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Effects of irrigation and straw mulch on water use and tuber yield of potato in eastern India

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ABSTRACT

Potato, being a temperate crop, its growth and tuber production are limited by high atmospheric temperatures (mean temperature >17 °C). As a result potato is grown in winter season only (November–March) in the eastern plain of India when temperature is favourable. But during winter season, rainfall is erratic and meagre, therefore, potato crop in the region can only be grown with supplemental irrigation. In this study, potato crop was grown with four phenology based irrigation treatments (75 mm water depth with each irrigation) with three replications. Straw mulch at a rate of 6 t ha^{-1} was applied during the first earthing up in half of the plots to observe the variation of plant growth, water use efficiency and tuber production between mulched and non-mulched plots. The experimental split-plot design consisted of irrigation treatments in the main plots with mulching and non-mulching as subplots. Two years of pooled data with four irrigations resulted in air-dry tuber yields of 14.9 and 11.2 t ha^{-1} for the mulched and non-mulched plots, respectively. Significantly ($p < 0.05$) higher leaf area index, water use efficiency and intercepted photosynthetically active radiation (IPAR) were recorded in the mulched plots compared to the non-mulched plots under the same irrigation treatment. Higher yield and better crop growth were observed in the mulched plots, which might be due to conservation of soil moisture and reduction of soil temperature by 4–6 °C. The highest PAR (89% of the PAR incident above the crop canopy) was found near the crop with mulching and four irrigations. The 77–103 mm less depleted soil moisture in the different treatments was due to the application of straw mulch. Application of straw mulch significantly increased the available phosphorus and potassium in the soil. Water use efficiency and tuber productions differed significantly among irrigation treatments in the non-mulched plots but they did not in the mulched plots with three and four irrigations. Therefore, three irrigations of 75 mm each and mulching were recommended for growing potato in the region when limited water was available.

1. Introduction

Being a temperate crop, potato growth and yield are highly affected by higher temperature, especially a mean temperature above 17 °C (Mendoza and Estarda, 1979). Tuberization occurs at low temperatures and is delayed or even inhibited at higher temperatures, tubers rarely being formed above 30 °C. As a result, potato is grown in countries where the prevailing mean air temperature is around 15–18 °C during the growing season and rainfall or irrigation provides ample water (Ben Khedher and Ewing, 1985; Borah and Milthrope, 1962; Marinus and Bodlaender, 1975; Menzel, 1985; Caldiz et al., 2001).

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Potato is a highly demanding crop in eastern India but due to cold temperature requirements, growing of potato is restricted only to the winter season (November–March). However, soil moisture availability is the main constraint for growing profitable crops in this area in the winter season. Though the region receives high average annual rainfall (1400 mm), 80% occurs within 4 months with the southwest monsoon (June–September). Rainfall during winter is erratic and meagre. Therefore, harvesting of rainwater and its recycling with proper irrigation management are necessary for growing potato in the winter (dry) season. Increased water use efficiency (WUE) of field crops was possible through proper irrigation scheduling and water management avoiding any soil moisture stress at critical growth stages (Norwood and Dumler, 2002; Eck, 1984; Wang, 1987; Turner, 1987; Hunsaker et al., 1996; Kar et al., 2006). Locally available mulch materials can also be applied on soils to reduce soil moisture loss from the profile. Many researchers studied the beneficial roles of mulch to conserve soil moisture and to reduce soil temperature (Epistein, 1966; Hay and Allen, 1978; Bristow, 1988; Kar, 2003; Kar and Singh, 2004). Owing to the poorly conducting surface of mulch material, the incoming solar energy into the soil is reduced, and as a result soil temperature is less in mulched plots. Lowering of soil temperature favoured tuberization and produced good quality tubers, but too low a dose of mulch (2–2.5 t ha^{-1}) was not effective for enhancing tuber yield (Doring et al., 2005).

Hay and Allen (1978) reported that soil temperatures between 15 and 18 °C were optimal for tuberization of potato. High soil temperatures increased stem elongation, branching, haulm weight, foliage development and root growth but decreased the accumulation of dry matter in tubers, leading to production of small malformed tubers (Slater, 1968).

Keeping the importance of above facts in view in this investigation, water use efficiency, plant growth and tuber yield of potato were studied under the mulched and the non-mulched conditions with different levels of irrigation. The intercepted photosynthetically active radiation (IPAR) was also measured to observe the radiation interception efficiency of the crop with different irrigations and mulching treatments.

2. Materials and methods

2.1. Study area

The study was conducted in a district of the eastern Indian state Dhenkanal, Orissa (Latitude: 20°40/N; Longitude: 85°36/E; Altitude: 139 m above mean sea level). The region belongs to the sub-humid and sub-tropical agro-ecological zone with an average annual rainfall of 1421 mm, 80% of which falls during the rainy season (June–September) due to the southwest monsoon. The mean date of the onset of the effective monsoon is the 15th of June and the monsoon generally ends on the 27th of October. The mean monthly maximum temperature ranges from 46.2 °C in May to 29.4 °C in December. On the other hand, the mean minimum temperature varies between 24.6 °C in July and 9.0 °C in December. The prevailing mean temperature during the winter season (November–February) is around 16–22 °C. The reference evapotranspiration varies from 8.7 mm day^{-1} in May to 3.3 mm day^{-1} in December. The upper layer (0–0.15 m) of the soil profile is sandy loam whereas next two layers (0.15–0.30 and 0.30–0.45 m) are sandy clay loam. The average bulk density of the upper soil layer is 1.55 Mg m^{-3} and increases with depth to 1.62 Mg m^{-3} for the 0.9- to 1.2 m-deep layer. The maximum available soil water ranges between 0.128 and 0.162 m^3 m^{-3} at different depths.

2.2. Experimental design and crop management

Based on earlier recommendations in the region (Kar, 2003), potato variety 'Kufri Jyoti' was planted in the last week of November (on the 27th and 25th November in 2001 and 2002, respectively). The crop was grown according to the ridge and furrow methods of planting with a spacing of 0.45 m (row to row) × 0.15 m (plant to plant). The applied fertilizer dose N:P:K was 120:60:60. Half of the nitrogen and the full dose of phosphorus and potassium were applied at planting and half of the nitrogen was applied at first irrigation. The irrigation treatments formed the main plots and mulching and non-mulching were the subplot of the experimental split-plot design. Each treatment was carried out in triplicate (Fig. 1). The size of the individual plot was 7 m × 5 m. In order to modify the soil micro-environments, rice straw mulch was applied at a rate of 6 t ha^{-1} after the first earthing up 24 days after sowing (DAS). Four irrigations treatments (I_1, I_2, I_3, I_4) were imposed based on critical phenological growth stages, *viz.*, (i) I_1: stolonization, (ii) I_2: stolonization + tuberization, (iii) I_3: stolonization + tuberization + tuber bulking and (iv) I_4: early vegetative growth + stolonization + tuberization + tuber bulking. In each irrigation, 75 mm water was applied and plots were bordered to prevent runoff.

2.3. Soil properties analysis and measurement of soil temperature

The soil chemical properties like pH, electrical conductivity, organic carbon, available nitrogen, phosphorus and potassium were determined in the mulched and non-mulched plots after crop harvesting. Maximum available water in the soil was measured by subtracting the amount of water held at 1.5 MPa (permanent wilting point) from that at 0.033 MPa (field capacity). Soil moisture at 0–0.15, 0.15–0.30, 0.30–0.45, 0.45–0.60, 0.60–0.90 and 0.90–1.20 m depths was measured using the gravimetric method to compute actual crop water use or evapotranspiration. In addition to the soil moisture measurement, soil temperature variation between the mulched and non-mulched plots was observed by installing soil thermometers (mercury type) on the ridges at 0.15 m and 0.30 m soil depths.

2.4. Crop water use and water use efficiency

The amount of soil moisture from 0 to 1.2 m depth was used to obtain crop water use or evapotranspiration under different irrigation and mulching treatments. Actual crop water use or evapotranspiration was calculated using the following water balance equation:

$$ET = R_e + I + \Delta S - D + \int_{t_1}^{t_2} F_X \, dt \quad (1)$$

	I_1	I_2	I_3	I_4
R_1	M_0	M_1	M_0	M_1
	M_1	M_0	M_1	M_0
R_2	M_0	M_1	M_0	M_1
	M_1	M_0	M_1	M_0
R_3	M_0	M_1	M_0	M_1
	M_1	M_0	M_1	M_0

Fig. 1 – Layout of experimental field. I_1: one irrigation, I_2: two irrigations, I_3: three irrigations, I_4: four irrigations; M_0: no mulch, M_1: mulch; R_1, R_2 and R_3 are three replications.

where R_e is the effective rainfall (mm), I the irrigation (mm), D the drainage (mm), ΔS the change in soil moisture storage (mm), F_X the vertical flux (mm/day) and t is the time.

Since the water table of the experimental plots was deep (>3.5 m), the upward flux F_X, was negligible. Drainage was also negligible because the amount of irrigation water was only sufficient to bring the water deficit to field capacity.

Change in soil moisture, ΔS, in the profile for a particular irrigation interval was determined using the following relationship:

$$\Delta S = \frac{(M_2 - M_1) \times \rho_b \times d_1}{100} \quad (2)$$

M_1 and M_2 are the percentage of soil moisture on weight basis before and after irrigation; ρ_b the bulk density (g cm^{-3}); d_1 is the depth of sampling (mm).

Effective rainfall was determined according to the method of USDA Soil Conservation Services.

Water use efficiency (WUE) was determined by dividing the tuber yield by the actual crop evapotranspiration and expressed as kg ha^{-1} mm^{-1} (Kar and Verma, 2005). The runoff was nil because crop was irrigated only at critical growth stages and plots were bordered.

2.5. *Leaf area index and intercepted radiation*

Leaf area index (LAI) of potato as one of the crop growth parameters was recorded at 1-week interval for the various treatments. Three plant samples from each plot in each replication were selected randomly for leaf area measurements. The green leaf portions were separated and the area of the leaves was measured using a leaf area meter (LICOR-3200, USA).

$$\text{LAI} = \frac{\text{Measured leaf area of 3 plants}}{\text{Ground area covered by 3 plants}} \quad (3)$$

The intercepted photosynthetically active radiation (IPAR) varied with LAI and was measured with a light transmission meter (EMS-7) using a line sensor. The IPAR was determined using the following relationship:

$$\text{IPAR by whole canopy} = I_n - I_r - I_t + I_g \quad (4)$$

where, I_n is the incident radiation on the canopy, I_r the reflected radiation by the canopy, I_t the transmitted radiation through the canopy, and I_g is the reflected radiation from the ground. The unit of measurement of radiation was μmol s^{-1} m^{-2}.

The reflected radiation by the canopy (I_r) was obtained by keeping the sensor inverted 0.5 m above the canopy. To obtain transmitted radiation (I_t), the sensor was kept on the ground under the canopy. To get the reflected PAR from the ground, the sensor was held in the inverse position at 0.05 m above the ground. The measurement was made at regular intervals on clear days between 11:00 and 12:00 h Indian Standard Time when disturbances due to leaf shading and leaf curling were minimum.

The IPAR was expressed as a percentage of the photosynthetically active radiation (PAR):

$$\text{IPAR}\,(\%) = \frac{\text{Intercepted photosynthetically active radiation by the whole canopy}}{\text{PAR incident above the crop canopy}} \times 100 \quad (5)$$

The statistical analysis of irrigation and mulch treatments was carried out using the Duncan's Multiple Range Tests (DMRT) with the MSTAT statistical package.

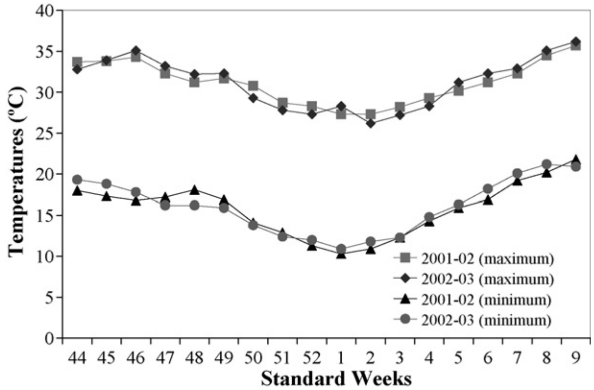

Fig. 2 – Variation of maximum and minimum temperatures during 2 study years.

3. Results and discussion

3.1. *Maximum and minimum air temperatures during crop growth period*

The maximum and minimum air temperatures during the crop growth period for the 2 study years (2001–2002 and 2002–2003) are presented in Fig. 2. The mean temperature varied from 18.3 to 22.6 °C which was comparable to normal. The average atmospheric temperatures were 3–4 °C higher during early vegetative stage but tuber-bulking stage (after 60 days) experienced 2–3 °C lower for November sown crop. November sown crop yielded higher tuber production. A 3–4 °C higher temperature during tuber bulking stage will affect tuber production of delayed-sown (2–3 weeks) crop (Kar, 2003). The higher temperature at that stage reduces tuber bulking and resulted in less tuber production.

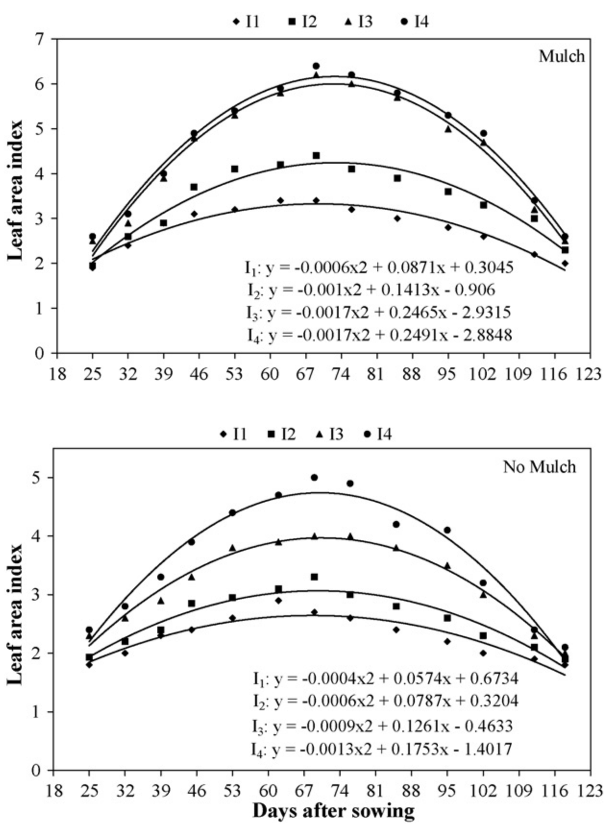

Fig. 3 – Leaf area index of potato as influenced by mulching and irrigations. I_1: one irrigation, I_2: two irrigations, I_3: three irrigations, I_4: four irrigations.

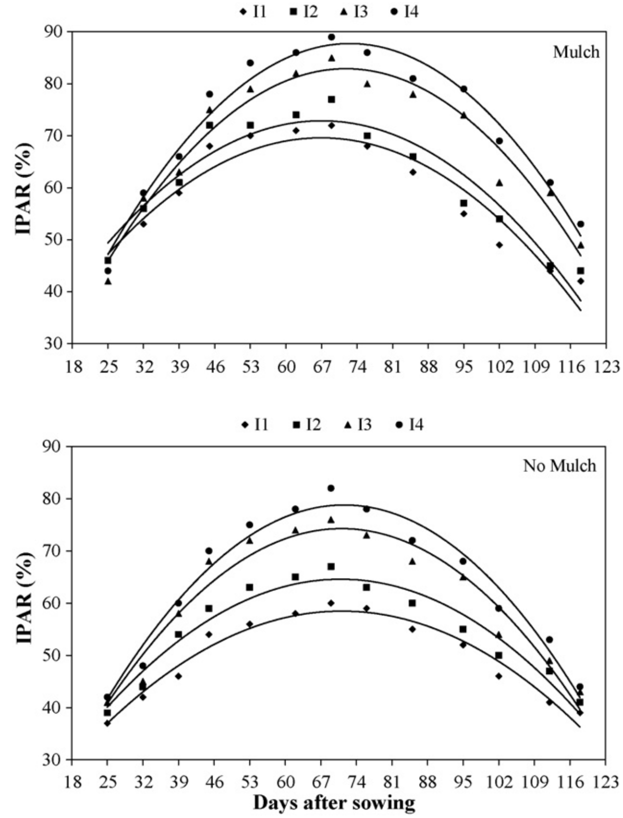

Fig. 4 – Variation of intercepted photosynthetically active radiation (IPAR) with mulching and irrigation. I_1: one irrigation, I_2: two irrigations, I_3: three irrigations, I_4: four irrigations.

3.2. *Leaf area index*

The leaf area index (LAI), as an indicator of growth, was measured in the mulched and non-mulched plots with different irrigation levels, and peak values of LAI are presented in Fig. 3. An average maximum leaf area index (pooled data of 2 years) of 5.0 was observed in non-mulched plots with significant differences ($p < 0.05$) in the production of maximum leaf area among different irrigation treatments. On the other hand, an average maximum LAI of 6.4 was recorded in the mulched plot with the four irrigations. Study revealed that maximum LAI was 21–35% greater in the mulched plots than in the non-mulched plots under different irrigation levels and hence straw mulch had an impact on LAI depending on the irrigation treatments. Maybe, the reduction of 4–6 °C in soil temperature during the tuber-bulking period, due to mulching, also created a suitable environment for crop growth.

The IPAR, which varies with days after sowing (DAS), was computed and is depicted in Fig. 4 for the various treatments.

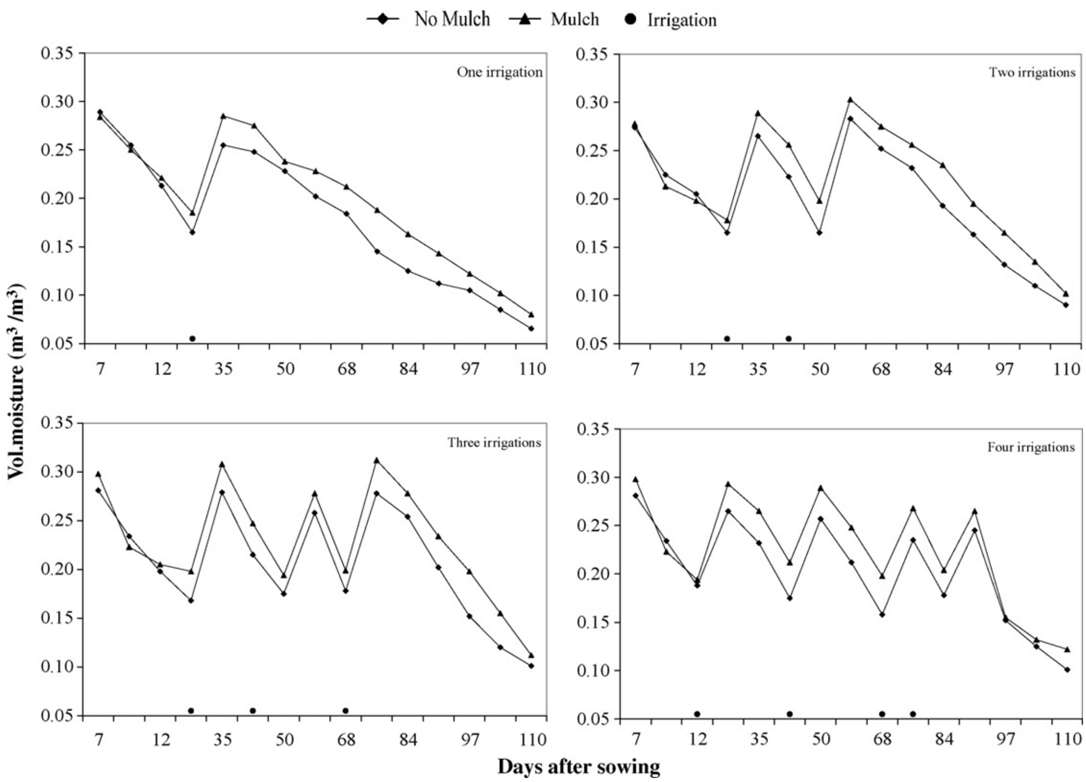

Fig. 5 – Variation of soil moisture at 0.45 m depth in mulched and non-mulched plots.

Maximum radiation interception of 89% was observed at 69 DAS for the mulched plot with four irrigations (pooled data of 2 years). The crop attained a peak LAI of 6.4 during that stage. Differences of IPAR (%) among the various irrigation treatments in the non-mulched plots were statistically significant and the maximum IPAR was 27% less in I_1 than in I_4. On the other hand, in the mulched plots, the maximum IPAR was 19% less in I_1 and 13% in I_2 compared to I_4. No

Table 1 – Water use, tuber yield and water use efficiency of potato as influenced by mulching and irrigations

	2001–2002		2002–2003		Mean of 2 years	
	M_0	M_1	M_0	M_1	M_0	M_1
Water use (mm)						
I_1	375^{d}	305^{d}	368^{d}	285^{d}	372^{d}	295^{d}
I_2	435^{c}	342^{c}	425^{c}	348^{c}	430^{c}	345^{c}
I_3	491^{b}	375^{b}	485^{b}	395^{b}	488^{b}	385^{b}
I_4	535^{a}	428^{a}	528^{a}	445^{a}	532^{a}	437^{a}
LSD (0.05)	24.81	34.81	26.77	37.22	42.77	46.78
Tuber yield (kg ha^{-1})						
I_1	3200^{d}	6350^{c}	3710^{d}	5650c	3455^{d}	6000^{c}
I_2	6950^{c}	9130^{b}	6550^{c}	8850^{b}	6750^{c}	8990^{b}
I_3	9025^{b}	12650^{a}	8980^{b}	12960^{a}	9003^{b}	12805^{a}
I_4	$11,150^{a}$	$14,800^{a}$	$11,250^{a}$	$15,050^{a}$	$11,200^{a}$	$14,925^{a}$
LSD (0.05)	1848.5	2212.5	1235.2	2150.1	1447.5	2205.2
Water use efficiency (kg ha^{-1} mm^{-1})						
I_1	8.53^{d}	20.82^{c}	10.08^{d}	19.82^{c}	9.31^{d}	20.32^{c}
I_2	15.9^{c}	26.70^{b}	15.41^{c}	25.43^{b}	15.66^{c}	26.06^{b}
I_3	18.3^{b}	33.73^{a}	18.51^{b}	32.81^{a}	18.41^{b}	33.27^{a}
I_4	20.8^{a}	34.51^{a}	22.30^{a}	33.82^{a}	21.05^{a}	34.16^{a}
LSD (0.05)	2.171	2.11	2.03	2.118	1.56	1.92

The same superscript letter within the column indicates no significant difference at the 5% level.

significant differences (4%) of IPAR were observed between I_3 and I_4 treatments under the mulched condition, which might be due to that LAI or crop growth did not significantly differed between those treatments.

3.3. Tuber yield and total seasonal evapotranspiration

Tuber yield of potato in relation to mulching and number of irrigations are presented in Table 1. There was a drastic reduction of yield when the number of irrigations was reduced and the economical yield for non-mulched plots up to two irrigations (I_1 and I_2) was not achieved. The highest tuber yield of 11.2 t ha^{-1} (pooled data of 2 years) in non-mulched plots and of 14.9 t ha^{-1} in mulched plots was achieved with four irrigations. Rice straw mulch application increased the potato tuber production with 24–42% in the different irrigation treatments (pooled data of 2 years).

Significant differences in tuber production among irrigation treatments were found in non-mulched plots, but in mulched plots tuber production between I_3 and I_4 treatments did not significantly differ. It was also observed that increased water application in I_4 treatment resulted in higher crop water use without corresponding increase in tuber yield.

Variation of soil moisture was monitored throughout the growing season in both the mulched and non-mulched plots. Fluctuation of the volumetric soil moisture at 0.45 m depth is depicted in Fig. 5 to give some insight on the soil moisture depletion pattern in mulched and non-mulched plots. Soil moisture depletion increased with higher irrigation and decreased with mulching. Due to reduction of incoming solar energy, less water was evaporated from the mulched plots compared to the non-mulched plots for all the irrigation treatments (Table 1). Without mulching the evapotranspiration amounts obtained from the soil profile depletion (0–1.2 m) were 372, 430, 488 and 536 mm with one, two, three and four irrigations, respectively. Mulch application reduced the soil moisture depletion with 77–103 mm. Under non-mulched condition, the highest water use efficiency (WUE) was 21.55 kg ha^{-1} mm^{-1} (pooled data of 2 years) with 4 irrigations and there were significant differences among the different irrigation treatments. In mulched plots, tuber yields of I_1 and I_2 were reduced with 148 and 66% compared to I_4. No significant differences in WUE were observed between I_3 and I_4 treatments (I_3 was only 3% less than I_4) under mulched condition which might be attributed to that the increased water application in I_4 treatment resulted in a higher crop water use without a corresponding increase in tuber yield. Water use efficiencies for the mulched plots with three and four irrigations were 33.19 and 34.19 kg ha^{-1} mm^{-1}, respectively (pooled data of 2 years). In mulched plots, three irrigations of 75 mm were sufficient to meet the water requirement of potato sown in November. Reduction of soil moisture depletion due to mulching was reported for many other crops (Moitra and Ghosh, 1998; Sharma et al., 2001; Aggarwal and Sharma, 2002; Kar and Singh, 2004).

3.4. Soil temperature

The thermal environment of the crop root zone was modified when mulch load at a rate of 6 t ha^{-1} was applied (Fig. 6). The maximum soil temperatures in the surface layer were 4–6 °C lower in the mulched than in the non-mulched plots. The low transmissivity of the mulch resulted in a larger fraction of solar radiation being absorbed at the top of mulch layer. At 0.30 m depth, soil was 2–3 °C cooler in the mulched than in the non-mulched plots. Tuber production was enhanced in the mulched plots under the same irrigation treatments, which might be due to the reduction of soil temperature with 4–6 °C during tuber-bulking stage (tuber enlargement to near-maturity).

3.5. Soil fertility properties

The soil fertility properties were measured after harvest of the crop in each season and pooled data are presented in Fig. 7. Higher available potassium and phosphorus after harvest were recorded in the mulched than in the non-mulched plots. The available phosphorus was improved due to application of straw mulch, which might be due to the reduced activity of iron and aluminium and to the reduced fixation of the added organic matter. The increase of available phosphorus and potassium due to mulching was also reported by Medcalf (1956), Robinson and Chenery (1958) and Mehlich (1966). Straw mulch application also reduced the available nitrogen content of the soil. In addition to the reduction of soil temperature and soil moisture conservation through mulching, enhanced availability of potassium and phosphorus might have also influenced higher tuber yield in the mulched plots.

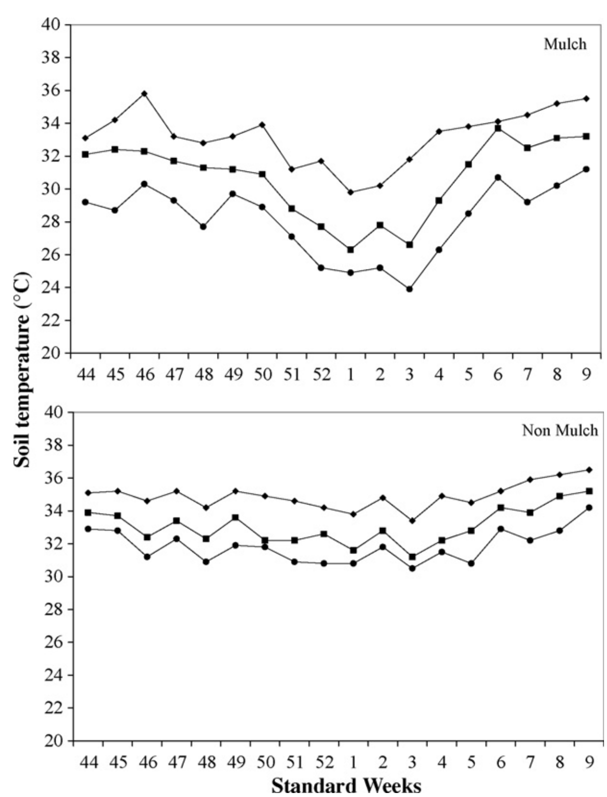

Fig. 6 – Variation of soil temperatures in mulched and non-mulched plots.

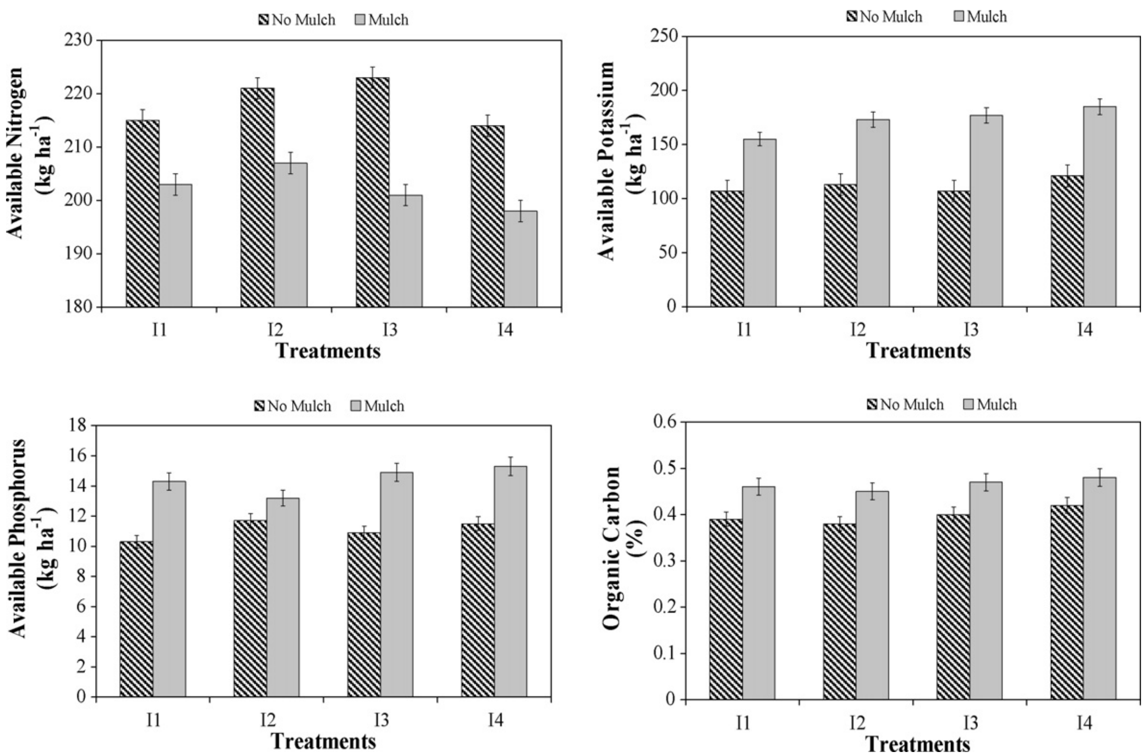

Fig. 7 – Soil fertility parameters as affected by mulching and irrigations.

4. Conclusion

Potato crop responded well to phenology based irrigation scheduling in combination with rice straw mulching (at a rate of 6 t ha^{-1}) after first earthing up. The soil temperature had impact on tuber production because, under the same irrigation treatments, tuber production was higher in mulched than in non-mulched plots. Reduction of soil temperature, conservation of soil moisture, increased available phosphorous, potassium and organic carbon through mulching might have enhanced crop growth and tuber yield production in the mulched treatments. Rice straw mulch application increased the potato tuber production with 24–42% (2 years pooled data) depending on the irrigation treatments. The crop evapotranspiration was reduced with 77–103 mm when applying rice straw mulch at a rate of 6 t ha^{-1} in the various irrigation treatments. Water use efficiency was significantly different among all the irrigation treatments (I_1, I_2, I_3, and I_4) in the non-mulched plots, but I_3 and I_4 irrigation treatments for the mulched plots were not significantly different (only 3% less in I_3 than in I_4). Therefore, under limited water availability and mulched condition, three irrigations of 75 mm each can be recommended to grow potato crop in the region, provided it is sown in November.

REFERENCES

Aggarwal, P., Sharma, N.K., 2002. Water uptake and yield of rainfed wheat in relation to tillage and mulch. Indian J. Soil Conserv. 30 (2), 155–160.

Ben Khedher, M., Ewing, E.E., 1985. Growth analysis of eleven potato cultivars grown in the greenhouse under long photoperiods with and without heat stress. Am. Potato J. 62, 537–554.

Borah, M.N., Milthrope, F.L., 1962. Growth of the potato as influenced by temperature. Indian J. Plant Physiol. 5, 53–72.

Bristow, K.L., 1988. The role of mulch and its architecture in modifying soil temperature. Aust. J. Soil Res. 26, 269–280.

Caldiz, D.O., Gaspari, F.J., Haverkort, A.J., Struik, P.C., 2001. Agro-ecological zoning and potential yield of single or double cropping of potato in Argentina. Agric. Forest Meteorol. 109 (4), 311–320.

Doring, T.F., Brandt, M., Hesz, J., Finckh, M.R., Saucke, H., 2005. Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically gown potatoes. Field Crops Res. 94 (2–3), 238–249.

Eck, H.V., 1984. Irrigated corn yield response to nitrogen and water. Agron. J. 76, 421–428.

Epistein, E., 1966. Effect of soil temperature on tuber initiation of the potato. Eur. Potato J. 58, 169–171.

Hay, R.K.M., Allen, E.J., 1978. Tuber initiation and bulking in the potato (*Solanum tuberosum*) under tropical conditions: The importance of soil and air temperature. Trop. Agric. Trinidad 55, 289–295.

Hunsaker, D.J., Kimball, B.A., Pinter Jr., P.J., LaMorte, R.L., Wall, G.W., 1996. CO_2 enrichment and irrigation effects on wheat evapotranspiration and water use efficiency. Trans. ASAE 39 (4), 1345–1355.

Kar, G., 2003. Tuber yield of potato as influenced by planting dates and mulches. J. Agrometeorol. 5, 60–67.

Kar, G., Singh, R., 2004. Soil water retention—transmission studies and enhancing water use efficiency of winter crops through soil surface modification. Indian J. Soil Conserv. 8, 18–23.

Kar, G., Verma, H.N., 2005. Phenology based irrigation scheduling and determination of crop coefficient of winter

maize in rice fallow of eastern India. Agric. Water Manage. 75 (3), 169–183.
Kar, G., Verma, H.N., Singh, R., 2006. Effects of winter crops and supplemental irrigation on crop yield. Agric. Water Manage. 79, 280–292.
Marinus, J., Bodlaender, K.B.A., 1975. Response of some potato varieties to temperature. Potato Res. 18, 189–204.
Moitra, R., Ghosh, D.C., 1998. Effect of tillage and mulching on soil physical properties, crop productivity and water use efficiency of rapeseed (*Brassica rapa*) in West Bengal. Indian J. Soil Conserv. 26 (2), 86–90.
Medcalf, J.C., 1956. Preliminary study on mulching mung coffee in Brazil. IBES Res. Inst. Bull. No. 12.
Mehlich, A., 1966. Production of maize for grain and mulching material. Kenya Coffee 31 (303), 109.
Mendoza, H.A., Estarda, R.N., 1979. Breeding potatoes for tolerance to stress: Heat and Frost. In: Mussell, H., Staples, R.C. (Eds.), Stress Physiology in Crop Plants. John Willey and Sons, pp. 227–262.
Menzel, C.M., 1985. The control of storage organ formation in potato and other species, a review. Part 1. Field Crop Abstr. 38 (9), 527–537.
Norwood, C.A., Dumler, T.J., 2002. Transition to dry land agriculture. Limited irrigation vs. dry land corn. Agron. J. 94, 310–320.
Robinson, J.B.D., Chenery, E.M., 1958. Magnesium deficiency in coffee with special reference to mulching. Emp. J. Agric. 26, 259–273.
Slater, J.W., 1968. The effect of night temperature on tuber initiation of the potato. Eur. Potato J. 11, 14–22.
Sharma, N.K., Singh, P.N., Tyagi, P.C., Mohan, S.C., 2001. Effect of application of Leucaena mulch on soil moisture conservation and productivity of rainfed wheat. Indian J. Soil Conserv. 29 (2), 143–147.
Turner, N.C., 1987. Crop water deficits: a decade of progress. Adv. Agron. 39, 1–39.
Wang, S.T., 1987. Water use efficiency of plant and dryland farming production. Agric. Res. Arid Areas 2, 67–80.