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(Indian Council of Agricultural Research)
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Preface

Agriculture is the largest user of fresh water; this water is under severe competition with industry, energy, domestic and other sectors. Per capita availability of fresh water is also decreasing and is projected to go below the scarcity level for human and livestock sustenance in future. Hence, water is a precious national asset and there are several concerns regarding water resources in the country. A large area in the canal command remains uncultivated during dry season due to lack of irrigation water. It is a challenge before us to increase the coverage of crops under irrigation during post-rainy season crops through crop management and/ or micro- irrigation techniques. Enhancing crop water use efficiency is the need of the hour. At the same time, enhancing crop productivity to increase water productivity is very essential with concomitant saving of irrigation water. To meet this challenge, efficient planting techniques, micro-irrigation are the potential options for saving of irrigation water and enhancing WUE, especially for post-rainy season crops.

The potential productivity of summer rice, locally called as 'boro dhan' in eastern India, is much higher due to greater availability of solar radiation, but this is grown depending entirely either on canal water and/or ground water. Water requirement for rice production by wet method of cultivation, starting from puddling operation to maintenance of standing water during crop growth period is 2-3 folds higher than any other crop which are grown with aerobic soil environment. As irrigated rice is the major consumer of fresh water, rice producers need to produce more rice with less water. Further, traditional wet method of low land rice cultivation is blamed for methane and nitrous oxide emissions. Hence, it was necessitated to search for an alternative method of rice cultivation.

A multidisciplinary team of scientists from Directorate of Water Management (ICAR), Bhubaneswar, conducted research on irrigation water saving techniques for post-rainy season crops including aerobic rice and the salient findings are included in this bulletin. Authors are grateful to Director General of ICAR, Deputy Director General and Assistant Director General of Natural Resources Management Division of the ICAR, New Delhi for their valuable support, suggestions and encouragement in carrying out this research under in-house projects. We sincerely thank research associates, all colleagues and staff members of this institute for their help, cooperation and encouragement.

We hope that this research bulletin will be very useful to the researchers, stake holders/ development agencies, water resources departments, farmers and to all those who will be interested for the management of water to enhance water use efficiency and thereby saving of irrigation water in canal commands or similar situations.

Authors

Executive Summary

Irrigation water saving and enhancing water use efficiency is of prime importance for post-rainy season crops. Field experiments were conducted for three consecutive years to study different planting techniques of dry season crops viz. groundnut and potato under different irrigation regimes at the DWM (formerly WTCER) Research Farm, Mendhasal under Deras minor command. In a separate experiment, drip irrigation method was also evaluated for maize, cowpea, sunflower and tomato. The agronomic practices were developed for rice production in summer season under aerobic method of cultivation with the aim to save irrigation water.

The experimental site and soil were characterized; weather data especially daily rainfall, pan evaporation were recorded for every year. Soil moisture was monitored regularly. The observation on crop physiological parameters viz. interception of PAR, chlorophyll fluorescence, gas exchange and soil physical parameters like soil organic carbon, soil temperature with respect to differential soil moisture regime; root growth, crop growth, crop yield (pod yield, haulm dry matter for groundnut & tuber yield and haulm yield for potato), and irrigation water parameters like irrigation water depth, ET, WUE and irrigation water use efficiency.

The pod and haulm yield of groundnut in ridge & furrow planting and paired row planting were significantly greater than flat bed method. The higher pod yield (13-20%) was due to the better soil moisture extraction and greater interception of photosynthetically active radiation (IPAR) by the crop canopy, as was evident from the recorded data on changes in soil moisture (ΔS) and IPAR. Irrigation water saving was 27 and 41% and in ridge & furrow and paired row method of planting, respectively compared to flat method of planting with the increase in WUE of the crop and IWUE.

The paired row method of planting for potato at 75 x 20 cm saved a significant amount of irrigation water compared to normal planting without reducing fresh tuber yield. The depth of irrigation for potato decreased in paired row planting compared to normal, implying a significant reduction in irrigation water requirement by 21-32%. The efficient planting techniques significantly enhanced the crop WUE.

The soil organic carbon ranged from 5.48-5.74 g kg^{-1} soil in the 0-15 cm and 4.57-4.83 g kg^{-1} soil in 15-30 cm soil depth. The studies on nutrient uptake viz. kernel -N uptake and haulm -N uptake by groundnut was determined. Kernel -N uptake ranged from 23.32 kg ha^{-1} in flat bed planting of groundnut under one irrigation to 42.70 kg ha^{-1} in paired row planting of groundnut under four irrigation.

The economics of groundnut and potato cultivation i.e., operation cost, economic return, and benefit cost ratio was estimated to study the economic feasibility of paired row planting methods. For groundnut, the B/C ratio was the lowest in flat-bed planting under one irrigation and it was the highest in paired row planting under four irrigation; and for potato, the ratio was the lowest in paired row planting at 100 x 15 cm receiving two irrigation and the highest in

paired row planting at 75 x 20 cm under five irrigation. Thus, saving of irrigation water and enhancing of WUE of dry season crops in rice-based systems in canal commands would be possible through paired row planting techniques.

By drip irrigation method water saving was 29, 3, 13 and 30% in maize, cowpea, sunflower and tomato, respectively over the furrow irrigation. The irrigation water use efficiency increased by 11-36% when drip irrigation was used.

Field experiments on aerobic rice systems revealed that the rice varieties viz. 'Surendra', 'Apo' and 'Lalat' showed the highest yield potential between 3.9 and 4.6 t ha^{-1} under aerobic conditions with soil moisture at 80-90% of field capacity throughout the growing season. Water input as a pre-sowing irrigation was estimated as 54-62 mm for aerobic rice, and 362-401 mm for wet land preparation for traditional flooded rice. On average, water input during crop growth stage was 506 mm for aerobic rice and 882 mm for traditional flooded rice. In total, saving potential of water input was 42-60% with aerobic rice when compared to traditional flooded rice.

Studies on irrigation x N interaction on aerobic rice revealed that a highest grain yield of 4.4 t ha^{-1} was obtained with N rate of 120 kg ha^{-1} receiving 780 mm irrigation for rice variety 'Surendra'. The next best combination viz. N rate of 80 kg ha^{-1} with 780 mm irrigation (3.84 t ha^{-1}) and N rate of 120 kg ha^{-1} with 660 mm irrigation (3.61 t ha^{-1}) were statistically similar. Irrespective of variety, aerobic rice with 120 N kg ha^{-1} with 780 mm irrigation gave the highest grain and straw yield of 4.24 and 6.63 t ha^{-1}, respectively.

1. INTRODUCTION

Water is essential for crop production, because plants require water for growth and tissue expansion. Agriculture, the largest user of water for producing food, is being seriously affected by the growing competition with industry, energy, domestic and other sectors for the available limited water resources. With the growing population, per capita availability of water is decreasing, and is projected to go below the scarcity level for human and livestock sustenance in the future years to come. The rising cost of irrigation projects and low rate of returns make the situation even more difficult. Much effort is being made to reduce water use by crops and produce 'more crop per drop'. In addition, erratic rainfall and seasonal differences in water availability can cause floods and droughts. In many areas, this water use is unsustainable. Water supplies are also being affected by the climate change. As water is becoming a limiting factor for crop production, soil and water management should be the key to the development of sustainable agriculture for both irrigated as well as rainfed areas.

The aim of any efficient water management system is to maximize the productivity per unit irrigation water used for crop production system. It is universally recognized that long-term improvement in productivity and stability thereof will only be possible, if we could manage water efficiently using cost effective and eco-friendly techniques. Farmers can use a variety of simple and affordable water management techniques to increase their yields and reduce vulnerability to erratic rainfall or drought. The primary focus of this bulletin concentrates on presenting the research findings for irrigation water saving for post-rainy season crops under rice-based cropping systems; and potential technologies for crop production and saving of irrigation water. Singh (1997) has defined water management in agriculture as those methods, systems and techniques of water conservation, remediation, application, use and removal that provide a socially, and environmentally favourable level of water regime to agricultural production system at least economic cost. Efforts were made to conduct experiments on water saving techniques. The team of scientists of the centre has developed alternate raised and sunken bed technology through land modification and crop diversification (Singh et al., 2005; Kannan et al., 2003). But, during dry season, when potential productivity of most crops are high due to greater accumulated solar radiation, a large area in the canal command remains uncultivated due to lack of irrigation water. Thus, efforts must be made for management of limited water resource for growing of crops during dry season. Saving of water or enhancing the use efficiency of water in canal command areas during dry season is required for stability of agricultural production.

Irrigation is a crucial input for agricultural production. It enables a higher productive potential from the land, and significant production response from associated use of high yielding varieties, fertilizer and other inputs. In Odisha, total area irrigated is only 3177 thousand ha which is 56.6% of the gross cropped area (Agril. Statistics, 2008-09, Govt. of Odisha). Even, when adequate irrigation water is supplied through canal, tail reach areas under the command suffer from scarcity of water. Considering the dry season crops, for example, groundnut is grown in Odisha in an area of 256.05 thousand ha; but its irrigated area is only 89.61 thousand ha i.e., 34.9% of the total area (2008-09); remaining areas are either rainfed or not under irrigation. Thus, it is a challenge before us to increase the coverage of crops under irrigation and enhance or maintain crop productivity with concomitant saving of water. Crop management viz. efficient planting techniques are potential options for saving of water and increasing water use efficiency.

The previous research work on different planting techniques for saving of irrigation and enhancing WUE is reflected on paired row planting of sugarcane and its ratoon under drip irrigation (More and Bhoi, 2004); for maize, maize/ moong and maize/ soybean intercropping (Shivoy and Singh, 2003); for rainfed hybrid pearl millet (Kaur et al., 2005); paired row sowing of cotton (Aujla et al., 2005); ridge and bed planting for oilseed rape (*Brassica napus* L.) (Buttar et al., 2006), broad-bed and furrow method of sowing in vertisols (Mandal et al., 2013). Since soil moisture plays a crucial role in plant growth, mineral nutrition and microbial activity in soil, its availability has to be increased in the soil profile. Results of experiment conducted by Ramesh and Devasenapathy (2007) showed that moisture conservation through tied ridging along with mulching recorded significantly higher soil moisture at all the critical stages of pigeonpea. In this context, practices like ridges and furrows, compartmental bunding, tie-ridging, mulching are useful water saving practices in crop production (Hulugalle, 1990; Ramesh and Devasenapathy, 2007). Nutrient application to crops increases water-use efficiency by increasing the evapo-transpiration (ET) particularly the transpiration (T) component of ET and transpiration efficiency of the crop. Thus the T/ET ratio, which is conducive to higher WUE, is higher for the fertilized than for the unfertilised crop. The field experiments on wheat and Indian mustard showed that, judicious application of limited irrigation water and enhancing water use efficiency (WUE) through integrated nutrient management could boost the productivity of wheat and enhancing WUE of the crop (Mandal et al., 2005; Mandal et al., 2006). For Indian mustard in central Indian vertisols, it was found that the ET-yield relationships were linear, with a lowest regression slope or marginal WUE (WUEm) of 3.09 kg ha^{-1} mm^{-1} and elasticity of water production (Ewp) of 0.63 in control and considerably higher WUEm (4.23 and 3.95 kg ha^{-1} mm^{-1}) and Ewp (0.71 and 0.61) in 100% NPK and 100% NPK + FYM. As the Ewp is positive and comparatively greater in 100% NPK, the scope of improving WUE and yield with only inorganic fertilizer is lesser, and relatively greater scope exists in the integrated management of organic manure and inorganic fertilizer, for which the Ewp was lesser (Mandal et al., 2010). In Chiplima, ginger is grown in inter-row spaces of banana on raised bed in combination with FYM, mulching and sand, and is compared with flatbed; in Almorah, raised -sunken bed system is compared with flat bed, rice and soybean is grown during kharif, and wheat and barley on rabi; ridge sowing is compared with flat sowing for bhindi; in Ludhiana, paired row techniques are tried for tomato in combination with irrigation to each furrow and irrigation to alternate furrow (AICRPWM, 2006-07). Planting in paired rows on raised bed at Faizabad gave significantly greater yield and WUE of rajmah compared to flat method of planting (AICRPWM, 2005-06).

Research reports revealed that tactical decisions concerning sowing pattern, soil tillage, type of crop and cultivar, fertilization, irrigation timing, amount and frequency had greatest bearing on the performance of crops (Philippe and Abdellah, 2004). When water is the most limiting, there is scope for improving water use efficiency by proper irrigation scheduling in combination with better crop management techniques, thereby reducing evaporative and other losses and fostering a good balance of water-use before and after flowering, which is needed to give a large harvest index (Ferreira and Gonçalves, 2007). To increase crop yield per unit of scarce water, it requires both better cultivars and better agronomy of crops (Passioura, 2006). The average maize yield increments of 22 and 28% were obtained due to the use of the tie-ridger and improved varieties, respectively in Ethiopia (Georgis et al., 2001). The distribution of roots has a marked influence on the rate of drying of the soil surface and thereby soil hydraulic conductivity which becomes more important as evaporative demand increases relative to rainfall (Gregory et al., 2000). Hasan et al. (2003) studied and found that soil and moisture conservation treatments were very effective for storing of soil moisture in the profile, and rice-chickpea/ mung bean was successful crop sequence. There was 80% yield increment when ridges were tied at 4 and 6 weeks after planting of cotton. Effective ridging reduced fibre length but produced the better fibre in terms of fineness (Ogunwole, 2004). Therefore, irrigation water saving and enhancing the use efficiency of water in canal command areas during dry season cropping was the essence of this study and trials were conducted for the post-rainy season crops like groundnut and potato.

In India, rice is cultivated in an area of about 44 million ha and it meets the requirement as a staple food and supply 43% of the calorie requirement to majority of Indian population (Viraktamath et al., 2006). The trend in the yield of this crop over this decade shows a deceleration mode at the average annual growth rate of 0.6% as compared to 1.3% in the previous decade. The rainfed upland constitutes 7.1 million hectare, of which more than 85% of eastern Indian upland area is located in the states of Assam, Bihar, West Bengal, Odisha, Andhra Pradesh, Chhattisgarh and Uttar Pradesh (Mandal et al., 2010b). Combining the growing demand for food with increasing water scarcity, rice producers in Asia need to produce more rice with less water (Belder et al., 2005; Bouman et al., 2005). Irrigated rice has very low water-use efficiency as it consumes 3000-5000 litres of water to produce 1 kg of rice (Shashidhar, 2007). The low land rice cultivation is a major source of methane and nitrous oxide emissions, contributing 48 and 52%, respectively of total greenhouse gases emitted by agricultural sources (Raman, 2006). In Asia, 17 million ha of irrigated rice areas may experience physical water scarcity and 22 million ha may have economic water scarcity by 2025 (Tuong and Bouman, 2001). Therefore, a more efficient management of water is needed in rice production. Several strategies are being pursued to reduce rice water requirements, such as saturated soil culture (Borell et al., 1997), alternate wetting and drying (Li, 2001;Tabbal et al., 2002), ground cover systems (Lin et al., 2002), system of rice intensification (Stoop et al., 2002), aerobic rice (Bouman et al., 2002, 2006, 2007). Research on different aspects of aerobic rice– its varietal performance, agronomic management, N economy, challenges, causes of low yield, water saving has got momentum in Asia (Belder et al., 2005; Bouman et al., 2005; Belder et al., 2005b; Belder et al., 2004; Choudhury et al., 2007; Kreye et al., 2008; Kreye et al., 2009; Lampayan and Bouman, 2005; Lampayan et al., 2009; Nie et al., 2008; Peng et al., 2006), but the site and soil specific as well as agro-ecosystem-wise appropriate technology packages are essential considering climate and water scarcity. Information on potential of aerobic rice, suitable varieties, management options are lacking in the eastern region.

Hence, the objectives of the experiments were:

i) To explore the feasibility of planting in paired rows and ridge & furrow for saving of irrigation water and enhancing WUE of post-rainy season crops,
ii) To study the soil moisture distribution, root growth, the physiology, crop yield, nutrient uptake and economics under different planting technique and irrigation levels,
iii) To study the drip irrigation to rabi season crops for saving of irrigation water,
iv) To study the water saving potential and water productivity under aerobic method of cultivation of rice.

2. METHODOLOGY

2.1 The study site

The study area is located near Bhubaneswar in the Khurda district of Odisha, India (Fig. 1). The area is under the Deras minor irrigation command, which is located in the eastern part of India. The Deras minor command irrigates an area of 398.53 ha through canal system with the supply of water from a storage reservoir viz. Deras (Nanda and Panda, 1998). Command area is actually meant for the entire cultivable area under a reservoir system. As this command area is less than 2000 ha, it comes under a minor irrigation system in Odisha. The region experiences a hot and moist sub-humid climatic condition. The land has 1 to 3% slope and its elevation varies from 90 to 100 m above mean sea level (Singh et al., 2000). This study site comes under the Agro-Eco Sub-Region 12.2 (AESR 12.2) according to NBSS&LUP (ICAR) and Agro-Climatic Zone 11 (ACZ 11) of India according to Planning Commission, Govt. of India classification.

2.2 Climate, experimental site and soil characteristics

The climate of the region is characterized by hot moist sub-humid i.e., hot summers and cool winters. The daily rainfall, pan evaporation, maximum and minimum air temperature (^{0}C) for 10 years (2000-2010) were collected from the weather station located at the Research Farm and analyzed. Annual rainfall in the area varies from 1000 to 1600 mm. This rainfall meets out about 80 per cent of the potential evapotranspiration (ET) leaving a deficit of 500 to 700 mm of water per year. Mean annual rainfall and evaporation was 1590.4 and 55.8 mm, respectively. The monthly effective rainfall was calculated using the USDA Soil Conservation Service method, as also used by Sharma et al. (2010). The study area received 81.7% of total annual rainfall during monsoon period (i.e. June to September); remaining 18.3% occurred during post-monsoon, winter and pre-monsoon period. Long-term average minimum air temperature varied from 13.3 to 26.2 ^{0}C whereas maximum air temperature varied from 28 to 37.6 ^{0}C.

The field experiments were carried out at the Research Farm of Directorate of Water Management (formerly Water Technology Center for Eastern Region) (20° 17' N latitude and 85° 41' E longitude), Mendhasal under Deras Minor Irrigation command. Soil moisture regime is Typic Ustic and the area comes under hyperthermic soil temperature regime. The dominant soils of the area are fine loam to clay, non-calcareous, saturated hydraulic conductivity of 1.14-1.78 cm h^{-1} slightly to moderately acidic (5.6-6.5) and have relatively low cation exchange capacity (9-15 cmol (+) kg^{-1} soil) (Singh et al., 2000). The mechanical composition revealed that, in the plough layer (i.e., 0-15 cm depth), soil was consisted of 46% coarse sand, 17% fine sand, 16%

silt and 21% clay; thus the textural class is sandy clay loam. The relative contribution of both the coarse and find sand fractions are declined towards greater depth of the soil, and the clay fraction is increased with the soil depth. The bulk density was 1.44 Mg m^{-3} in the 0-15 cm soil depth, and it increased with soil depth. The saturated hydraulic conductivity (Ks) decreased towards greater depth of the soil. As the sand fractions were relatively more in the upper layers, water holding capacity and available water capacity were lower and increased in the lower depths because of relatively greater contribution of clay fractions. The soil moisture characteristics revealed that, maximum water holding capacity (θs) in the 0-15 and 15-30 cm soil layer was comparatively lower than the θs values in greater depth. The field capacity, permanent witling point and available water capacity increased with soil depth.

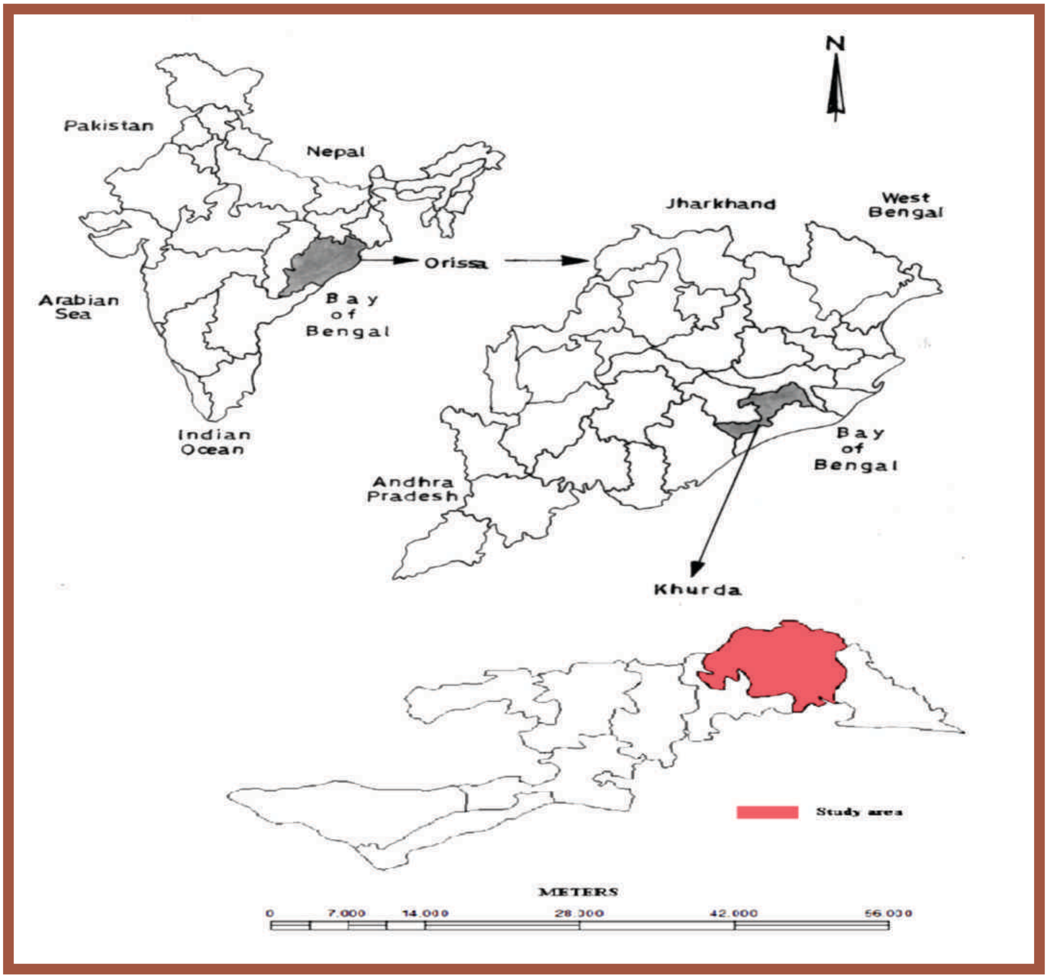


Fig. 1. The study area under the Deras minor irrigation command in the Khurda district of Odisha, India.

2.3 Weather condition during crop growing periods of groundnut and potato

In the first season, the total rainfall received during the crop growth period (23 Jan-23 May 2008) was 140.9 mm. The evaporation increased gradually from 2.3 mm/day on 23 Jan 2008, it exceeded 5 mm/day on 9 April 2008, and further increased during the month of May. The average minimum air temperature was 12.3 and 24.9 ^{0}C in the month of Jan and May 2008, respectively and the corresponding maximum temperature was 27.2 and 37.2 ^{0}C. In the second season, no rainfall was received during the crop growth period i.e., 4 Dec 08 -12 Mar 09 for potato and 10 Jan- 2 May 09 for groundnut (Fig. 2 & 3). For potato growing period, the evaporation gradually decreased from 3.1 mm/day on 4 Dec 08 to 2.3 mm/day on 29 Dec 08; thereafter it increased gradually and reached to 4.3 mm/day on 12 Mar 09. The cumulative pan evaporation was 308.9 mm for the period of 4 Dec 08 to 12 Mar 09. For groundnut, daily rate of evaporation increased gradually from 2.6 mm/day on 10 Jan 09, reached to 5.0 mm/day on 4 Apr 09, and ≥ 6.0 mm/day during the last week of April and first week of May 09. The cumulative pan evaporation was 471.9 mm for the period of 10 Jan 09 to 2 May 09.

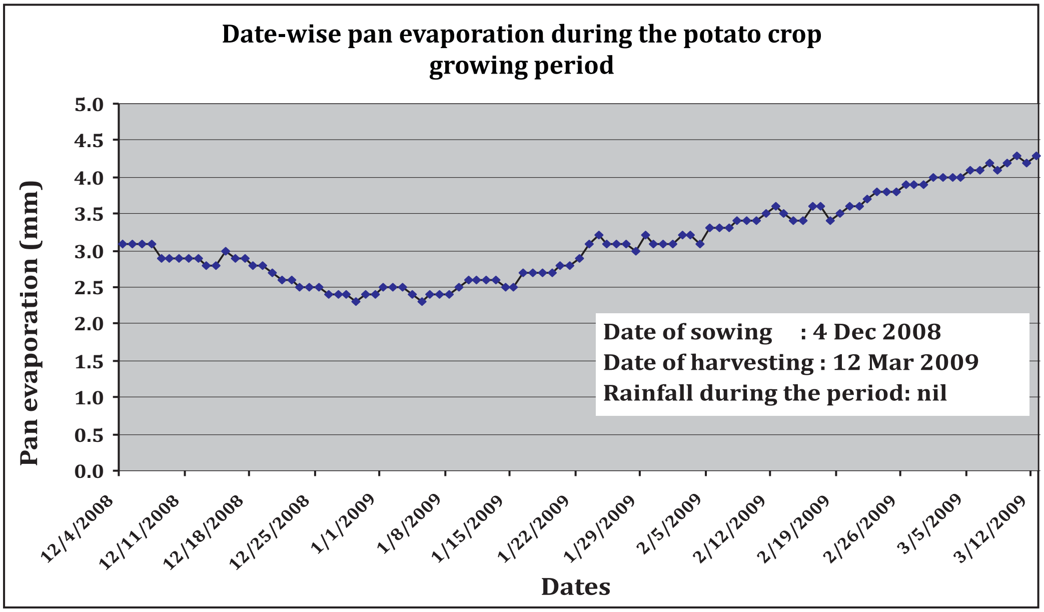


Fig. 2. Daily rate of pan evaporation during the potato growing period (2008-09)

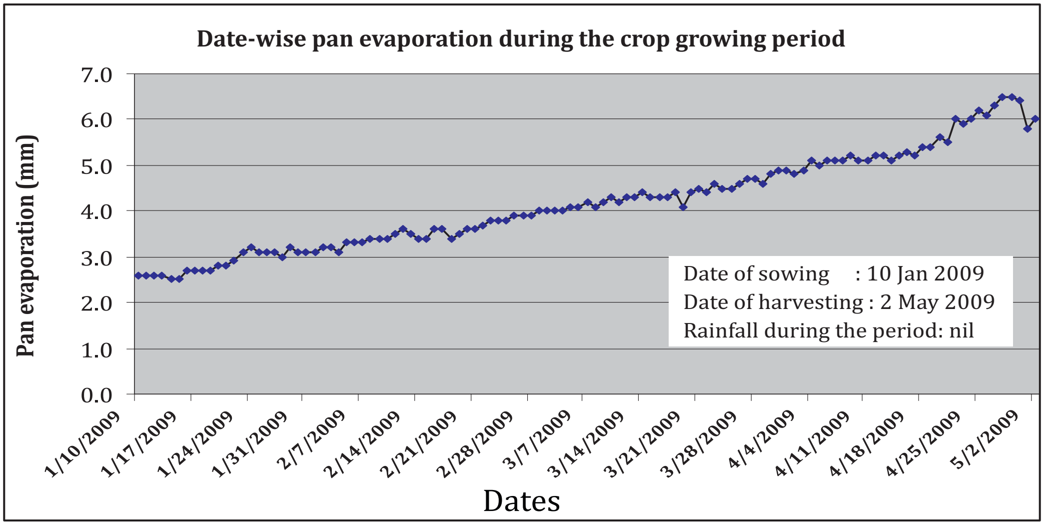


Fig. 3. Daily pan evaporation during the groundnut growing period (2009)

In the third season, rainfall was 8.7 mm only during the crop growth period i.e., 26 Nov 09 - 4 Mar 10 for potato and 27 Jan- 20 May10 for groundnut (Fig. 4 & 5). For potato growing period, the evaporation gradually decreased from 4.3 mm/day on 26 Nov 09 to 2.4 mm/day on 13 Jan 10; thereafter it increased gradually and reached to 4.1 mm/day on 4 Mar 10. The cumulative pan evaporation was 332.6 mm for the period of 26 Nov 09 to 4 Mar 10. For groundnut, the cumulative pan evaporation was 524.7 mm for the period of 27 Jan to 20 May 10.

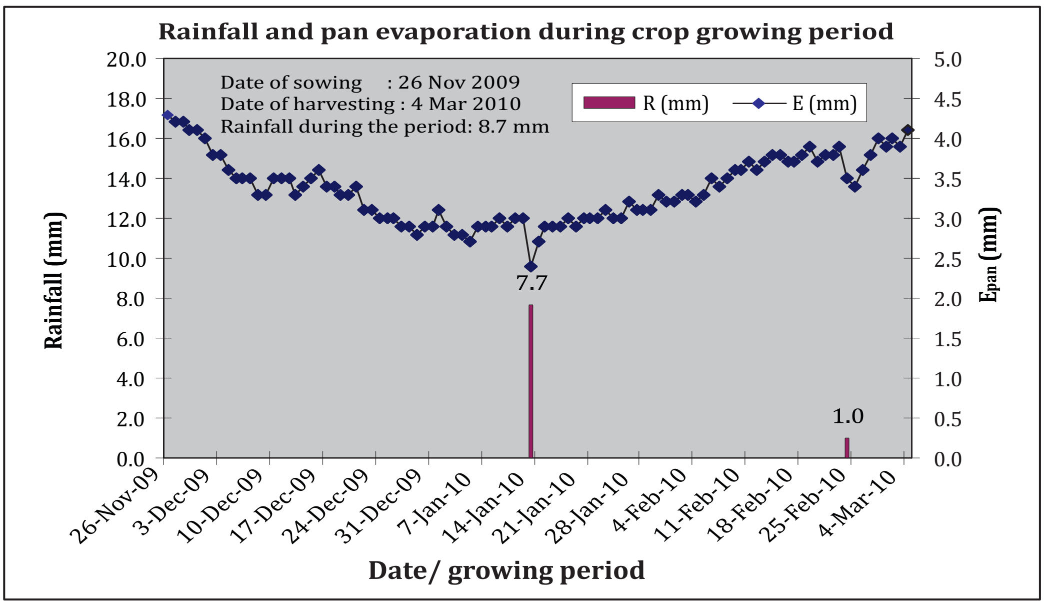


Fig. 4. Rainfall and daily pan evaporation during the potato growing period (2009-10)

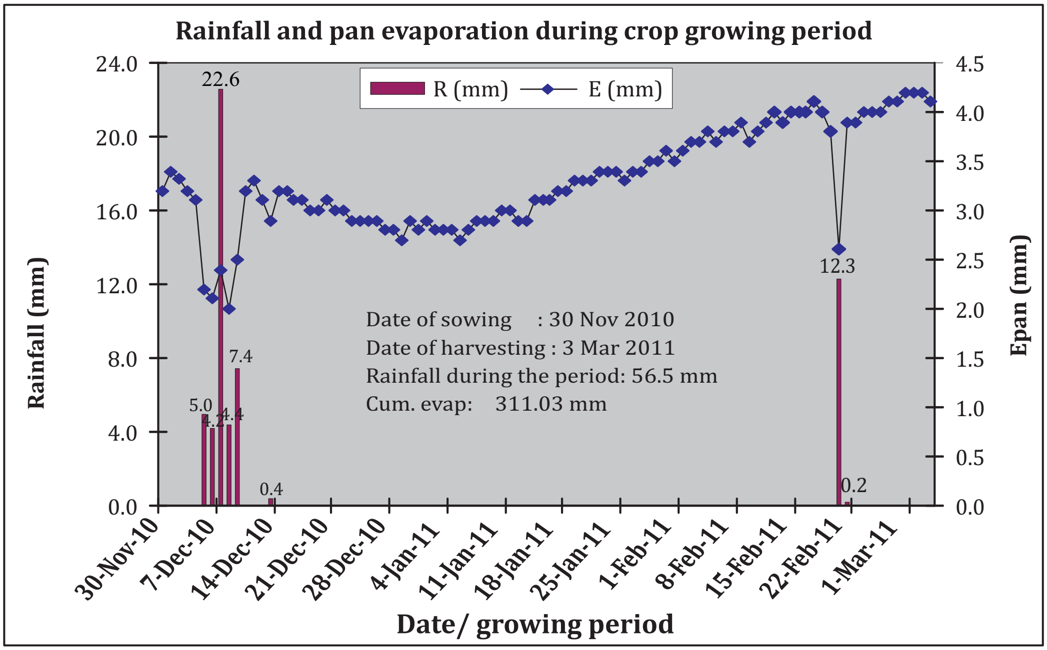


Fig. 5. Rainfall and pan evaporation during the potato growing period (2010-11)

For the last season of potato (2010-11), rainfall was 56.5 mm during the crop growth period i.e., 30 Nov '10 - 3 Mar '11. The cumulative pan evaporation was 311.03 mm for the period of 30 Nov 10 to 3 Mar 11.

2.4 Crops, treatments and design of experiments

For groundnut, treatments were as follows:

Number of irrigation – 4 (Factor A)

I_1: 1 irrigation (flowering & pegging)

I_2: 2 irrigation (flowering & pegging, pod development)

I_3: 3 irrigation (vegetative, flowering & pegging, pod development)

I_4: 4 irrigation (vegetative, flowering & pegging, pod formation, pod development)

Planting technique - 3 (Factor B)

S_1: Flat method of sowing/ planting at 30 x 10 cm spacing

S_2: Ridge and furrow planting: planting at 30 x 10 cm spacing and making ridges in the crop row after emergence; single row on a ridge

S_3: Paired row planting at 45 x 15 cm spacing and making ridges in the crop row after emergence; paired row at 15 cm row spacing on a ridge

Design of experiment was split-plot with three replication.

For potato, treatments were as follows:

Number of irrigation- 4 (Factor A)

I_1: 2 irrigation (stolonization, tuberization)

I_2: 3 irrigation (stolonization, tuberization, tuber bulking)
I_3: 4 irrigation (vegetative, stolonization, tuberization, tuber bulking)
I_4: 5 irrigation (vegetative, stolonization, tuberization-2, tuber bulking)

Planting technique -3 (Factor B)
S_1: Normal planting at 50 x 15 cm spacing (planting in 50 x 15 cm spacing and making ridges in the crop row after emergence, i.e., furrow spacing 50 cm.
S_2: Paired row planting at 75 x 20 cm spacing (planting of 2 rows at 25 cm spacing, and making of 1 ridge with 2 rows); furrow spacing 70 cm.
S_3: Paired row planting at 100 x 15 cm spacing (planting of 2 rows at 50 cm spacing and making of 1 ridge with 2 rows); furrow spacing 100 cm.
Design of experiment was split-plot with three replication.

2.5 Field experiments, crop management and observations

The experiment on groundnut was conducted (as shown in the photo plates) for the three years (2008-2010) with irrigation treatments in the main-plots and planting techniques in the sub-plots. The irrigations were scheduled in critical growth stages viz. vegetative, flowering, pod formation and pod development. The number of replication was three. The individual plot size was 6 m x 3 m. Before final land preparation and layout, organic manures and soil sakti was applied and incorporated into the soil. The fertilizers were applied @ 20, 40 and 40 kg ha^{-1} as N, P_2O_5 and K_2O, respectively. The variety, TAG 24 was sown during the dry season on Jan every year. The need based management of the crop like weeding, hoeing and plant protection measures were taken. Observations on soil moisture, plant growth, physiological parameters, light interception, root growth, yield attributes, yield and water use were recorded for groundnut grown during dry season.

A view of the experimental plots of groundnut


Demonstration of planting techniques to the farmers

Field experiments on potato were conducted during 2008-09 to 2010-11 (as shown in the photo plates) with four main-plot treatments viz. two (I_1), three (I_2), four (I_3) & five (I_4) irrigations and three planting techniques as sub-plot treatments viz., S_1, normal planting at 50 x 15 cm spacing (planting in 50 x 15 cm spacing and making ridges in the crop row after emergence; furrow spacing 50 cm), S_2, paired row planting at 75 x 20 cm spacing (planting of 2 rows at 25 cm spacing, and making of 1 ridge with 2 rows; furrow spacing 75 cm), and S_3, paired row planting at 100 x 15 cm spacing (planting of 2 rows at 50 cm spacing and making of 1 ridge with 2 rows; furrow spacing 100 cm). The irrigations were scheduled in critical growth stages viz. vegetative, stolonization, tuberization and tuber bulking. Before final land preparation and layout, 'soil sakti', organic manure, was applied and incorporated into the soil. The fertilizers were applied @ 150, 100 and 100 kg ha^{-1} as N, P_2O_5 and K_2O, respectively; sources were urea, DAP and MOP. The variety, 'Kufri Jyoti' was sown after seed tuber treatment with pesticides. Irrigations were scheduled as per the treatments, and measured by RBC flume 13.17.02. Other agronomic practices like weeding, hoeing, earthing up and spraying of insecticides and pesticides were made for every treatment.

Observation on paired row planting of potato in the year 2009-10

A view of the experimental plots under potato crop during 2010-2011

Paired row planting of potato

Normal planting of potato

2.6 Measurement of parameters, methods of analyses and calculation

Core sampling was done for determination of soil bulk density. Particle size distribution was determined by the hydrometer method (Bouyoucous, 1951) and soil texture class was determined by following the procedure of USDA classification. Soil pH was measured with a digital pH meter (pHTestr30, Malaysia), and electrical conductivity (EC) by EC meter (ECtestr model). Field capacity and permanent wilting point was determined by pressure plate apparatus (Eijkelkamp, Model 505); available water capacity (AWC) of soils, expressed as volume of water per unit volume of soil, was estimated as the difference between field capacity (FC) and permanent wilting point (PWP). The soil parameters were determined using standard procedures (Page et al., 1982; Klute, 1986; Nelson and Sommers, 1996). The irrigation water use efficiency (WUE) was estimated as the crop yields divided by total irrigation water applied (Mishra and Ahmed, 1987). Organic carbon was determined by wet digestion method (Walkley and Black, 1934).

2.7 Evaluation of drip irrigation to winter season crops

In a separate experiment, the post-rainy season crops during rabi season viz maize, cowpea, sunflower and tomato were grown with recommended package of agronomic practices after harvest of kharif season. Sowing/ planting were done manually by the 3 to 4 week of November. The spacing was 50 cm row-to-row and 30 cm plant-to-plant on the beds separated with furrows for irrigation. Two lines per bed were maintained. One unit of bed and furrow was 1 m in width. The drip irrigation was given on drippers (4 l hr^{-1} with a uniformity coefficient of 90%) placed on the bed with a 30-cm dripper spacing in between two crop rows. For furrow irrigation, the irrigation water was measured through RBC flume (model 13.17.02). For maize, seed rate was 18 kg ha^{-1}. Entire dose of P and K was applied as basal; N was applied in 3 splits, 25% as basal, 50% at 3 weeks stage and 25% at 6-7 weeks stage (Table 1). The seed rate for cowpea was 30 kg ha^{-1}. Entire dose of fertilizer was applied as basal. The seed rate for sunflower was 5 kg ha^{-1}; entire P and K, and 50% of N was applied as basal, and rest 50% N was applied at flowering stage. For tomato, 25 kg N, 50 kg P_2O_5 and 20 kg K_2O was incorporated at the time of transplanting. Rest 100 kg N and 80 kg K_2O was applied in two equal splits at 15 and 30 days after transplanting. Intercultural operation and plant protection was done as per the need.

Table 1. The crop varieties used and their fertilizer (N, P & K) application rates for rabi crops

Sl. No.	Crops grown	Variety used	Fertilizer doses (kg ha^{-1})		
			N	P_2O_5	K_2O
1	Maize	'Navjot'	80	40	40
2	Cowpea	'Barabati Long'	20	40	20
3	Sunflower	'PAC 36'	60	80	60
4	Tomato	'BT 10/ Utkal Kumari'	125	50	100

2.8 Experiments on water saving in rice production by aerobic method of cultivation

Three field experiments were conducted during dry seasons of 2007-08 to 2009-10. In the first experiment, three rice varieties viz. 'Surendra', 'Lalat' and 'Khandagiri' and four irrigation regimes viz. irrigating the crop at 80-90% of field capacity soil moisture content throughout season (I_1), at 60-70% of field capacity during vegetative and at 80-90% of field capacity from panicle initiation to maturity (I_2), and at 60-70% of field capacity soil moisture throughout season (I_3) and were imposed on aerobic rice cultivation, and traditional flooded transplanted rice i.e., TFR (I_4). The design of experiment was split- plot. In the second experiment, the effect of irrigation regimes, fertilizer N rates and irrigation x N rates interaction on crop growth and yield of aerobic rice var. 'Surendra' was studied. Three main-plot treatments (irrigation water input) viz. 540 mm, 660 mm and 780 mm i.e. 9, 11 and 13 number of irrigations each of 6 cm and four sub-plot treatments (fertilizer-N rates) viz. 0 (N_0), 40 (N_{40}), 80 (N_{80}) and 120 (N_{120}) kg ha^{-1} were tested in a split-plot design. Nitrogen fertilizer was applied in 3 splits- 25% at four weeks after sowing, 50% at eight weeks after sowing and the remaining 25% at twelve weeks after sowing. The variety was 'Surendra' and its sowing was done in the first week of January with spacing of 20 x 10 cm. Other agronomic management practices were followed as per the needs. In the third experiment, the effect of fertilizer-N rates on crop growth and N-uptake of three rice varieties ('Apo', 'Lalat' and 'Surendra') were studied under aerobic system. Three varieties viz. Apo, Lalat and Surendra and four fertilizer N rates viz. 0, 40, 80 and 120 kg ha^{-1} were tested in a split-plot design. The split application schedule for fertilizer N was similar to the second experiment. Soil and water management was under aerobic system. Total of 13 irrigations each of 6 cm i.e., 780 mm was applied. Sowing time and spacing was similar to the second experiment.

Soil samples were collected from the experiment site before commencement of the experiment, covering all treatments and replications. Samples were mixed and bulked, and a representative sample was taken for physical and chemical analyses of soil. The samples were analyzed for organic carbon, available N, P and K. These chemical analyses were made following the standard procedures. Plant dry matter was determined from plants harvested from sample area. The dry matter was then determined after drying the plant material at 65 ^{0}C. Rice crop was harvested at physiological maturity. The fluorescence was measured through a portable pulse modulated chlorophyll fluorescence monitoring system (Hansatech Instruments, UK). Root samples for determination of root mass density were collected through monolith method.

The irrigation water input was measured through RBC flume (model 13.17.02). The water productivity (WP) with respect to grain yield (GY) and straw yield (SY) was estimated as: WP_{GY} = {Grain yield/ (irrigation input + rainfall)}, and WP_{SY} = {Straw yield/ (irrigation input + rainfall)}. These WP parameters are expressed as kg grain or straw per ha per mm water.

2.9 Statistical analyses

The analysis of variance (ANOVA) technique was carried out on the data for each parameter as applicable to split-plot design with equal replications (Gomez and Gomez, 1984) . The significance of the treatment effect was determined using F-test at 5% level. The mean differences between treatments were compared using the least significant difference (LSD) and the ordering of treatments was done by using Duncan's multiple range test (DMRT) at 5% level of probability.

3. Research findings and discussion

3.1 Experiments on water saving planting techniques of groundnut and potato

3.1.1 Soil moisture and root growth studies

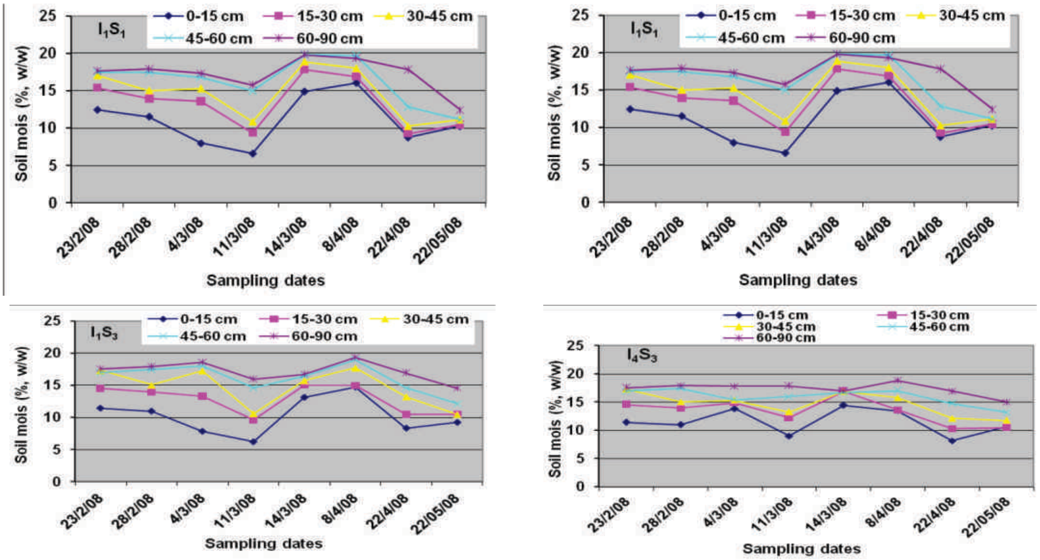


Fig. 6. Variation of soil moisture content due to different depths in different treatment combinations in the year 2008

Soil moisture contents in the profile showed differences in S_1 and S_3, implying a differential pattern of moisture uptake by the crop (Fig. 6 & 7) and root growth (Fig. 8).

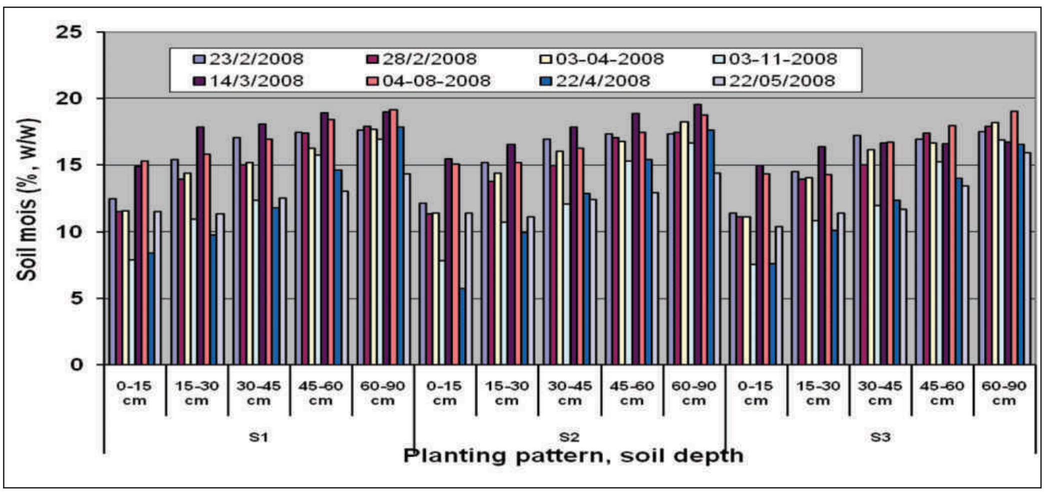
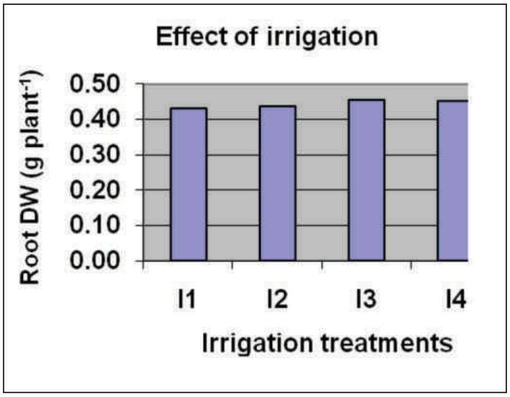


Fig. 7. Depth-wise soil moisture content (%,w/w) as influenced by different treatments during groundnut growing period in 2008



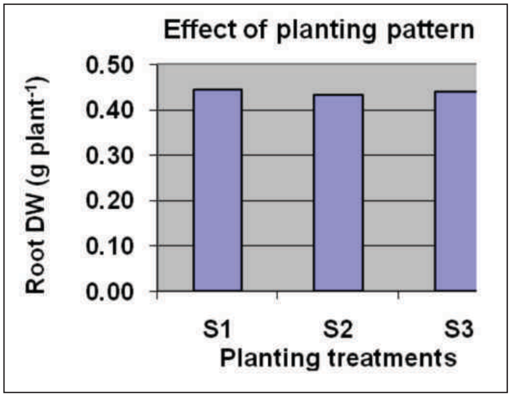
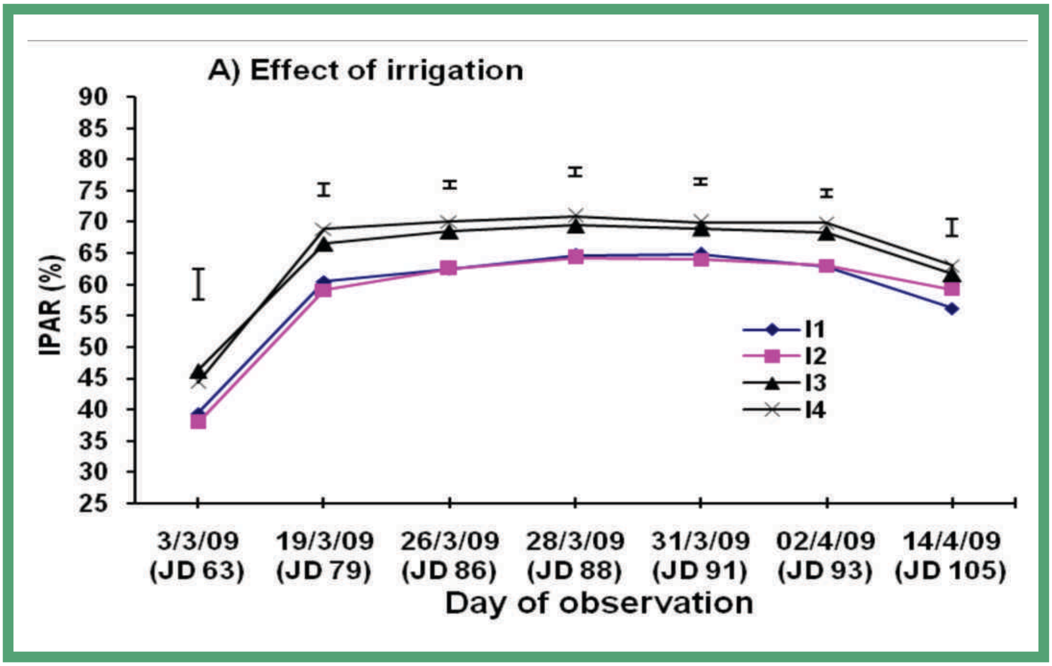


Fig. 8. Root dry weight of groundnut as influenced by irrigation and planting technique

3.1.2 Studies on crop physiology- interception of PAR (IPAR), Fv/Fm and ΦPS II

The intercepted PAR (IPAR) was 46.3 to 57.7% in S_1, 52.8 to 61.8% in S_2 and 64.5 to 74.4% in S_3 in the year 2008. There was significantly greater interception in I_3 and I_4 than I_1. In S_3, rate of photosynthesis (Pn) and transpiration (E) was 21.6 µmole m^{-2} s^{-1} and 7.2 mmol m^{-2} s^{-1}, respectively. In the year 2009, the observed physiological parameters viz. maximum fluorescence efficiency (Fv/Fm) and actual fluorescence efficiency (ΦPS II) showed higher values in the higher irrigation regimes (I_3 and I_4) than the lowest irrigation (I_1) treatment.



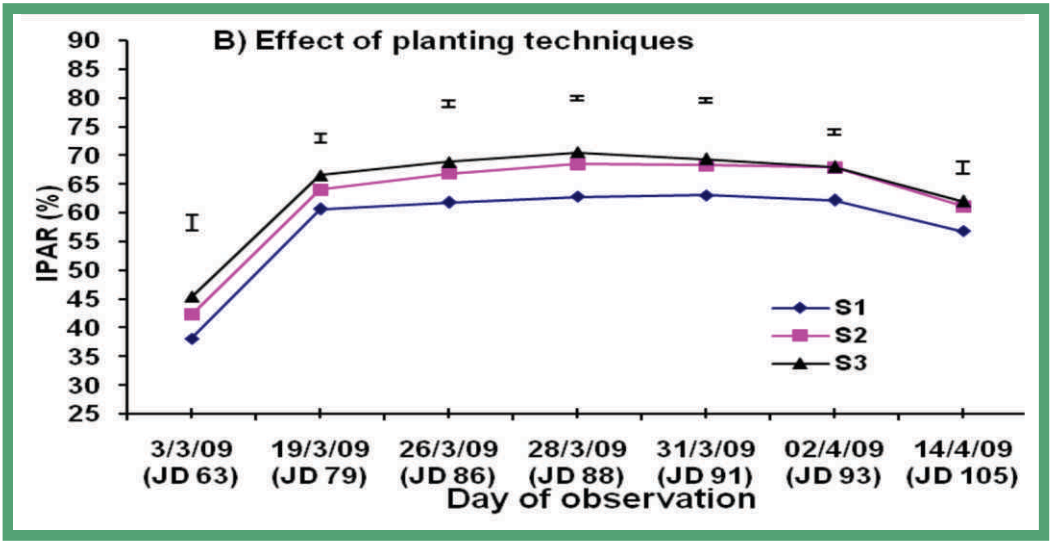


Fig. 9. Intercepted photosynthetically active radiation (IPAR) at JD 63 through JD 105 as influenced by, A) different irrigation regimes, and B) planting techniques of groundnut during 2009 field experiment, vertical bars show the LSD at 5%; JD is Julian Day.

Recording of chlorophyll fluorescence

Recording of interception of PAR

This indicates a better efficiency of plants for photosynthesis under better irrigation regime; however, planting treatments did not show significant variation. The intercepted PAR (IPAR) was higher in I_3 and I_4 than I_2 and I_1. Over different date of observation (from JD 63 through JD 105), the range of IPAR was 38-63% in S_1, 42-69% in S_2 and 45-71% in S_3 (Fig. 9). The higher yield in S_2 and S_3 was might be due to the better soil moisture extraction and greater interception of photosynthetically active radiation (PAR) by the crop canopy, as was evident from recorded data on changes in soil moisture (ΔS) and %IPAR. The observed physiological parameters viz. maximum fluorescence efficiency (Fv/Fm) and actual fluorescence efficiency (ΦPS II) showed higher values in the higher irrigation regimes (I_3 and I_4) than the lowest irrigation (I_1) treatment.

Irrigation to a plot with flat bed planting

Paired row planting saves irrigation water

3.1.3 Studies on variation in soil temperature

Soil temperature was measured using manual soil thermometers. Measurements were made in the plots receiving full irrigation (irrigated) and in plots receiving only one irrigation (dry) on 3rd week of April. Temperature was recorded for four depths up to 30 cm (0-5, 5-10, 10-20 and 20-30 cm) during the day time (8:00 am to 5:00 pm) in 30-min intervals (Fig. 10a & b). On an average over four depths, the soil temperature was greater in dry condition than the irrigated plots because of less moisture regime in dry than the irrigated conditions. The temperature of surface soil (0-5 cm) increased at a faster rate and reached to the maximum of 43.6 ^{0}C at 11:30 am under dry; whereas the temperature increase was gradual and maximum temperature of 35.8 ^{0}C was recorded at 11:30 and 1:30 pm under irrigated condition. The falling rate was also very fast after 1:30 pm through 5:00 pm. In the soil depth 5-10 cm, the maximum temperature reached to 37.8 and 33.6 ^{0}C in dry and irrigated, respectively. Soil depths 10-20 and 20-30 cm, showed less variation in temperature. Of course, average temperature was greater in dry than irrigated. The regulation of temperature in the irrigated condition was largely due to higher moisture regime in the soil profile.

Soil temperature measurement in groundnut plots having differential soil moisture regime and planting technique

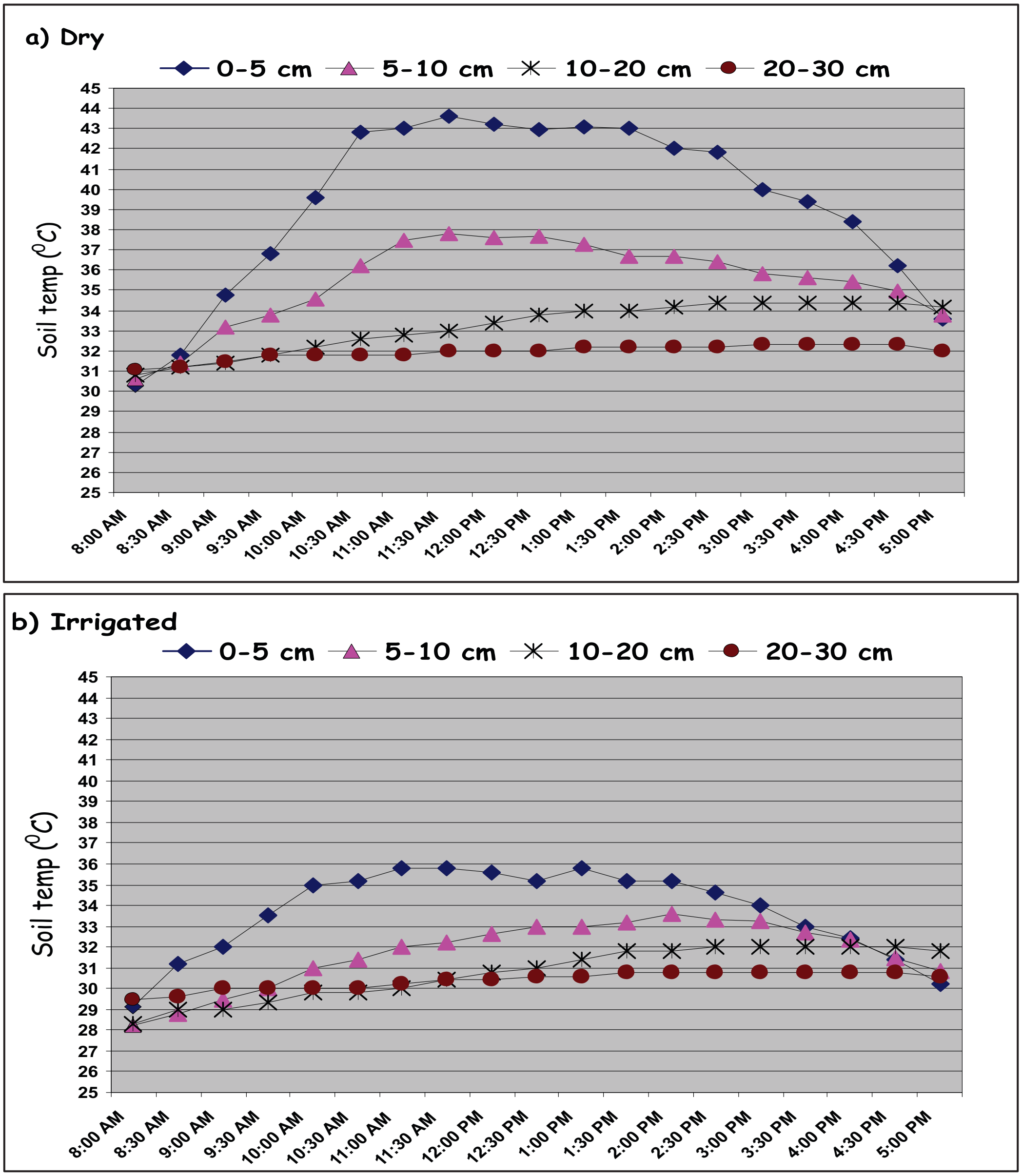


Fig. 10. Changes in soil temperature (0-30 cm) in the groundnut growing plots in dry (a) and irrigated conditions (b) during the day time (8:00 am- 5:00 pm)

3.1.4 Pod and haulm yield of groundnut as influenced by planting method and irrigation

Pooled data on groundnut revealed that both pod and haulm yields in S_2 and S_3 were significantly greater than S_1 (Table 2). However, S_2 and S_3 were statistically at par. Total dry biomass production i.e., pod yield plus haulm yield, was also significantly influenced by the planting techniques. The higher pod yield by 13-20% in S_2 and S_3 was might be due to the better soil moisture extraction and greater interception of photosynthetically active radiation by the crop canopy, as was evident from the recorded data on changes in soil moisture (ΔS). Regarding irrigation treatments, higher irrigation regimes led to greater yield; highest yield was being in I_4, and the lowest in I_1. As there was very less rainfall received during the crop growing period, a continuous and positive response to applied irrigation was recorded even at highest irrigation regime; and the interaction between irrigation and planting treatments was also significant. However, the harvest index was statistically similar for both irrigation and planting treatments.

3.1.5 Irrigation water depth, evapotranspiration and water use efficiency of groundnut

Pooled data on irrigation water depth was 10.58 and 13.30 cm in S_3 and S_2, respectively compared to 18.15 cm in S_1; implying a significant reduction in irrigation water requirement by 41 and 27% in S_3 and S_2, respectively compared to S_1 (Table 3). The crop WUE and irrigation water use efficiency (IWUE) was also significantly greater in S_3 and S_2 than in S_1. The crop WUE was significantly greater in S_3 (7.03) than S_2 (6.30) and S_1 (4.75 kg pod $ha^{-1}mm^{-1}$ET), implying a considerable enhancement of WUE of the crop. The evapotranspiration (ET) decreased in S_2 and S_3 compared to S_1; the irrigation water use efficiency (IWUE) was 10.06, 16.30 and 20.63 kg pod mm^{-1} depth of irrigation in S_1, S_2 and S_3, respectively. The depth of irrigation and ET increased with increase in irrigation regimes, the highest being in I_4 and the lowest in I_1; and both the crop and irrigation water use efficiency decreased with increase in irrigation regimes.

Table 2. Pod yield and haulm yield of groundnut as influenced by irrigation and planting techniques

Treatments	Flat-bed planting (S_1)	Ridge & furrow planting (S_2)	Paired row planting (S_3)	Mean
(a) Pod yield (kg ha^{-1})				
I_1	1194	1381	1429	1335
I_2	1447	1681	1677	1602
I_3	1615	1907	1977	1833
I_4	1830	2051	2056	1979
Mean	1522	1755	1785	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	111	31	62	
(b) Haulm yield (kg ha^{-1})				
I_1	2120	2867	3010	2666
I_2	2992	3501	3610	3368
I_3	3330	3929	3838	3699
I_4	3386	4061	4124	3857
Mean	2957	3590	3646	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	502	181	NS	

I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing

3.1.6 Tuber yield and haulm dry matter of potato

Pooled data of three years field experiment revealed that fresh tuber yield of potato in S_1 (15.09 t ha^{-1}) was statistically at par with S_2 (14.78 t ha^{-1}), and both S_1 and S_2 was significantly greater than S_3 (12.71 t ha^{-1}) (Table 4). It implies that by paired row method i.e., planting of two rows on a ridge, tuber yield was not reduced significantly. Haulm dry matter was significantly higher in S_1 (30.52 g m^{-2}) than S_2 (28.57 g m^{-2}) and S_3 (24.13 g m^{-2}). Irrigation treatments also showed significant variation; highest tuber yield was recorded with I_4, and it was similar with I_3. The lowest yield was obtained in I_1. Similar trend was observed in haulm dry matter of this crop. However, irrigation x planting technique interactions for both fresh tuber yield and haulm dry matter yield was significant.

Table 3. Irrigation water depth, evapotranspiration (ET) and water use efficiency (WUE) and irrigation water use efficiency (IWUE) of groundnut as influenced by irrigation and planting techniques

Treatments	Flat-bed planting (S_1)	Ridge & furrow planting (S_2)	Paired row planting (S_3)	Mean
(a) Irrigation water depth (cm)				
I_1	7.93	5.78	4.49	6.06
I_2	14.94	10.94	8.61	11.49
I_3	20.61	14.79	12.34	15.91
I_4	29.14	21.70	16.89	22.58
Mean	18.15	13.30	10.58	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	3.64	0.67	1.35	
(b) Evapotranspiration (cm)				
I_1	23.28	21.83	20.35	21.82
I_2	30.06	26.36	24.09	26.84
I_3	35.38	30.02	28.03	31.14
I_4	43.75	37.10	32.81	37.89
Mean	33.12	28.83	26.32	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	3.64	0.67	1.35	
(c) Water use efficiency, WUE (kg pod/ ha mm water)				
I_1	5.28	6.54	7.29	6.37
I_2	4.86	6.52	7.19	6.19
I_3	4.65	6.53	7.22	6.13
I_4	4.23	5.63	6.41	5.42
Mean	4.75	6.30	7.03	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	NS	0.18	NS	
(d) Irrigation water use efficiency, IWUE (kg pod/ mm ir rigation water)				
I_1	15.86	25.98	33.48	25.10
I_2	10.02	16.34	20.30	15.56
I_3	8.01	13.36	16.40	12.59
I_4	6.34	9.51	12.33	9.39
Mean	10.06	16.30	20.63	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	6.46	1.07	2.14	

I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing

Table 4. Fresh tuber yield and haulm dry weight of potato as influenced by irrigation and planting techniques

Treatments	Normal planting 50 x 15 cm (S_1)	Paired row planting 75 x 20 cm (S_2)	Paired row planting 100 x 15 cm (S_3)	Mean
(a) Fresh tuber yield (t ha^{-1})				
I_1	12.02	11.67	10.36	11.35
I_2	14.60	14.49	12.41	13.83
I_3	16.65	16.16	13.95	15.59
I_4	17.09	16.80	14.13	16.01
Mean	15.09	14.78	12.71	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	1.41	0.36	NS	
(b) Haulm dry matter (g m^{-2})				
I_1	25.38	25.03	19.06	23.16
I_2	30.17	29.20	22.27	27.22
I_3	31.56	28.41	27.00	28.99
I_4	34.98	31.62	28.19	31.59
Mean	30.52	28.57	24.13	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	1.82	1.04	2.07	

I_1: 2 irrigation, I_2: 3 irrigation, I_3: 4 irrigation, I_4: 5 irrigation, irrigation at critical growth stages; S_1: normal planting at 50 x 15 cm spacing; S_2: paired row planting at 75 x 20 cm spacing, S_3: paired row planting at 100 x 15 cm spacing

3.1.7 Depth of irrigation water, evapotranspiration and water use efficiency of potato

The water use parameters i.e., the depth of irrigation water, evapotranspiration (ET), crop water use efficiency (WUE) and irrigation water use efficiency (IWUE) were significantly influenced by irrigation and planting technique treatments (Table 5). The depth of irrigation increased with increase in irrigation regimes from I_1 through I_4. On the contrary, it was decreased in S_2 (17.73 cm) and S_3 (15.21 cm) compared to S_1 (22.49 cm). This implies a significant reduction in irrigation water requirement by 21 and 32% in S_2 and S_3, respectively compared to S_1. The ET increased due to increase in irrigation regimes. The higher ET was estimated for I_4 and I_3, and the lowest in I_1. Thus, the increase in amount of irrigation water increased ET; and again ET decreased significantly in S_2 and S_3 compared to S_1; irrigation x planting technique interaction was also significant. The increase in ET with higher irrigation levels (I_4) decreased the crop WUE because of not recording commensurate increase in tuber yield; the irrigation treatment for WUE was significant. However, the efficient planting techniques, S_2 (44.11) significantly enhanced the crop WUE when compared to S_1 (40.75) and S_3 (41.07 kg tuber per ha mm water). The IWUE decreased with higher irrigation regimes, and planting techniques showed similar trend as with crop WUE.

Table 5. Irrigation water depth, evapotranspiration (ET) and water use efficiency (WUE) and irrigation water use efficiency (IWUE) of potato as influenced by irrigation and planting techniques

Treatments	Normal planting 50 x 15 cm (S_1)	Paired row planting 75 x 20 cm (S_2)	Paired row planting 100 x 15 cm (S_3)	Mean
(a) Irrigation water depth (cm)				
I_1	11.00	9.36	8.07	9.48
I_2	17.78	14.97	12.62	15.12
I_3	26.48	19.47	16.51	20.82
I_4	34.71	27.12	23.65	28.50
Mean	22.49	17.73	15.21	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	1.02	0.94	1.88	
(b) Evapotranspiration (cm)				
I_1	26.87	26.14	24.84	25.95
I_2	32.87	30.86	28.01	30.58
I_3	41.85	35.26	32.62	36.58
I_4	50.47	43.29	40.32	44.69
Mean	38.02	33.89	31.45	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	1.02	0.94	1.88	
(c) Water use efficiency, WUE (kg tuber ha^{-1} mm^{-1} water)				
I_1	44.93	44.79	41.93	43.88
I_2	44.44	46.97	44.49	45.30
I_3	39.80	45.86	42.75	42.80
I_4	33.85	38.83	35.11	35.93
Mean	40.75	44.11	41.07	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	4.41	1.66	NS	
(d) Irrigation water use efficiency, IWUE (kg tuber mm^{-1} irrigation water)				
I_1	109.79	125.69	128.56	121.34
I_2	82.31	97.05	98.61	92.66
I_3	63.42	84.07	84.85	77.45
I_4	49.38	62.31	60.10	57.26
Mean	76.22	92.28	93.03	
	Irrigation (I)	Planting (S)	I x S	
LSD at 5%	9.35	6.03	NS	

I_1: 2 irrigation, I_2: 3 irrigation, I_3: 4 irrigation, I_4: 5 irrigation, irrigation at critical growth stages; S_1: normal planting at 50 x 15 cm spacing; S_2: paired row planting at 75 x 20 cm spacing, S_3: paired row planting at 100 x 15 cm spacing

3.1.8 Studies on soil organic carbon in the rice-groundnut and rice-potato sequence

Soil samples were collected for determination of periodical soil moisture contents. Soil organic carbon (SOC) contents (0-15 cm & 15-30 cm soil depth) were determined (Fig. 11). It reveals that the SOC content in upper soil layer (0-15 cm) was more than the lower layer (15-30 cm). The influence of irrigation and planting techniques was not significant. However, SOC content ranged from 5.48-5.74 g kg^{-1} soil in the 0-15 cm and 4.57-4.83 g kg^{-1} soil in 15-30 cm soil depth.

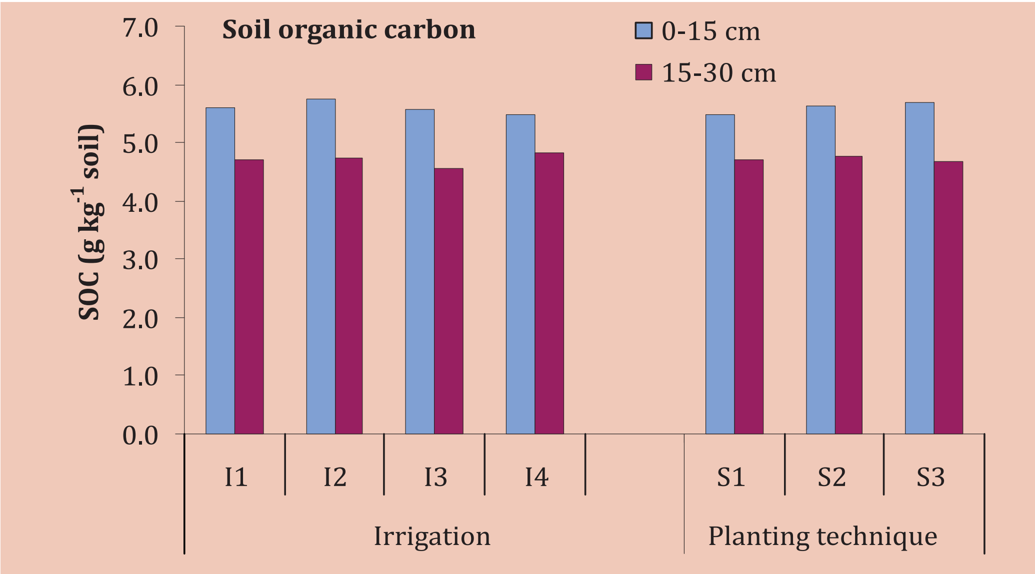


Fig. 11. Soil organic carbon (SOC) content of soil collected after harvest of groundnut as influenced by irrigation and planting treatments; I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing

3.1.9 Studies on nutrient uptake

Nutrient N content was determined for kernel and above-ground biomass i.e., haulms of groundnut. The nutrient N content in kernels and above-ground biomass of groundnut did not vary significantly due to the different irrigation and planting technique treatments. However, kernel N content ranged from 2.79 to 3.51% and haulm N content from 1.71 to 2.52%. Nutrient N-uptake by kernel and haulms varied significantly (Fig. 12 & 13). Kernel N uptake ranged from 23.32 kg ha^{-1} in flat bed planting of groundnut under one irrigation to 42.70 kg ha^{-1} in paired row planting of groundnut under four irrigation; and haulm N uptake ranged from 38.46 to 77.53 kg ha^{-1} in the corresponding treatments. The variation of uptake in different treatment combination was due to the variation in pod and haulm yield of groundnut grown during summer under rice-based system.

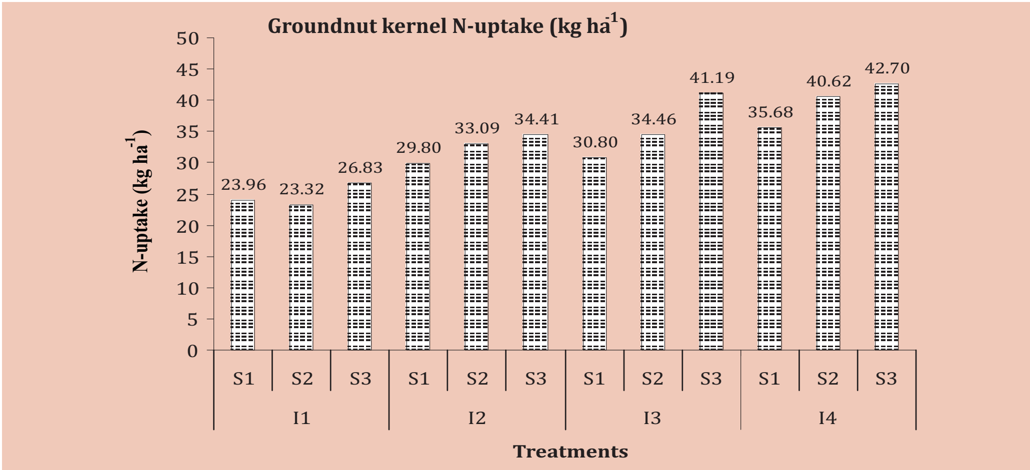


Fig. 12. Groundnut kernel N-uptake in different irrigation and planting treatment combinations (I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing)

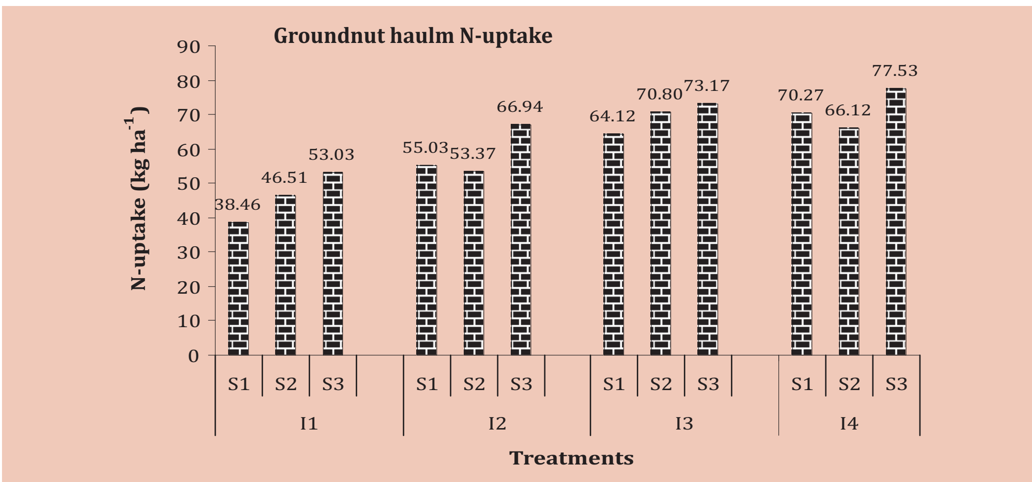


Fig. 13. Groundnut haulm N-uptake in different irrigation and planting treatment combinations (I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing)

3.1.10 Economic returns and benefit-cost ratio

The economic analysis was done for both groundnut and potato cultivation with respect to different treatments imposed on both the crops. The cost of inputs for each operation i.e., the operational cost was estimated with the current rate of ploughing, seed, labour, fertilizer, manure and plant protection chemicals. The gross return was estimated with the pooled yield of both the crops. The cost of cultivation of groundnut ranged from Rs 20732 ha^{-1} in flat-bed planting (S_1) under one irrigation (I_1) to Rs 21821 ha^{-1} in ridge & furrow planting (S_2) under four irrigation (I_4) (Table 6). Though the cost of cultivation did not vary much, the gross return and the net return varied significantly because of the variation in physical output i.e., pod yield of this crop due to irrigation and planting treatments. The gross return ranged from Rs 26007 ha^{-1} in flat-bed planting (S_1) under one irrigation (I_1) to Rs 45239 ha^{-1} in paired row planting (S_3) under four irrigation (I_4); and the net return varied from Rs 5275 to Rs 23659 ha^{-1} in the corresponding treatment combinations. The benefit-cost ratio was the lowest (1.25) in flat-bed planting (S_1) under one irrigation (I_1) and the highest (2.10) in paired row planting (S_3) under four irrigation (I_4), but this highest ratio was almost similar to the ridge & furrow planting (S_2) under four irrigation (I_4) and paired row planting (S_3) under three irrigation (I_3).

Similarly, for potato, the cost of cultivation ranged from Rs 46131 ha^{-1} in normal planting (S_1) under two irrigation (I_1) to Rs 48057 ha^{-1} in normal planting (S_1) under five irrigation (I_4) (Table 7). However, both the paired row planting methods i.e., paired row at 75 x 20 cm (S_2) and paired row at 100 x 15 cm (S_3) has led to lesser cost of cultivation than normal planting method due to the lesser number of irrigation furrows to be made for imposition of treatments. Irrigation cost increased marginally with the increase in number of irrigation. The gross return ranged from Rs 62188 ha^{-1} in normal planting (S_1) under two irrigation (I_1) to Rs 102563 ha^{-1} in normal planting (S_1) under five irrigation (I_4); and the net return varied from Rs 16056 in paired row planting at 100 x 15 cm (S_3) under two irrigation (I_1) to Rs 54506 ha^{-1} in normal planting under five irrigation (I_4). The benefit-cost ratio was the lowest (1.35) in paired row planting at 100 x 15 cm (S_3) receiving two irrigation (I_1) and the highest (2.15) in paired row planting at 75 x 20 cm (S_2) under five irrigation (I_4), but this highest ratio was similar to other three treatment combinations viz. normal planting with five irrigation, normal planting with four irrigation and paired row planting at 75 x 20 cm with four irrigation.

Table 6. Economic analyses of groundnut cultivation as influenced by irrigation and planting techniques

Treatments		Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B/C ratio
I_1	Flat-bed planting (S_1)	20732	26007	5275	1.25
	Ridge & furrow planting (S_2)	21011	30481	9470	1.45
	Paired row planting (S_3)	20905	31591	10687	1.51
I_2	Flat-bed planting (S_1)	21032	31940	10908	1.52
	Ridge & furrow planting (S_2)	21281	37112	15831	1.74
	Paired row planting (S_3)	21130	37144	16015	1.76
I_3	Flat-bed planting (S_1)	21332	35630	14297	1.67
	Ridge & furrow planting (S_2)	21551	42071	20520	1.95
	Paired row planting (S_3)	21355	43384	22030	2.03
I_4	Flat-bed planting (S_1)	21632	39987	18354	1.85
	Ridge & furrow planting (S_2)	21821	45087	23266	2.07
	Paired row planting (S_3)	21580	45239	23659	2.10

I_1: 1 irrigation, I_2: 2 irrigation, I_3: 3 irrigation, I_4: 4 irrigation, irrigation at critical growth stages; S_1: flat-bed planting at 30 x 10 cm spacing; S_2: ridge & furrow planting at 30 x 10 cm spacing, S_3: paired row planting on beds at 45 cm spacing

Table 7. Economic analyses of potato cultivation as influenced by irrigation and planting technique treatments

Treatments		Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B/C ratio
I_1	Normal planting 50 x 15 cm (S_1)	47157	72113	24956	1.53
	Paired row planting 75 x 20 cm (S_2)	46264	70038	23773	1.51
	Paired row planting 100 x 15 cm (S_3)	46131	62188	16056	1.35
I_2	Normal planting 50 x 15 cm (S_1)	47457	87613	40156	1.85
	Paired row planting 75 x 20 cm (S_2)	46504	86950	40446	1.87
	Paired row planting 100 x 15 cm (S_3)	46356	74438	28081	1.61
I_3	Normal planting 50 x 15 cm (S_1)	47757	99925	52168	2.09
	Paired row planting 75 x 20 cm (S_2)	46744	96938	50193	2.07
	Paired row planting 100 x 15 cm (S_3)	46581	83688	37106	1.80
I_4	Normal planting 50 x 15 cm (S_1)	48057	102563	54506	2.13
	Paired row planting 75 x 20 cm (S_2)	46984	100813	53828	2.15
	Paired row planting 100 x 15 cm (S_3)	46806	84750	37944	1.81

I_1: 2 irrigation, I_2: 3 irrigation, I_3: 4 irrigation, I_4: 5 irrigation, irrigation at critical growth stages; S_1: normal planting at 50 x 15 cm spacing; S_2: paired row planting at 75 x 20 cm spacing, S_3: paired row planting at 100 x 15 cm spacing

3.2 Evaluation of drip irrigation to winter crops

Though the crop yields under drip and furrow irrigation system were similar (Table 8), water saving was more in drip irrigation than furrow irrigation. The irrigation water use and WUE of crops differ with the type of crops grown (Fig. 12 a & b). By drip irrigation method water saving was 29, 3, 13 and 30% in maize, cowpea, sunflower and tomato, respectively over the furrow irrigation method. The irrigation water use efficiency was increased when drip irrigation was used. The percent increase in irrigation WUE (kg ha^{-1} mm^{-1}) was 11-36% depending upon the type of crops, water use and their yield.

Table 8. Crop yields and rice equivalent yield of winter season crops grown with furrow irrigation and drip irrigation system under different cropping systems

Rabi season crops	Crop yield (t ha^{-1})			REY (t ha^{-1})
	With furrow irrigation	With drip irrigation	Mean	
Maize	5.03	4.90	4.97	8.11b
Cowpea	1.13	1.06	1.10	4.13c
Sunflower	1.32	1.28	1.30	5.31c
Tomato	18.13	16.80	17.47	21.39a
LSD at 5%	-	-	-	1.21

REY is the rice equivalent yield; Mean values of REY followed by different letters are significantly different according to Duncan's multiple range test (P = 0.05).

Drip irrigation to maize

Drip irrigation to tomato

Drip irrigation to cowpea

Drip irrigation to sunflower

Similar results were also obtained by Singandhupe et al. (2003), they reported an increase in fruit yield of tomato by 3.7-12.5% with a saving of water by 31-37% and an increase in water use efficiency by 68-77% in the drip system as compared to the furrow irrigation in Rahuri, India. In other findings, there was an increase in tomato yield and water use efficiency when drip method of irrigation was adopted on a deep clay loam soil at Dire Dawa, Ethiopia (Yohannes and Tadesse, 1998), in Florida (Zotarelli et al., 2009), and on a fine textured heavy soils of Western India (Shrivastava et al., 1994).

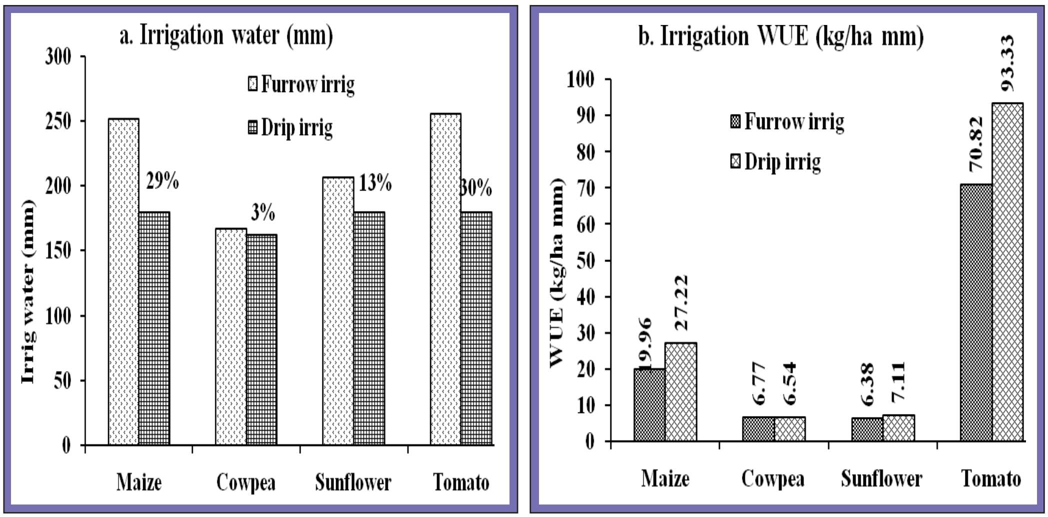


Fig. 12 a &b. Irrigation water (mm) and irrigation water use efficiency (WUE, kg ha^{-1} mm^{-1}) of winter season crops viz. maize, cowpea, sunflower and tomato grown under furrow and drip irrigation systems; bars with % values for each crop show the water saving by using drip irrigation when compared to surface furrow irrigation

3.3 Results of the experiment on aerobic rice

3.3.1 Crop growth and physiological parameters

The number of tillers per hill, tiller height and dry biomass yield of rice grown under aerobic soil with irrigation regimes viz. I_1, I_2 and I_3 were significantly lower than those under traditional flooded rice (TFR) with irrigation regime i.e., I_4 (Table 9). Among the I_1, I_2 and I_3 water regimes, aerobic rice with I_1 treatment produced significantly more tillers and greater tiller height up to 40 days after sowing. Tiller height at 60 and 90 days at I_1 and I_2 was similar, whereas biomass production at 60 days differed significantly; and at 90 days biomass production at I_1, I_2 and I_3 were at par. The crop performance with I_3 irrigation regime under aerobic condition was poor with respect to other irrigation treatments.

Among the three varieties, 'Surendra' gave more number of tillers at maximum tillering stage i.e. about 60 days after sowing compared to 'Lalat' and 'Khandagiri', whereas tiller height was greater in 'Lalat' than other two varieties in every observation date viz. 40, 60 and 90 days. The biomass production per hill was the highest in 'Surendra' in every observation up to 90 days. This difference might be due to the varietal difference i.e. genetic make-up of the plants which influenced the differential crop growth and physiological behaviour of the plants in response to different soil moisture regimes under aerobic and TFR cultures under our study (Bouman et al., 2006; Peng et al., 2006).

Table 9. Irrigation and varietal effects on tiller height, number of tillers and biomass yield of rice under aerobic soils and traditional flooded condition

Treatments	No. of tillers/ hill		Tiller height (cm)			Biomass yield (g/hill)		
	40 days	60 days	40 days	60 days	90 days	40 days	60 days	90 days
Irrigation regimes								
Aerobic (I_1)	13.1a	16.3b	40.7b	69.7b	74.9b	5.12a	15.84b	25.11a
Aerobic (I_2)	13.5a	15.3c	37.8c	67.8b	72.5b	5.02a	14.23c	23.42ab
Aerobic (I_3)	12.2b	15.0c	38.1c	59.0c	69.8c	5.13a	10.12d	21.33b
TFR (I_4)	13.6a	17.3a	43.8a	79.7a	82.4a	4.11b	18.91a	24.62a
Variety								
Surendra	13.4a	16.6a	38.7b	64.7b	68.7b	5.22a	16.62a	36.03a
Lalat	12.7a	14.2b	41.6a	71.2a	74.1a	4.83b	13.73b	24.62b
Khandagiri	13.5a	13.7b	39.2b	60.7c	62.1c	4.45b	13.62b	23.24b

I_1: aerobic soils with irrigation at 80-90% of field capacity throughout season, I_2: aerobic soils with irrigation at 60-70% soil moisture during vegetative and 80-90% soil moisture from panicle initiation, and I_3: aerobic soils with irrigation at 60-70% of field capacity soil moisture throughout season I_4: traditional flooded rice (TFR); Mean values with different letters vary significantly according to Duncan's multiple range test ($P<0.05$).

Root mass density (RMD) recorded under TFR rice was on an average 60% higher than the aerobic rice (Table 10). While comparing varieties, RMD averaged over aerobic rice cultures and TFR, was the maximum with 'Apo' variety followed by other three varieties viz. 'Surendra', 'Lalat' and 'Khandagiri'. Root anatomy showed that xylem vessels were more in variety 'Apo'. The cortex cells were disintegrated more in case of aerobic rice compared to TFR. The fv/fm ratio was higher in TFR compared to average response of aerobic rice under I_1, I_2 and I_3 water regimes (Fig. 13). Similar trend was also observed in ΦPS II value. It indicates that rice crop grown under transplanted condition utilized light more effectively. Specific leaf weight of rice was more under aerobic than the TFR. It might be due to the reduced leaf area under deposition of wax materials in the leaf of plants grown under aerobic culture. However, the difference was less for the variety 'Surendra'. Rate of moisture loss was more in transplanted rice compared to aerobic rice. Further, moisture loss from the plant was slow in variety 'Apo' and it was followed by 'Lalat' and 'Khandagiri'. The rate of moisture loss was highest in case of 'Surendra'. Our results correspond well with results obtained by previous researchers (Belder et al., 2004; Lu, 2000; Bouman and Tuong, 2001).

Table 10. Root mass density of rice plants as influenced by aerobic and transplanted rice system

Treatment	Root mass density (x 10^{-4} g cm^{-3})				Mean
	Surendra	Lalat	Khandagiri	Apo	
Aerobic soils	9.69	15.30	14.50	15.63	13.28
Traditional flooded rice	22.50	19.06	18.75	25.03	21.32
Mean	16.09	17.19	16.62	20.31	

Mean values with different letters vary significantly according to Duncan's multiple range test (P<0.05).

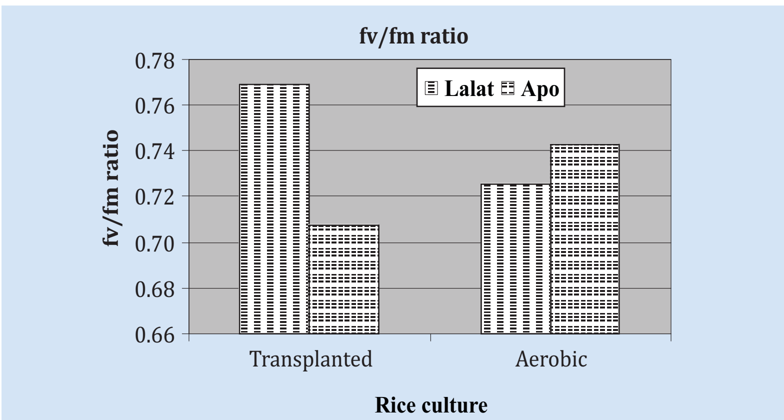


Fig. 13. Fv/Fm ratio of rice plants of two varieties grown under aerobic and traditional flooded system.

3.3.2 Differential water input, crop yield and water productivity

Water inputs varied largely due to different irrigation (I_1, I_2 and I_3) under aerobic condition and TFR (I_4) in our experiment in both the year (Table 11). The irrigation water inputs and rainfall received during the growing seasons are valid for the varieties viz. 'Surendra', 'Lalat', 'Khandagiri' and 'Apo' as well.

Table 11. Water input through irrigation and rainfall for different aerobic soil moisture regimes and for traditional flooded rice

Water input/ year	Irrigation and rainfall	Aerobic rice			Flooded rice
		Aerobic (I_1)	Aerobic (I_2)	Aerobic (I_3)	TFR (I_4)
Water input (Year 2008)	Pre-sowing irrigation/ irrigation for land preparation (mm)	54	56	58	362
	Irrigation during crop growth (mm)	573	458	341	829
	Rainfall (mm)	126	126	126	126
	Total (mm)	753	640	525	1317
Water input (Year 2009)	Pre-sowing irrigation/ irrigation for land preparation (mm)	61	62	59	401
	Irrigation during crop growth (mm)	644	557	466	936
	Rainfall (mm)	4	4	4	4
	Total (mm)	709	623	529	1341

I_1: aerobic soils with irrigation at 80-90% of field capacity throughout season, I_2: aerobic soils with irrigation at 60-70% soil moisture during vegetative and 80-90% soil moisture from panicle initiation, and I_3: aerobic soils with irrigation at 60-70% of field capacity soil moisture throughout season I_4: traditional flooded rice (TFR)

The average water application as pre-sowing irrigation for the aerobic rice (under I_1, I_2 and I_3 regimes) was 54-62 mm, and for the TFR (under I_4) it was 362-401 mm during wet land preparation for transplanting of rice seedlings. Irrigation during crop growth stage under aerobic rice was 341-573 mm in year 2008 and 466-644 mm in 2009. In aerobic rice, total water input including rainfall received was 525 to 753 mm in 2008 and 529 to 709 mm in 2009. The rainfall received was very less in the second year; hence irrigation was more to maintain the treatment requirements under I_1, I_2 and I_3. The total water input in TFR was 1317 and 1341 mm in 2008 and 2009, respectively. The water input during crop growth under aerobic rice plots decreased in I_2 compared to I_1 and further decreased in I_3 due to treatments conditions. Our results clearly show the potential of saving of irrigation water if aerobic rice cultivation methods are followed. Actually, aerobic soils even with irrigation at 80-90% of field capacity throughout the rice growing period require less water than flooded transplanted rice with maintenance of standing water of about 1-2 cm. The water amounts to about 350-400 mm, which is required for puddling and transplanting of rice seedlings, could be saved. In our experiment, the saving of water input in total was 42-47% in I_1, 51-53% in I_2 and 60% in I_3 under aerobic rice when compared to traditional flooded rice (I_4). During the crop growth stage, the saving of water input was 30-31% in I_1, 40-44% in I_2 and 58-60% in I_3 under aerobic rice when compared to traditional flooded rice (I_4). Bouman et al. (2005) estimated the total water input was 1240-1880 mm in flooded fields and 790-1430 mm in aerobic fields. The saving of water due to aerobic method of rice cultivation was also reported by previous researchers (Belder et al., 2005; Bouman et al., 2005). On average, the mean yield of some varieties was 32% lower under aerobic conditions than under flooded conditions in the dry season and 22% lower in the wet season as obtained by Bouman et al., (2005).

Table 12. Grain and straw yield of rice and water productivity with respect to total water input as influenced by irrigation regimes and varieties grown under aerobic and traditional flooded condition

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index	WP_{GY} (kg ha^{-1} mm^{-1})	WP_{SY} (kg ha^{-1} mm^{-1})
Irrigation regimes					
Aerobic (I_1)	3.36b	3.68b	0.48a	4.60a	5.03a
Aerobic (I_2)	3.15b	3.42b	0.47a	4.99a	5.42a
Aerobic (I_3)	2.39c	2.98c	0.44a	4.54a	5.65a
TFR (I_4)	4.04a	4.52a	0.48a	3.04b	3.40b
Variety					
Surendra	3.67a	4.09a	0.47a	4.44a	4.95a
Lalat	3.63a	3.74a	0.52a	4.33a	4.46a
Khandagiri	2.24b	2.83b	0.46a	3.10b	3.92b

WP_{GY} and WP_{SY}, water productivity with respect to grain and straw yield per ha per mm water input (irrigation plus rainfall); I_1: aerobic soils with irrigation at 80-90% of field capacity throughout season, I_2: aerobic soils with irrigation at 60-70% soil moisture during vegetative and 80-90% soil moisture from panicle initiation, and I_3: aerobic soils with irrigation at 60-70% of field capacity soil moisture throughout season I_4: traditional flooded rice (TFR); Mean values with different letters vary significantly according to Duncan's multiple range test ($P<0.05$).

The grain yield ranged from 2.39 to 3.36 t ha^{-1} under aerobic treatments (I_1, I_2 and I_3) with the highest being in I_1 (Table 12). However, the highest grain yield under I_1 was significantly lower than the grain yield under TFR (I_4). Similar was the trend in straw yield of rice varieties grown under aerobic condition. In experiments, the results show a reduction in yield under aerobic treatments. This yield reduction or the penalty, as compared to traditional flooded rice, was to the extent of 16-40% depending on the variation in irrigation regimes in our study; yield reduction in I_1 (16%) was much less than I_2 (22%) and I_3 (40%) treatment. In aerobic condition, the highest grain and straw yield was recorded in variety 'Surendra'; however, it was at par with variety 'Lalat'. The variation in harvest index was not significant. In our study, the yield difference was attributed to difference in biomass production than harvest index. The yield reduction due to aerobic method of cultivation was also observed by previous researchers (Bouman et al., 2005; Peng et al., 23006). Peng et al. (2006) reported that the yield difference between aerobic and flooded rice ranged from 8-69% depending on the number of seasons that aerobic rice has been continuously grown, dry and wet seasons, and varieties. The yield difference between aerobic and flooded rice was attributed more to the difference in biomass production than to harvest index.

Water productivity (WP_{GY} and WP_{SY}) varied significantly due to aerobic rice and traditional flooded rice (Table 12). However, both WP_{GY} and WP_{SY} did not vary significantly within the aerobic irrigation regimes (I_1, I_2 and I_3). The average WP_{GY} and WP_{SY} (mean of values under I_1, I_2 and I_3) under aerobic were significantly greater than those with TFR (I_4). Though the grain and straw yield under TFR was higher, WP was lower than aerobic irrigation regimes due to much greater water input for TFR. Water

Table 13. Interaction effect of irrigation regimes and fertilizer nitrogen rates on grain and straw yield of rice var. 'Surendra' under aerobic method of cultivation

Treatments	Fertilizer nitrogen rates (kg ha $^{-1}$)				Mean
	N_0	N_{40}	N_{80}	N_{120}	
		Grain yield (t ha^{-1})			
I_{540}	1.10g	1.62f	2.01e	2.21de	1.73
I_{660}	1.51f	2.39d	3.01c	3.61b	2.63
I_{780}	1.99e	3.20c	3.84b	4.40a	3.36
Mean	1.53	2.40	2.95	3.41	
	Irrigation (I)	Nitrogen (N)	I x N		
LSD (P<0.05)	0.16	0.20	0.35		
		Straw yield (t ha^{-1})			
I_{540}	1.91j	2.80hi	3.51fg	3.82ef	3.01
I_{660}	2.51i	4.02e	4.83d	5.49bc	4.21
I_{780}	3.19gh	5.17cd	5.90b	6.61a	5.22
Mean	2.54	3.99	4.75	5.31	
	Irrigation (I)	Nitrogen (N)	I x N		
LSD (P<0.05)	0.29	0.26	0.44		

I_{540}: irrigation with total of 540 mm water, I_{660}: irrigation with total of 540 mm water, and I_{780}: irrigation with total of 780 mm water; N_0, N_{40}, N_{80} and N_{120} are N rates at 0, 40, 80 and 100 kg ha^{-1}, respectively; interaction values superscripted with different letters vary significantly according to Duncan's multiple range test (P<0.05).

productivity was greater in the varieties, 'Surendra' and 'Lalat' compared to 'Khandagiri', because of lower yield in the latter. In our study, hence, water productivity of rice (with respect to rainfall and irrigation water input) under aerobic conditions was 49-57% higher than under traditional flooded conditions. Our results correspond well with results obtained by previous researchers.

3.3.3 Irrigation and nitrogen interaction in aerobic rice

In the experiment, the studies on irrigation x N rates interaction for an aerobic rice variety, 'Surendra' revealed that the grain yield of 4.40 t ha^{-1} was the highest with I_{780} x N_{120} combination (Table 13). However, the other combinations viz. I_{780} x N_{80} with a grain yield of 3.84 t ha^{-1} was statistically similar to the I_{660} x N_{120} with a grain yield of 3.61 t ha^{-1}; I_{780} x N_{40} with a grain yield of 3.20 t ha^{-1} was statistically similar to the I_{660} x N_{80} with a grain yield of 3.01 t ha^{-1}; I_{660} x N_{40} with a grain yield of 2.39 t ha^{-1} was statistically similar to the I_{540} x N_{120} with a grain yield of 2.21 t ha^{-1}. Similar trend was also observed for straw yield data. Thus, the interdependence of irrigation regime and nitrogen rates was clearly observed in the yield data of aerobic rice in our study. This has a very positive management implication. The aerobic rice yield even with higher rate of N was caused by water stress, as was evident, in the 540 mm irrigation treatment in our study, and this corresponds well with previous researchers (Belder et al., 2005).

3.3.4 Varietal response to nitrogen rates under aerobic condition

The variety and N interaction was not found significant because of similar duration of the varieties chosen as well as almost similar performance under aerobic condition with 780 mm irrigation water. However, the main effects i.e., N-rates and effects of varieties were significant for grain and straw yield and N-uptake. Both the grain and straw yield increased with increase in N-rates from 0 to 120 kg ha^{-1}. Similar trend was obtained with N- uptake by grain and straw. Irrespective of variety, aerobic rice with 120 N kg ha^{-1} gave the grain and straw yield of 4.24 and 6.63 t ha^{-1} with grain and straw N-uptake of 52.17 and 52.63 kg ha^{-1}, respectively. This trend of yield increase due to increased application of N was might be due to the presence of optimum soil moisture in the root zone. The varieties viz. 'Apo' and 'Surendra' was comparatively better in realizing the slightly greater grain and straw yield than 'Lalat' in our experiment.

4. Conclusions

The research findings indicated that the pod and haulm yield of groundnut in ridge & furrow planting and paired row planting were significantly greater than flat bed method. An yield advantage of 18-20% would be possible through paired row planting of groundnut due to the better soil moisture extraction and greater interception of photosynthetically active radiation by the crop canopy, and irrigation water saving to the extent of 27 and 41% would be possible in ridge & furrow and paired row method of planting, respectively compared to flat method of planting with the increase in water use efficiency of the crop. The gross return and benefit cost ratio also increased in paired row planting compared to the flat-bed planting.

The paired row method of planting for potato at 75 x 20 cm have the potential to save a significant amount of irrigation water compared to normal planting without significant reduction in fresh tuber yield. The depth of irrigation would also be decreased in paired row planting compared to normal to the extent of 21-32%. The paired row method of planting at 75 x 20 cm spacing significantly enhanced the crop water use efficiency, gross and net returns. The benefit-cost ratio was the highest in paired row planting at 75 x 20 cm under five irrigation and the lowest in paired row planting at 100 x 15 cm. The results have been demonstrated to the farmers during the training programmes organized at the Research Farm, and also discussed with selected farmers of different districts of Odisha. The improved planting techniques for potato and groundnut would save the irrigation water. Based on the results of this project, farmers will be benefited through adoption of this technology of improved planting technique for dry season crops grown after *kharif* season. The canal water irrigating the dry season crops would also be utilized efficiently. The adoption of drip irrigation method for post-rainy season crops should be popularized as this is an efficient water saving technique.

The methods of aerobic rice cultivation, varietal performance, effects of N-rates and quantities of irrigation water inputs have been investigated. The comparison is made with the traditional flooded rice. Based on our studies, rice varieties viz. 'Apo', 'Surendra' and 'Lalat' are recommended for our ecological conditions viz. acid aerobic soils under Deras command in Odisha, an eastern Indian state. These varieties may also be grown as aerobic rice in similar situations. We conclude from our study that, though there was a reduction in grain yield of rice under aerobic condition compared to traditional flooded method, this method of rice cultivation holds promise for future, especially in the situations of increasing water scarcity. The huge amount of water, which is required for land preparation under flooded rice, may be avoided in aerobic systems. The total amount of water input would be reduced by 42-60% when compared to flooded rice. Hence, there is tremendous scope for saving of irrigation water through aerobic method of rice cultivation. Water productivity with respect to rainfall and irrigation input would be enhanced by aerobic culture; the enhancement could be to the tune of 49-57% compared to traditional flooded conditions. We recommend the soil moisture for aerobic rice as 80-90% of field capacity throughout the crop growing season; and in this irrigation regime the yield reduction would be about 16% compared to flooded rice. Results of the irrigation x N interaction studies would be helpful to economize the water inputs due to the synergistic effect of water and N. This has important management implications also. In view of the limited water supply situations, fertilizer-N applications over which farmers have better control need to be managed properly to save irrigation water input. We recommend N rate of 120 kg ha^{-1} in combination of irrigation water of 780 mm for the variety 'Surendra'. This quantification is applicable to the variety 'Apo' and 'Lalat' also. Further, this amount of water i.e., 780 mm with 80 kg N ha^{-1} would produce a grain yield which is similar to the combination of 660 mm irrigation and 120 kg N ha^{-1}. Thus, based on availability of irrigation water during dry season, N rate has to be optimized and rice production during dry season would be made successfully through aerobic method of cultivation.

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