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Effect of land configuration on water economy, crop yield and profitability under rice (*Oryza sativa*) -based cropping systems in north-east India

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ABSTRACT

A field experiment was conducted during the winter *(rabi*) season of 2006 and 2007 to evaluate the water economy and performance of different crop combinations under standard raised and sunken bed system of cultivation in mid-hills of Meghalaya, north-eastern part of India. The treatment consisted of various winter vegetables crops like tomato *(Lycopersicon esculentum* L. Mill. nom. cons.), potato (*Solanum tuberosum* L.) grown on sunken beds and gardenpea (*Pisum sativum* L.) and Frenchbean (*Phaseolus vulgaris* L.) grown on raised beds under organic mulched and without mulched condition. Periodical observations on soil moisture content and yield attributes of various crops were recorded for further analysis on water economy and profitability of cropping systems. Organic mulching significantly increased the soil moisture content in all the crop combinations. The profile soil moisture content was significantly higher in rice (*Oryza sativa* L.)–tomato/gardenpea cropping system (29.3%), lowest being in rice-fallow system (22.5%). Results showed that organic mulch decreased soil temperature by 3–5°C compared to that in the plots without mulch. Among the various crop combinations, rice–tomato/gardenpea gave the highest rice equivalent yield and production efficiency (18 138 kg/ha and 77.18 kg/ha/day, respectively), followed by rice–potato/gardenpea system (16 982 kg/ha and 76.50 kg/ha/day, respectively), lowest being in rice monocropping (4 420 kg/ha and 36.23 kg/ha/day, respectively). Highest net returns (Rs 56 730/ha) was recorded in rice–tomato/gardenpea, followed by rice–potato/ gardenpea (Rs 51 465/ha).

Key words: Cropping systems, Production efficiency, Profitability, Raised-sunken bed system, Water economy

The north-eastern region despite being bestowed with a bountiful of water resources and receiving the highest rainfall, experiences acute shortage of water during post-monsoon period. Due to lack of proper water management practice only 0.88 million ha-m out of total 42.0 million ha-m of the water resources has been utilized (NEH 2005). The irrigation potential of the region remains untapped and about 80% of the cultivated area is rainfed. In this region, rice is the major food crop, occupying about 72% of the total cultivated area. However, quite often rice crop is suffered from soil moisture stress during later growth stage. Farmers are not in position to take any crop during winter (*rabi*) season because of severe moisture stress. Therefore monocropping of rice is the traditional practice in valley land and therefore, the region is still not self-sufficient in foodgrain production.

Therefore, proper land configuration is must for utilizing the residual soil moisture effectively for *rabi* crop cultivation. A simple land configuration through raised and sunken bed system, in this context, is a useful technology for proper land and water management, inter-plot water harvesting to increase crop intensity (Sharma 2003). This system also called *sorjan* is popular in Java and tidal wetlands in Indonesia, where high value upland crops are grown on raised beds and rice in sunken beds. This would increase the cropping intensity as well as the farmers' income. Standard width ratio of raised and sunken bed was tested and evaluated in north-eastern parts of India for better crop production (Mishra and Saha 2007). Effective management of crop residues, jungle grass, stubbles and weed biomass can have a beneficial role as mulching materials in moisture conservation practice and also as source of organic matter and plant nutrients in soil fertility (Munda *et al.* 2006). There is tremendous scope for cultivation of winter vegetable crops. However, the resource-poor farmers are ignorant about this fact. The present study, was therefore, conducted to evaluate different crop combinations in association with mulching effect under standard raised and sunken bed system, water economy/use efficiency and production level for sustainable crop production throughout the year.

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MATERIALS AND METHODS

The field experiment was carried out in Alfisol at the experimental farm of ICAR Complex for North Eastern Hill (NEH) Region, Umiam, located at East *Khasi* Hills of Meghalaya, India (25° 41′N, 91° 63′E, 980 m above mean sea level) during 2006 and 2007. The area falls under the mild tropical hill zone and the climate is per-humid. The daily temperature during a year varies widely between 2.5° (January) and 32.5°C (August). The region receives an average rainfall of 2 439 mm with high degree of temporal and spatial variations. Eighty per cent of the annual rainfall is received during April to October. The soil of the study area is acidic in nature classified under Typic Hapludalf. The soils are clay loam in texture, acidic in reaction (*p*H 4.9), and high in organic carbon (1.10 g/kg), available N (alkaline permanganate N, 235 kg/ha), available P (Olsen P, 10.1 kg/ha) and available K (ammonium acetate K, 387.5 kg/ha). Moisture retention at 0.033 and 1.5 MPa, bulk density and saturated hydraulic conductivity were 29.0% and 18.4%, 1.34 Mg/m^3 and 554.4 mm/hr, respectively, in 0–15 cm soil depth.

The raised-sunken beds were made in sequence for inter-plot water harvesting with a fixed dimension, ie 1 m for raised and 2.5 m for sunken bed, respectively. The length of the all the plots was same (6 m). The surface soil layer of each sunken bed was removed and deposited on the adjacent raised beds about 30 cm height. The raised beds were leveled in such a way that the 50% of run-off water from half of the each raised bed will drain off into its intervening sunken bed. All treatments were replicated thrice in factorial randomized block design.

Transplanted 'RCPL 1-87-8' rice were grown during rainy (*kharif*) season in the sunken beds with recommended N, P and K doses, ie 100 kg/ha N through urea, 60 kg/ha P through single superphosphate and 40 kg/ha K through muriate of potash (100: 60: 40). Farmyard manure @ 10 tonnes/ha were applied in raised and sunken bed system well in advance of the sowing/transplanting of the crops. Farmyard manure contained 0.60% N, 0.15% P and 0.30% K on a dry-weight basis, 25-days-old seedlings were transplanted with spacing 0.25 m × 0.15 m spacing during first week of July and other management practices were followed as and when required and ultimately the crop harvested in October. Rice yield was recorded from the net plot area of 15 m^2 at 14% seed moisture. Thereafter, 'Kufri Giriraj' potato and 'Pusa Rubi' tomato crops were grown as *rabi* crops in those sunken beds with spacing 0.50 m × 0.30 m with standard recommended N, P and K doses i.e. 120: 120: 60 and 100: 150: 60. Other intercultural operations were followed as per the need. The crops were harvested in February–March. Frenchbean (pole type) and 'Sultan' gardenpea were grown in raised beds. Frenchbean received 80 kg N, 60 kg P and 40 kg K, whereas gardenpea received 20 kg N, 60 kg P and 30 kg K. Both the crops harvested as and when they matured for table purposes. Staking was done for Frenchbean and gardenpea at appropriate stages to prevent lodging. Moisture conservation practices consists straw mulching @10 tonnes/ha and no mulch. Mulch materials were applied in the field just after harvesting of *kharif* crop and thereafter it remained till harvest of *rabi* crops. The yield of various crops of the respective cropping systems were converted to rice equivalent yield based on the price prevalent in the local market. Production efficiency in terms of kg/ha/day was calculated from the rice equivalent yield values of the system divided by the total duration of crops in the sequence (Tomar and Tiwari 1990). Crop intensification was measured by calculating land utilization efficiency by dividing the total duration of respective cropping systems by the numbers of days in a year (365 days), expressed in percentage.

Soil samples were collected at 15 days interval throughout crop growing season for gravimetric soil moisture analysis. Water storage up to 0.60 m depth of soil profile was computed using gravimetric water content, bulk density and depth of soil layer. Bulk density was determined by core method. The profile soil moisture extraction was estimated using the following water balance equation:

$$ET = P + I + C_P - D_P - R_P - \Delta S$$

Where P is the precipitation, I is the depth of irrigation water applied, C_P is the contribution through capillary rise from ground water-table, D_P is deep percolation loss, R_P is surface water runoff and ΔS is change in soil water profile. In the present study, no irrigation is applied. The C_p was assumed to be negligible as the water-table was below 4 m throughout the crop season. The soil surface was covered with crop biomass and grasses to reduce surface run-off or deep drainage. This was confirmed by the periodic monitoring of the soil-water profile. So, all these parameters (I, C_p, D_P and R_P) was ignored during calculation.

The change in soil water profile (ΔS) was measured by:

$$\Delta S = S_i - S_f$$

Periodical soil temperature recorded with the help of soil thermometer installed in the study area.

RESULTS AND DISCUSSION

Soil moisture status

Seasonal net changes in profile soil moisture content under different crop combinations are shown in Fig 1. In all the cropping system, the total stored water in soil profile depleted continuously with the advancement of crop growing season due to extraction of water from the profile by the crops. It is observed that the mulched plots had higher gravimetric moisture content in all the soil layers as compared to that under plots without mulch. This might be attributed to incorporation of mulch materials which conserved soil moisture favouring higher uptake of water from deeper layers. The profile soil moisture content was significantly higher in rice–tomato/gardenpea cropping system (29.3%), lowest being in rice–fallow system (22.5%). This might be because

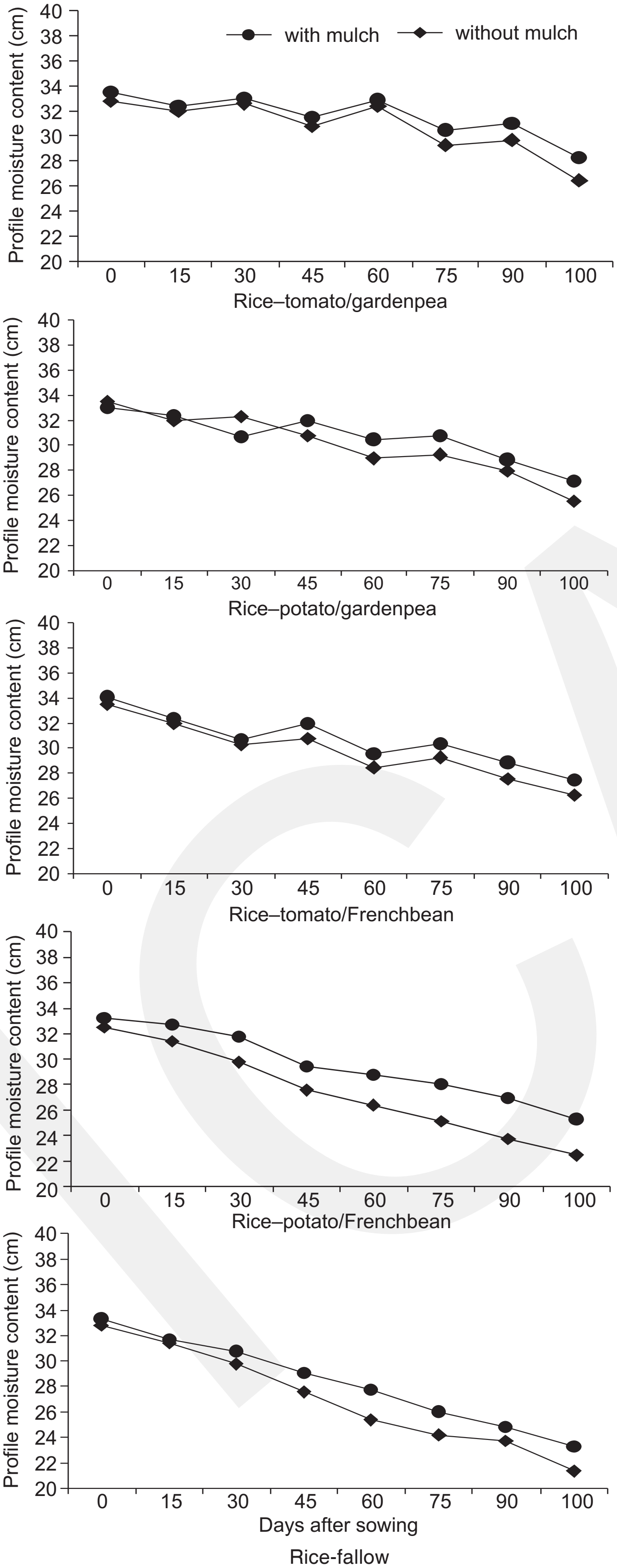

Fig 1 Changes in soil profile moisture content (0–60 cm depth) during winter crop growing season

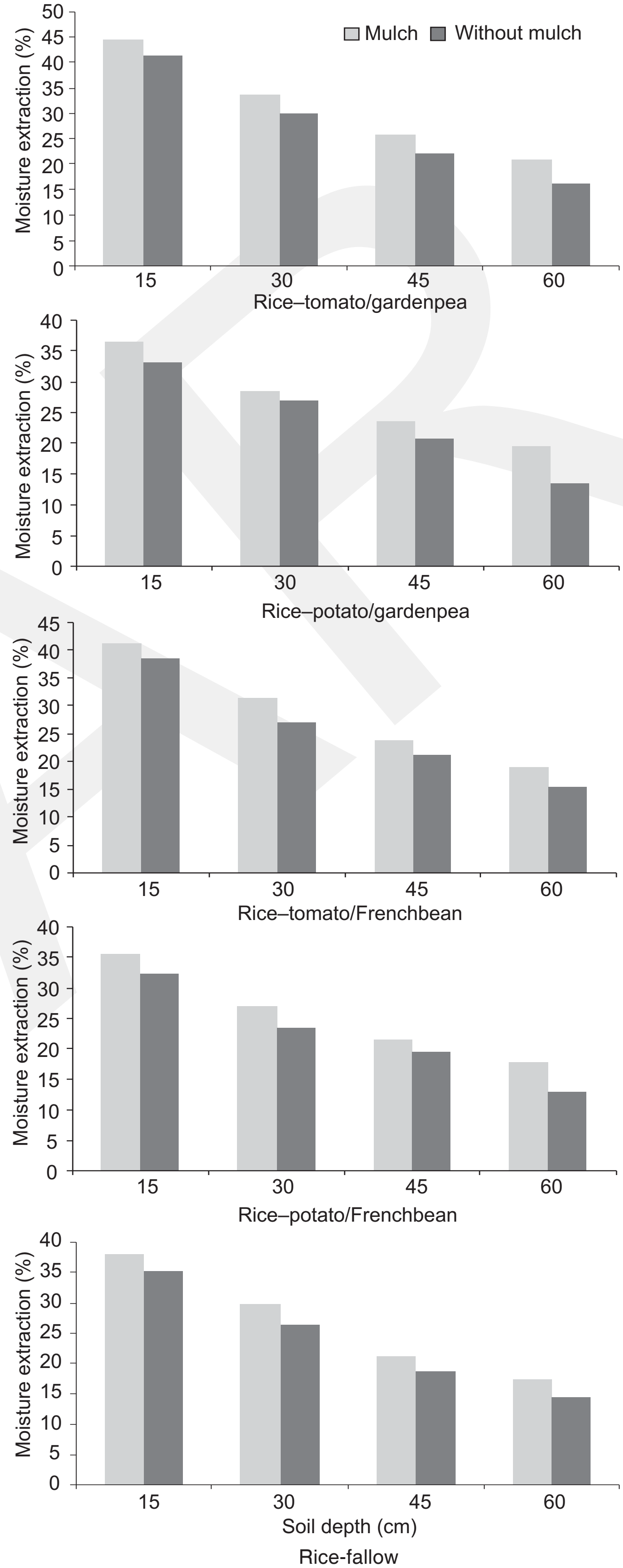

Fig 2 Soil moisture extraction (%) pattern by various winter crop treatments

of greater opportunity of rain-water infiltration in organic mulches.

Soil moisture extraction

The water extraction pattern (Fig 2) in the soil profile under different crop combinations reflected that the moisture extraction was maximum (32.2 to 44.5%) from 0–15 cm soil depth irrespective of crop combinations, and mulch treatments and it also decreased with soil depth. Increased water uptake by the crop from surface layers due to availability of surface soil moisture by mulch treatment may be the possible reason for such increase in moisture extraction pattern. Most of the soil water (65–75%) was extracted by the crop from the top 30 cm soil depth (Fig 2). On the other hand, in case of no mulch, moisture extraction was more from deeper layers (30–60 cm). Moisture stress in crop root zone allowed going deeper in search of water, which promoted relatively more utilization of water from deeper layers.

Soil temperature regulation

A notable variation in soil temperature at surface layer (0–15 cm) was observed by mulching during the winter crop growing season (Fig 3). Data recorded everyday at 2 PM

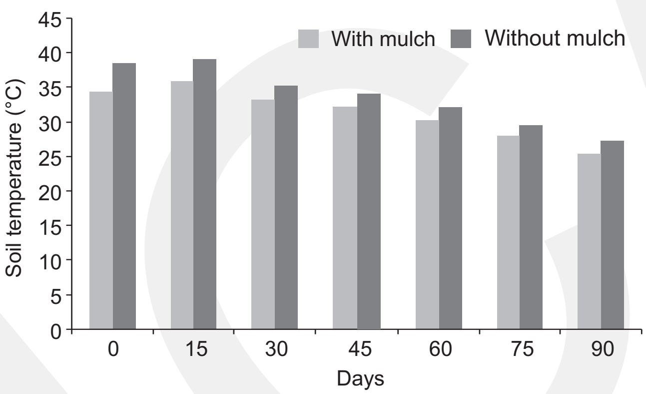

Fig 3 Effect of mulching on surface soil (0–15 cm) temperature (°C) at 2 PM during winter crop growing season

revealed that the organic mulches maintained a static soil temperature of 25.5 to 35.9°C during winter crop growing season, whereas the soil temperature of the plots without any mulch fluctuated in between 27.3 and 39.1°C. Organic mulch with straw recorded 3–5°C less temperature than the plots without mulch. In organic type of mulching acting as insulator, which hindered the rising of soil temperature (Goswami and Saha 2006). Wade and Sanchez (1983) reported that mulching with guineagrass decreased topsoil temperatures by 5°C prior to the establishment of a crop canopy, conserved soil moisture in the top 5 cm during dry weather, prevented surface crusting and decreased weed growth.

Productivity and equivalent yield

Mulch treatment significantly influenced crop growth. On an average, there was 14 to 30% yield increase under straw mulched plots compared to that in plots without mulch. The substantial increase in crop yield under mulch treatments might be because of the favourable soil hydrological environment, thus enabling better condition for crop physiological functions.

Rice monocropping gave 4 420 kg/ha rice yield, which is marginally higher than the rice yield under various rice-based cropping systems (Table 1). Among the rice-based cropping systems, the highest rice grain yield was recorded in rice–tomato/Frenchbean (4250 kg/ha), followed by rice–potato/Frenchbean (4 210 kg/ha). The higher rice yield under these cropping systems was significantly superior to the grain yield obtained from rice–potato/gardenpea (4 130 kg/ha) and rice–tomato/gardenpea (4 080 kg/ha) sequences. The higher yield of rice in rice–legume cropping systems might be due to effect of leguminous stover through biological N-fixation in soil. The results are in conformity with the findings of Singh and Yadav (2006). Unlike rice grain yield, the highest fresh vegetable biomass was harvested in tomato/garden-pea (16 870 kg/ha), followed by potato/gardenpea (14 020 kg/ha), tomato/Frenchbean (10 320 kg/ha) and potato/Frenchbean (8 500 kg/ha). The highest rice equivalent yield

Table 1 Yield, relative equivalent yield (REY), production efficiency, land utilization efficiency and economics of various cropping systems

Cropping system (duration in days)	Yield (kg/ha)		REY (kg/ha)	Production efficiency (kg/ha/day)	LUE (%)	Cost of cultivation (Rs/ha)	Total production in monetary term (Rs)	Net returns (Rs/ha)	Benefit: cost ratio
	Kharif	*Rabi*							
Rice–tomato/gardenpea (235)	4 080	16 870	18 138	77.18	64.38	36 050	92 780	56 730	1.57
Rice–potato/gardenpea (222)	4 130	14 020	16 982	76.50	60.82	36 775	88 240	51 465	1.40
Rice–tomato/Frenchbean (217)	4 250	10 320	12 872	59.32	59.45	33 710	80 230	46 520	1.38
Rice–potato/Frenchbean (210)	4 210	8 500	10 543	50.20	57.53	33 890	75 360	41 470	1.22
Rice–fallow (122)	4 420		4 420	36.23	33.42	14 630	26 520	11 890	0.81
CD (P = 0.05)	1.64		29.74						

Price of produce: rice at Rs 600/100 kg, tomato Rs 500/100 kg, potato Rs 550/100 kg, gardenpea at 700/100 kg and Frenchbean at Rs 500/100 kg at local market of the system was achieved with rice–tomato/garden pea cropping system (18 138 kg/ha), followed by rice–potato/ gardenpea (16 982 kg/ha), being significantly superior than the other cropping systems studied. The lowest productivity in terms of rice equivalent yield was recorded with rice–potato/Frenchbean system (10 543 kg/ha). The increase in system productivity (REY) compared to rice monocropping (4 420 kg/ha) ranged from 139% with rice–potato/ Frenchbean system to 310% in rice–tomato/gardenpea cropping system.

Production and land-use efficiency

Production efficiency (Table 1) followed almost the similar trend as that of relative equivalent yield (REY). The highest production efficiency of 77.18 kg/ha/day was obtained with rice–tomato/gardenpea, followed by rice–potato/gardenpea system (76.50 kg/ha/day). In other cropping systems, it varied in between 50.20 and 59.32 kg/ha/day, lowest being in rice monocropping (36.23 kg/ha/day). Higher production efficiency due to inclusion of vegetables in the rice-based systems was also reported by Kumar *et al.* (2005). Rice–tomato/gardenpea (64.38%) and rice–potato/gardenpea (60.82%) cropping systems recorded higher land utilization efficiency (LUE) because of their efficient utilization of land for longer duration. Rice–potato/Frenchbean (57.53%) was lowest in terms of land utilization, as the land remained idle for a longer duration compared to other cropping systems. The production efficiency and LUE were 39–113% and 72–93% higher, respectively, with rice-based cropping systems as compared with monocropping of rice. This is due to lower REY value (4 420 kg/ha) and inefficient utilization of land (122 days) with monocropping of rice.

Economic analysis

Economic analysis of various cropping systems (Table 1) revealed that the cost of cultivation varied with the vegetable species grown and the associated cultivation practices. The highest cost of cultivation was involved in the rice–potato/ gardenpea sequence (Rs 36 775/ha), followed by rice–tomato/gardenpea (Rs 36 050/ha), mainly because of higher costs involved in land preparation. The cost of cultivation for rice–tomato/Frenchbean and rice–potato/Frenchbean are almost at par (Rs 33 710/ha and 33 890/ha respectively). Among different cropping systems, the highest net returns was recorded in rice–tomato/gardenpea (Rs 56 730/ha), followed by rice–potato/gardenpea (Rs 51 465/ha), rice–tomato/Frenchbean (Rs 46 520/ha) and rice–potato/ Frenchbean (Rs 41 470/ha) cropping systems. Among the various cropping systems, the maximum benefit : cost ratio was achieved by the rice–tomato/gardenpea (1.57) system, followed by rice–potato/gardenpea (1.40), rice–tomato/ Frenchbean (1.38) and rice–potato/Frenchbean (1.22). However, the net returns and B : C ratio remained much lower in rice monocropping as compared to other cropping systems because of lower relative equivalent yield. Therefore, it can be concluded that winter crops can be grown with residual soil moisture with simple land configuration of raised-sunken bed system under organic mulched condition. Moreover rice–tomato/gardenpea and rice–potato/gardenpea cropping systems were found to be most promising and profitable for resource poor farmers of north-east India.

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