many farmers have been growing plantations like *Acacia sp. Eucalyptus*, etc having bio-drainability since the year 2000 and the saplings were supplied by different organization as a part of post-cyclone rehabilitation programme. These efforts were mainly for the purpose of promoting social forestry and making shelterbelts in the cyclone-prone waterlogged coastal areas. Therefore, farmers have mostly grown those plants in their backyard, farm bund and as a scattered plantation. They have not experienced the benefits of bio-drainage plants in solving waterlogging problems. The organized effort to utilize these plants for the purpose of bio-drainage was a missing link, which has been addressed through application of biodrainage in waterlogged areas. Scientific growing of bio-drainage plants and its positive impact motivated the farmers and widened the scope of use of this tool. Farmers grew the plantations following scientific approach and realized the benefits of reclamation of waterlogged areas. Success of the approach has inculcated the scientific understanding among the farmers in taking up bio-drainage measure to tackle the waterlogging problem and bring all round positive impact on the farming system with enhanced production, income and diversified livelihood options. Replication of the system by the neighbouring farmers gives testimony to success and profitability of the system strengthening the 'seeing is believing' principle.

Hence, the principle of use of bio-drainage vegetation to lower the rising water table with *Eucalyptus* and *Casuarina* vegetation appears promising. The successful intervention with pisciculture, integration of intercrops like oilseed and pulses and crops like watermelon in reclaimed area is also feasible to enhance productivity of areas which otherwise remain sub-productive due to excess soil moisture and waterlogged condition.

REFERENCES

Alexendra, J. 1991. The role of trees in the sustainable management of irrigated land. In Heuperman, A.F.(ed) Tree as a tool for resource management in irrigation areas. Proceeding of symposium held at Institute of Sustainable Agriculture. Victorian Dept. of Agril. Tatura, Australia , July 1991.

Benyon, RG, Marcar, NE., Crawford, D.W. and Nicholson, A.T.1999. Growth and water use of Eucalyptus camaldulensis and E occidentalis on a saline discharge site near Wellington,NSW,Australia. Agricultural Water management.39.299-244.

Bhutta, M.N. and Choudhry, M.R. 2000. Biological control of water logging Bio-drainage and other alternatives to drainage. 8th ICID International drainage workshop "Role of Drainage and challenges in 21st century. 31st Jan-4th Feb. 2000. New Delhi pp 33 - 45.

Blum, U., Shafer, S.R., and Lehman, M.E. 1999. Evidence for inhibitory allelopathic interactions involving phenolic acids in field soils: Concepts vs. an experimental model. Critical Reviews in Plant Sciences. 18(3): 673-693.

Chhabra, R. and Thakur, N.P, 1998. Lysimeter study on the use of bio-drainage to control water logging and secondary salinization in (canal) irrigated arid / semiarid environment. Irrigation and drainage system. 12 . 265-288.

Chorley, R.J and Barry, R.G.1971. Introduction to physical hydrology. Routledge (Taylor and Francis). ISBN 0416688101, 9780416688108, London.

Cramer, V.A., Thorburn, P.J. and Fraser, G.W. 1999. Transpiration and ground water uptake from farm forest plots of *Casuarina glauca* and *Eucalyptus camaldulensis* in saline areas of south east Queensland, Australia, J. Agricultural Water Management 39. 187-204.

Heuperman, A. 1999. Hydraulic gradient reversal by trees in shallow water table areas and repercussions for the sustainability of tree growing systems. J. Agric. Water Management. 39. 153-167.

Heuperman, A. 2000. Bio-drainage: an Australian overviews and two Victorian studies. 8th ICID International drainage workshop "Role of Drainage and challenges in 21st century." 31st Jan- 4th Feb. 2000. New Delhi, pp. 1-16.

JK Paper Ltd. Crafting Green Prosperity through technology. Folder published by JK paper Limited, Jaykaypur, Rayagada,Orissa.

Kapoor, A.S. 1998. Bio-drainage, principles of planning and design.

MOWR 1991. Working group of Ministry of Water resources (only in irrigated commands). In Rana,K.S. and Ghosh,U.K.1996.Waterlogging and salinity problem in irrigated areas in India. Technical papers presented at National workshop on reclamation of waterlogged ,saline and alkaline lands and prevention thereof:MOWR, New Delhi.

Naik, G.R. and Manjunath, G.T.S. 2000. Project (UKP) areas through bio-drainage concept. 8th ICID International drainage workshop "Role of Drainage and challenges in 21st century. 31st Jan- 4th Feb. 2000. New Delhi.

Sasikumar, K., Vijayalakshmi, C. and Parthiban, K.T. 2001. Allelopathic effects of four *Eucalyptus* species on redgram (*Cajanus cajan* L.). Journal of Tropical Agriculture. 39:134-138.

Singh,B., Singh, V., Singh , R.P. and Srivastava, B.K. 1998. Economic prospects of vegetable intercropping in young Eucalypts plantation. Annals of Agricultural Research. 19(4):470-474.

Silberstein, R.P., Vertessy, R.A. Morris, J. and Feikema, P.M. 1999.Modelling the effect of soil moisture and solute conditions on long term tree growth and water use: a case study from the Shepparton irrigation area .J. Agric. Water Management 39. 283-315

Stirzaker, R.J. Cook, F.J. Knight, J.. 1999. Where to plant tress on cropland for control of dryland salinity: some approximate solution. J. Agric. Water Management. 39 : 115-133.

Zang, L., Dawes, W.R, Slavich, P.G., Meyer, W.S, Thorburn, P.J. Smith, D.J. and Walker, G.R. 1999. Growth and ground water uptake responses of Lucerne to changes in ground water levels and salinity: lysimeter, isotope and modelling studies J. Agric. Water Management 39. 265-282.

KEY TO PHOTOGRAPHS

Plate 1.a..Layout at Baghadi,Dec,2004; **b**, *Casuarina* saplings after four month of planting; **c**,Installation of peizometer ; Inter crops like (**d**) paddy in kharif , (**e**) water melon in rabi and (**f**) cow pea in *rabi* season inside *Casuarina* plantation; **g**, Director, WTCER, interacting with farmer at plantation site with watermelon intercrop; **h**, *Casuarina* plantation on February,2009.

Plate 2. a,**b**, *Casuarina* plantation at Patna; **c**, Installation of peizometer at *Eucalyptus* plantation site, trainees from Orissa University of Agriculture and Technology are also seen ; **d**, Layout at Ambapada,Feb,2005 ; **e, f, g, h** *Eucalyptu*s plantations at different stage in 2005, till inundation due to monsoon (**h**).

Plate 3.a. *Eucalyptus* plantation inundated due to monsoon; **b**, Measurement of transpiration with porometer in *Eucalyptus* ; **c**, Paddy intercrop in *rabi* season with *Eucalyptus* plantation at Ambapada ; **d, e**, Waterlogged condition at Alishibindha before plantation development. A palm tree at left is a reference point ; **f**, Installation of peizometer ; **g**, Growing *Eucalyptus* at plantation site; **h**, *Eucalyptus* plantation showing lodging trend in soft waterlogged soil.

Plate 4.a. Ploughing inside *Eucalyptus* plantation before monsoon for kharif crop;**b**, Waterlogging at *Eucalyptus* plantation during *kharif* ; **c**, *Eucalyptus* plantation showing lodging tendency in wet waterlogged soil; **d**, support provided to prevent lodging of trees; **e**, Paddy intercrop in *kharif* season inside and periphery of *Eucalyptus* plantation at Alishibindha ;**f**, Harvested paddy at Alishibindha;**g**, Black gram intercrop in *rabi* season inside *Eucalyptus* plantation at Alishibindha; **h**, *Eucalyptus* at plantation over grown reference palm tree at the site.

Plate 5.a. The team of experts from CWC visiting site. ; **b**, District Agricultural Officer, Jagatsinghpur district,Govt. of Orissa and his team interacting at plantation site; **c**, Asst Director general (IWM), ICAR, Dr. P.S. Minhas visiting experimental site; **d,** Director, CADA, Govt. of Orissa, Er.Jagannath Sahoo, inspecting a bore well at plantation site; **e**, National level training programme “Command area development with special emphasis on biodrainage” sponsored by MOWR, New Delhi in 2007 . Thirty four senior level officers were trained about application of biodrainage for

sustainable agricultural development in canal commands; **f**, trainees visiting experimental site ; **g**, Er.G.C. Panda, Jt. Director, CADA, Govt. of Orissa, Er. Debabrata Jena,Suptd. Engg. Cuttack Division,CADA, visiting site; **h**, Dr. Ashwani Kumar,Director, WTCER, visiting the experimental site along with farmers.

Plate 6.a.Paddy intercrop inside *Eucalyptus* plantation in *kharif*. **b**, Cow pea intercrop in rabi season inside C*asuarina*; **c**,Farmers training programme organized at plantation site; **d**, Paddy intercrop in rabi inside *Eucalyptus* plantation at Ambapada; **e**, A neighbor farmer at Baghadi, who converted his 6.4ha site to a plantation (bund plantation) **f, g, h**, his plantation at different stages of growth till Feb,2009.

Plate-1

Plate - 2

Plate-3

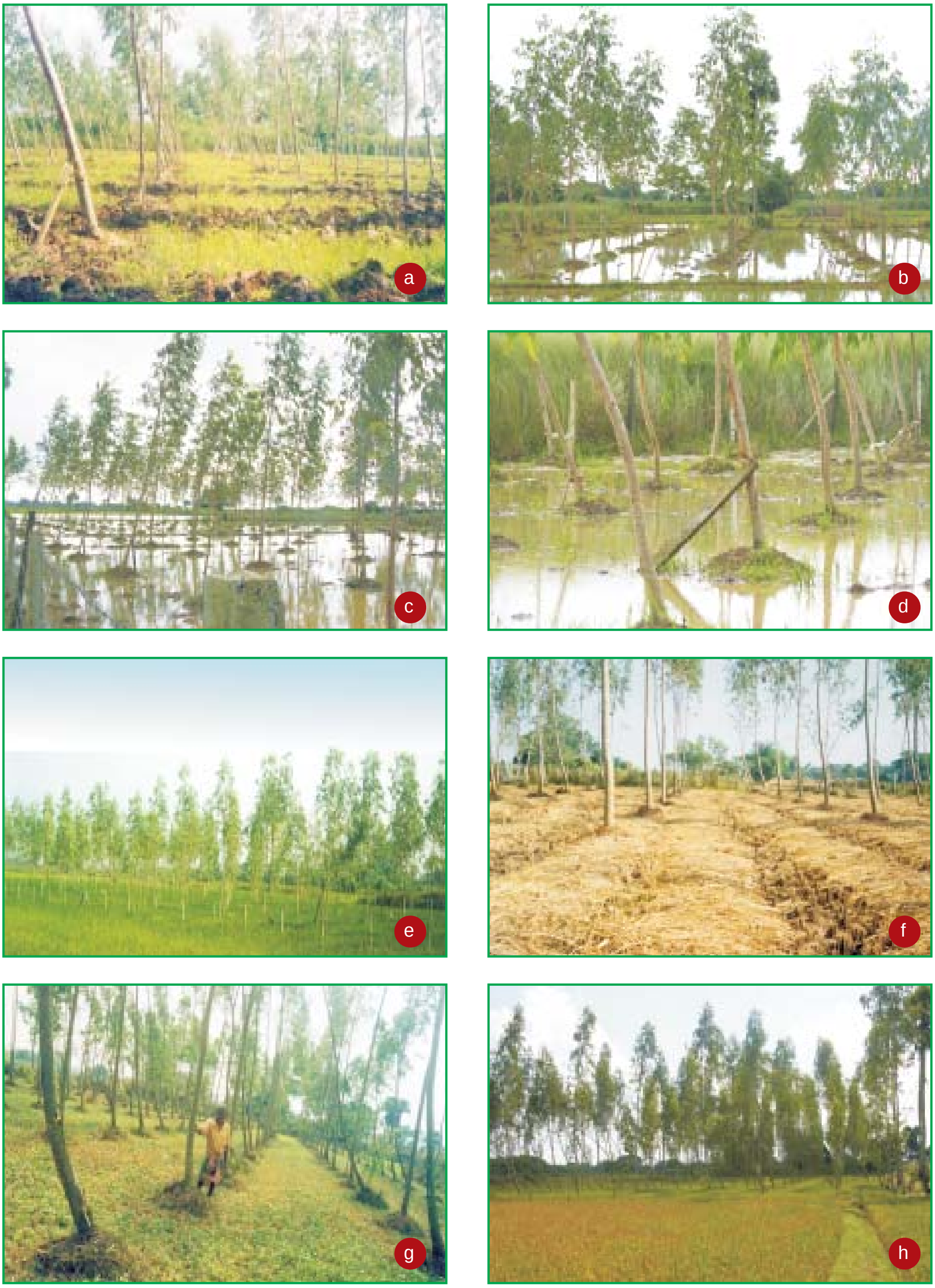


Plate-4

Plate-5

Plate-6