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Research Paper

Effect of liming, planting time and tillage on system productivity, profitability and resource-use efficiency of rice (*Oryza sativa*)-based cropping systems under rainfed valley land condition of North East India

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ABSTRACT

A field experiment was conducted during 2010–12 at Imphal, Manipur, to study the effect of liming, planting time and tillage on system productivity, profitability and resource-use efficiency of rice (*Oryza sativa* L.)–rapeseed [*Brassica campestris* (L.) var. *toria*] and rice (*Oryza sativa* L.)–lathyrus or khasari (*Lathyrus sativus* L.) cropping systems. The treatments consisted of 2 factors, i.e. liming (liming and no liming) and planting time (early and normal) which were given to rice crop during rainy (*kharif*) season in the main plots. During the winter (*rabi*) season after rice, 2 tillage practices (no tillage and conventional tillage) were given in sub plots and again 2 *rabi* crops (rapeseed and lathyrus) in sub-subplots. The experiment was laid out in split split plot design with 3 replications. Application of lime @ 500 kg $CaCO_3$/ha before planting rice recorded higher system productivity in terms of rice-equivalent yield (REY) of 6.30 t/ha, nitrogen-use efficiency (NUE) and water-use efficiency (WUE) of the system; however, it failed to increase benefit: cost ratio. Advancing planting time of rice 15 days ahead of normal planting enhanced growth and yield of *rabi* crops, resulting increase in REY (6.57 t/ha), land use efficiency (LUE), production efficiency and partial factor productivity (PFP) of the system by 16.70, 2.90, 13.05 and 16.1% respectively. No tillage enhanced PFP and NUE of the system, while conventional tillage increased energy consumption by 12.4%. Regarding cropping system, rice–rapeseed gave higher net return, benefit: cost ratio and production efficiency over rice–lathyrus system. However, rice–lathyrus system increased NUE, WUE and energy productivity. Rice–rapeseed system showed higher productivity and profitability under conventional tillage and normal planting, but rice–lathyrus gave better performance under early planting with no tillage.

Key words : Liming, Planting time, Rice-based cropping system, Rice-equivalent yield, Tillage

North East India, the rice-dominated area of the country, accounts for about 7.8% of the India's total rice area. The crop occupies about an area of 3.5 million ha, with an average productivity of 1.78 t/ha (Kumar *et al*., 2013). Though a major portion of lowland rice areas is able to support a good second crop with carry-over residual soil moisture (due to heavy texture and high moisture retention), it is mostly monocropped and not fully utilized for crop production in subsequent *rabi* (post-rainy) season for ages.

So, such underutilized area offers enormous opportunity to overcome the problem of food and nutrition insecurity in the region. Nonetheless, mere broadcast seeding of *rabi* crops under no or suboptimal management results in meager yields and this necessitates the need of following improved crop and nutrient-management approaches (Ghosh, 2002). Efficient natural resource management using left-over soil moisture and nutrients that remain in the soil after the preceding rice crop could turn lowland rice farming into a profitable enterprise (Maclean *et al.*, 2002).

Soil acidity may not create any problem for the growth and productivity of rice due to water stagnation during growth and nature of the crop. Since rice is being cultivated predominantly as monocrop, neutralization of acidity by liming was not given priority in the past. However, advocacy of growing vegetables, oilseeds and pulses into rice fallow land would certainly require management of acidity to raise productivity and profitability.

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The importance of managing rice cultivation to facilitate *rabi* cropping and to increase total system productivity has been well recognized. The one management option in this regard is time scheduling like early sowing of rice, if possible. The practice of puddling benefits rice cultivation, but it adversely affects the succeeding *rabi* crops by altering physico-chemical and microbial properties of the soil. The key to successful management of *rabi* crops in rice fallows lies in maintenance of optimum plant stand by manipulating the soil tilth through proper tillage practices. The pulses and oilseeds fit in such a condition without much disruption of rainy (*kharif*) season cereal production system. As such pulses and oilseed crops are ideal crops that can occupy the area vacated by *kharif* rice. Keeping these in view, a study was carried out to explore the possibility of growing second crops after *kharif* rice and to improve sustainability of rice-production system besides enhancing production and augmenting income in rainfed rice-fallow system.

MATERIALS AND METHODS

A field experiment was conducted in a subtropical climate of Imphal Valley during 2010–11 and 2011–12 at the experimental field of College of Agriculture, Central Agricultural University, Iroisemba ($24^o46'$ N, $93^o54'$ E 774.5 m above the mean sea-level) Imphal. The soil of the experimental site was clayey, strongly acidic (*p*H 5.2), high in organic carbon (18.5 g/kg) medium in available N (442.0 kg/ha), low in P (10.6 kg/ha) and high in K (214.9 kg/ha). The total rainfall received during 2010–11 and 2011–12 cropping seasons varied from 1,115.7 to 1,320.2 mm and 1,175.5 to 1,220.8 mm respectively (Fig. 1). The experiment was conducted on using 2 cropping systems, i.e. rice–rapeseed and rice–lathyrus, covering 2 seasons and laid out in split-split plot design with 4 factorial combinations of liming (liming and no liming) and planting time (early and normal) treatments to rice during *kharif* season in main plots; 2 tillage practices (no tillage and conventional tillage) before *rabi* crops in subplots and 2 *rabi* crops (rapeseed and lathyrus) in sub-subplots with 3 replications. There were 2 × 2, i.e. 4 treatments in *kharif* season and 4 × 2 × 2, i.e. 16 treatments in *rabi* season. The dimensions of the different plots were 15 m × 6 m in main plot, 15 m × 2 m in subplot and 6 m × 2 m in sub-subplot. Liming @ 500 kg/ha by using $CaCO_3$ in the form of powdered lime stone was added annually 25 days before transplanting *kharif* rice where liming treatment was necessary. Lime application @ 500 kg $CaCO_3$/ha was only 5% of lime requirement (LR) which was estimated to 10 tonnes $CaCO_3$/ha in acid soils of Manipur (Raychaudhuri and Kumar, 2002). Considering the cost ineffectiveness of liming, a lower dose was tried in this experiment. 'Leimaphou ('KD 2-6-3') rice, 'M 27' rapeseed and 'Local' lathyrus were grown as test crops. Rice was sown on 20 May and 7 June and transplanted on 17 June for early sowing and 4 July for normal sowing (27 days old seedlings with 2/3 seedlings/hill at 20 cm × 10 cm spacing). The succeeding *rabi* crops were sown on 15 October and 30 October in both the years for early planted rice followed by no-tillage plot and normal-planted rice followed by no-tillage plot respectively. However, the crops were sown on 22 October and 6 November for early planted rice followed by conventional tillage and normal planted rice followed by conventional tillage plots in both the years respectively. In no-tillage plot, *rabi* crop seeds were broadcast on untilled soil, but in conventional tillage plots, 2 harrowing were done and then followed by planking. All standard package of practices as recommended for all the 3 crops were followed except for the treatments. Urea, single superphosphate and muriate of potash were used as sources of N, P and K respectively. A common dose of N, P and K @ 60, 17.2 and 24.9 kg/ha was applied in all the treatments in main plots of rice. Half of the nitrogen and full dose of P and K were applied as basal dose at the time of final puddling. Of the remaining N, one-half of it was applied at maximum tillering stage and the rest at panicle-initiation stage. For conventional tillage of rapeseed, the recommended N, P and K dose of 40, 8.6 and 16.6 kg/ha was applied. Nitrogen for rapeseed was applied in 3 splits (half at the time of sowing, one-fourth at 1 month after sowing and one-fourth 2 months after sowing). In case of no-tillage plots, only N @ 20 kg/ha was applied in 2 splits, i.e. half 1 month after sowing and another half 2 months after sowing avoiding basal dressing. For lathyrus grown under conventional tillage, a basal dose of N, P and K @ 20, 25.8 and 24.9 kg/ha was applied. However, in case of no tillage of lathyrus, only nitrogen @ 20 kg/ha was top dressed 15 days after sowing, i.e. just after emergence of seedling. Fertilizer was side-dressed in crop rows in both the years. The data on growth and yield attributes, grain and straw/stover yields, protein and oil content, plant N, P and K contents of the component crops were recorded following standard procedures. The total nutrient uptakes were calculated by multiplying plant NPK contents with respective dry weights. Water-use efficiency (WUE) was calculated based on grain/seed yield and evapotranspiration (ET) as:

$$WUE = \frac{Y}{ET_{crop}}$$

where WUE = water use efficiency (kg/ha-mm), Y = yield of grain or seed (kg/ha) and ET_{crop} = cumulative crop evapotranspiration (mm). The ET was estimated by following Pan Evaporation method. The partial factor productivity (PFP) and system productivity expressed as rice-equivalent yield (REY) were also calculated as:

$$\text{PFP (NPK)} = \frac{\text{Grain yield (kg)}}{\text{kg } (N + P_2O_5 + K_2O) \text{ applied}}$$

$$\text{REY} = Y_{rice} + \frac{Y_{rapeseed\,/\,lathyrus} \times P_{rapeseed\,/\,lathyrus}}{P_{rice}}$$

where, Y = yield of grain or seed, (t/ha) and P = price for grain or seed (₹/t).

Based on the energy equivalents of the inputs and outputs, energy-use efficiency, energy productivity, energy intensity in physical terms and energy intensity in economic terms were calculated as:

$$\text{Energy-use efficiency} = \frac{\text{Gross energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{[Total output (grain + straw) (kg/ha)]}}{\text{Total energy input (MJ/ha)}}$$

Net energy output (MJ/ha) = Gross energy output (MJ/ha)–Energy input (MJ/ha)

$$\text{Energy intensity in physical terms (MJ/kg)} = \frac{\text{[Total input (MJ/ha)]}}{\text{Total output (grain + straw) (kg/ha)}}$$

$$\text{Energy intensity in economic terms (MJ/)} = \frac{\text{Gross energy output (MJ/ha)}}{\text{Cost of cultivation (₹/ha)}}$$

Data collected on different parameters were compiled and tabulated and subjected to statistical analysis by using MSTAT C package in computer, where the significance of different main effects of the treatments involved were tested with ‘F-test’. The critical difference (CD) values at 5% level of significance were calculated for the effects which were found significant at least at 5% level of significance.

RESULTS AND DISCUSSION

Effect of liming on rice

Liming to rice crop did not show much influence on growth attributes of rice such as plant height, tiller count and dry-matter accumulation as well as on yield attributes such as panicles/m^2, spikelets/panicle and 1,000-grain weight. Rather, filled grains/panicle were found comparatively higher in no-liming treatment over liming treatment (Fig. 2). As a resultant effect, liming to rice failed to show any promising effect on grain and straw yields. Significant yield benefit was found by Chang and Sung (2004) in rice crops grown in the acid soil receiving liming treatment in a pot culture experiment. They attributed the increased yields to the enhanced uptake of nutrients like Ca, Mg, P and K. Suresh and Savithri (2000) also reported increased grain and straw yields of rice owing to liming under field conditions.

Effect of planting time on rice

Among the growth attributes of rice, higher plant height and dry matter/hill were obtained owing to advancement of rice planting by 15 days, but number of tillers/hill remained unaffected. Increased dry matter accumulation had been reflected in higher grain and straw yields under early planting. The increases in grain yields of rice might had been achieved mainly owing to higher percentage of filled grains and higher 1,000-grain weight under early planting (Fig. 2). A significant decline in rice grain yield with delay in sowing or transplanting was observed by Gill *et al.* (2006). Chopra and Chopra (2004) also reported that planting made up to the middle of July was safe for higher seed yield and quality.

Residual effect of liming on rapeseed

Liming applied to preceding rice crop had residual effect on rapeseed which improved number of seeds/siliqua

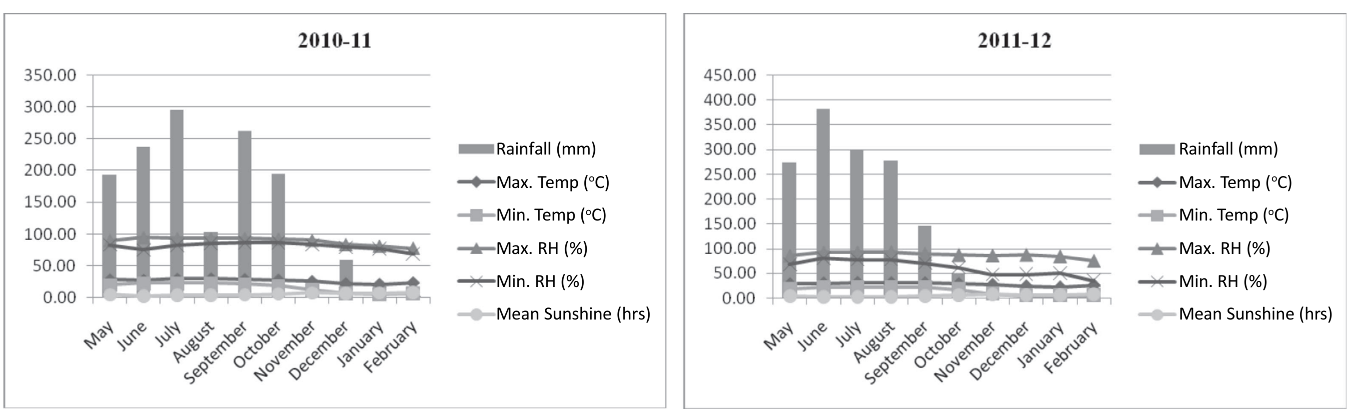

Fig. 1. Weather data during the cropping seasons of 2010–11 and 2011–12

and stover yield significantly but not on the seed yield (Table 1). There was 7.96% and 9.74% increase in seeds/siliqua and stover yield respectively. Increased stover yield of rapeseed due to liming could be attributed to increase plant height and number of branches/plant. Although the oil yield of rapeseed was increased significantly, seed oil content was not increased significantly due to liming. Liming did not result in significant increase in N uptake, but it did increase P and K uptake by the crop which can be attributed to increased seed and stover yields and increased P and K contents in seed and stover under the treatment. The increase in P uptake due to liming may be due to fact, that it breaks the Fe and Al phosphates in soil, thereby making P available to plant. Raychaudhuri and Kumar (2002) found the increased uptake of N, P and K in maize due to residual effect of liming done to preceding crop of soybean.

Effect of planting time on rapeseed

The seed yield of rapeseed was increased by 9.16% under early planting compared to normal planting. The significant increase in seed yield under early planting was contributed by the increase in yield attributes such as number of siliquae/plant, seeds/siliqua and 1,000-seed weight of which the 1,000-seed weight contributed significantly (Table 1). Similar results were observed by Singh and Singh (2002), who reported that growth characters, yield attributes, yields and qualities of *Brassica juncea* were found to be more when sowing was done on 14 October compared to 20 October, 13 November and 28 November sowing. Oil content was not affected by planting time significantly. Early planting of the crop resulted higher removal of all the major nutrients, i.e. N, P and K, by stover and P and K by seed due to higher concentration of N, P and K and increase in seed and stover yield (Fig. 3). Rana (2002) also reported that delay in sowing of *Brassica* spp. caused reduction in the uptake of N and P.

Effect of tillage practices on rapeseed

The seed and stover yields of rapeseed were significantly lower under no tillage (NT) than conventional tillage (CT). These findings could be supported by the observations on yield attributes such as siliquae/plant, seeds/siliqua and 1,000-seed weight which were mostly remained higher, sometimes even significant under conventional tillage practice. These findings confirmed the results of Chaudhary *et al*. (1991), who reported higher wheat grain yield in conventional tillage and deep tillage in comparison to no till. Chitale *et al*. (2007) also reported that conventional tillage in wheat produced 19.1% higher grain yield than zero tillage wheat. Seed oil content and oil yield also remained unaffected due to tillage practices treatments. The uptake of nitrogen, phosphorus and potassium by grain were significantly higher under CT (Fig. 3). This might be owing to the favourable root environment created by CT leading to better root growth, nutrient uptake which ultimately resulted better plant growth. However, only the uptake of potassium by the stover was significantly higher under CT than NT. The results corroborate with the findings of Sarma and Gautam (2010).

Table 1. Growth, yield, oil content and oil yield of rapeseed in rice–rapeseed cropping system (pooled data of 2 years)

Treatment	Growth		Yield					Oil	Oil
	Plant height (cm)	Branches/ plant	Siliquae/ plant	Seeds/ siliqua	1,000-seed weight (g)	Seed yield (t/ha)	Stover yield (t/ha)	content (%)	yield (kg/ha)
Liming									
No liming	42.1	6.4	20.5	11.1	2.46	0.51	1.07	36.57	167.4
Liming	42.9	7.0	23.7	11.9	2.58	0.57	1.17	36.63	186.0
SEm±	0.7	0.3	0.4	0.2	0.05	0.01	0.03	0.35	4.9
CD (P=0.05)	NS	NS	NS	0.8	NS	0.05	0.10	NS	17.1
Planting time									
Early	43.5	7.0	22.6	12.0	2.54	0.56	1.21	36.08	181.9
Normal	41.5	6.4	21.6	11.0	2.51	0.51	1.02	37.12	171.5
SEm±	0.7	0.3	0.4	0.2	0.05	0.01	0.03	0.35	4.9
CD (P=0.05)	NS	NS	1.4	0.8	NS	0.05	0.10	NS	NS
Tillage									
NT	42.5	5.9	20.5	11.9	2.46	0.51	1.04	37.11	170.8
CT	42.5	7.5	23.7	11.1	2.59	0.56	1.20	36.10	182.7
SEm±	1.5	0.1	0.6	0.2	0.04	0.01	0.03	0.60	6.3
CD (P=0.05)	NS	0.4	1.8	NS	0.13	0.04	0.01	NS	NS

Residual effect of liming on lathyrus

Significant effect of lime application to rice was noted on the yield attributes and yield of lathyrus grown as succeeding crop after rice (Table 2). However, the residual effect of liming was significant on growth attributes of lathyrus. Liming did not result in significant increase in protein content, but there was a significant increase in protein yield of seed owing to liming. As liming in acid soil brings favourable soil reaction for increased population of *Rhizobium* colonies and also improves the root distribution in the soil (Raychaudhuri *et al.*, 1998), that might had caused better growth and yield of lathyrus which ultimately resulted in increased protein yield though protein content could not be increased. Owing to liming, significant increases in uptake of N, P and K by grain and stover except K uptake by grain were observed (Fig. 4).

Effect of planting time on lathyrus

Growth and yield of lathyrus were also influenced by planting time significantly. Early planting recorded 30.77% higher seed yield than normal one. Higher protein yield recorded under early planting was owing to increased seed yield as well as higher protein content in seed under the treatment over normal planting (Table 2). Singh *et al*. (2009) reported a significant reduction in seed yield of lentil with delay in sowing from 20 October to 10 November by a margin of 10.4% with a significantly higher yield on 20 October sowing. Higher amount of nutrient removals was also observed by the crop under early planting over normal planting.

Effect of tillage practices on lathyrus

Both the seed and stover yields of lathyrus under no tillage were marginally higher than those recorded under CT.

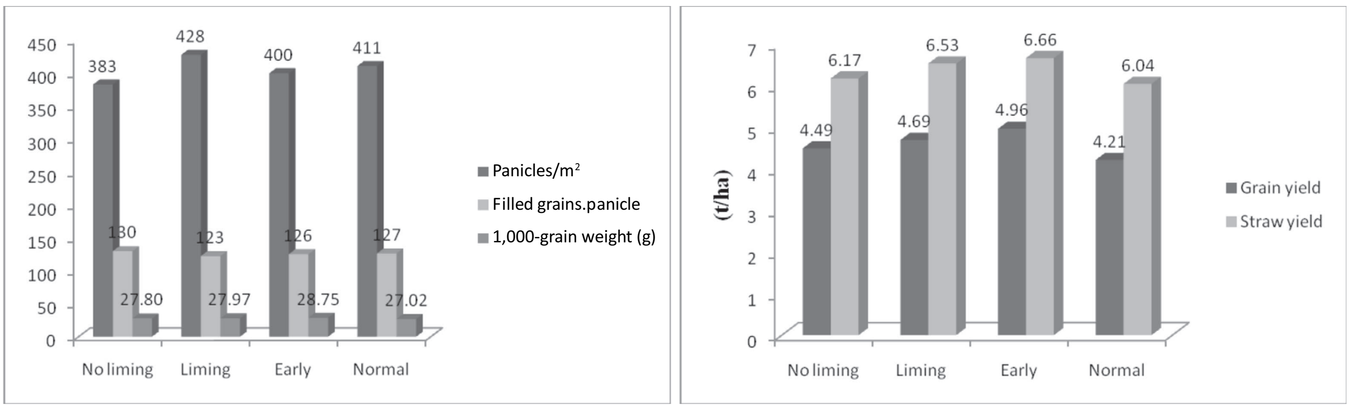

Fig. 2. Yield attributes and yield of rice (pooled) as influenced by liming and planting time of rice

Table 2. Growth, yield and protein content and protein yield of lathyrus in rice-lathyrus cropping system (pooled data of 2 years)

Treatments	Growth		Yield					Protein	Protein
	Plant height (cm)	Branches/ plant	Pods/ plant	Seeds/ pod	1,000-seed weight (g)	Seed yield (t/ha)	Stover yield (t/ha)	content (%)	yield (kg/ha)
Liming									
No liming	28.3	10.5	13.9	3.6	32.5	0.34	1.39	18.3	67.6
Liming	29.8	11.6	14.7	3.8	32.5	0.35	1.40	18.9	73.5
SEm±	0.4	0.3	0.5	0.1	1. 7	0.02	0.02	0.2	0.8
CD (P=0.05)	1.2	1.1	NS	NS	NS	NS	NS	NS	2.9
Planting Time									
Early	30.4	11.6	14.8	3.9	33.5	0.39	1.44	19.0	80.4
Normal	27.8	10.5	14.0	3.4	31.5	0.30	1.35	18.3	60.7
SEm±	0.3	0.3	0.5	0.1	1.67	0.02	0.02	0.2	0.8
CD (P=0.05)	1.2	1.1	NS	0.3	NS	0.06	0.06	0.7	2.9
Tillage									
NT	30.4	11.6	14.8	3.6	33.3	0.35	1.39	18.6	69.8
CT	27.7	10.6	14.0	3.7	31.7	0.33	1.40	*18.7*	71.3
SEm±	0.4	0.1	0.2	0.1	0.1	0.01	0.02	0.5	2.8
CD (P=0.05)	1.4	0.4	0.7	NS	0.3	NS	NS	NS	NS

Yield attributes of lathyrus such as pods/plant and 1,000-seed weight mainly contributed toward increase in seed yield under NT. The results confirm the findings of Yadav *et al*. (2005). The tillage treatments also did not show any significant influence on protein content and protein yield. The effect of tillage practices also remained mostly insignificant on the uptake of N and P by the grain but K uptake by grain was significant. However, uptake of P and K by stover was found significantly higher under no-tillage treatment.

Effect of liming on performance of rice-based cropping systems

When the performance of the system was evaluated, liming to rice crop improved rice equivalent yield (REY) of the system by 6.6% and water-use efficiency (WUE) by 11.2% over no liming. There was 6.3% (Table 3) increase in partial factor productivity (PFP) of the system owing to liming on rice, though it was insignificant. Since liming treatment resulted increase in grain yield of rice as well as seed yield of rapeseed and lathyrus, REY was also increased. Since WUE and PFP were calculated based on the REY, their trend was also closely related to REY. The system efficiency was also assessed through land-use efficiency (LUE), production efficiency (PE) and nutrient-use efficiency (NUE). Liming did not produce any significant change in LUE and PE, as the total crop duration of the sequence was not affected by lime application. However, liming resulted in higher productivity of the system by a margin of 1.72 kg/ha/day over no-lime application. Higher NUE (74.7%) was obtained from liming to rice crop than no-liming treatment (70.18%). However, liming did not enhance P-and K-use efficiencies of the system.

Effect of planting time on performance of rice-based cropping systems

Advancement of rice planting by 15 days resulted in the advancement of sowing time of *rabi* crops in the sequence for a similar period (Table 3). Because of this advancement of planting time, the system productivity in terms REY was greatly increased (16.6%). This was simply because of positive effect of early planting on all the compo-

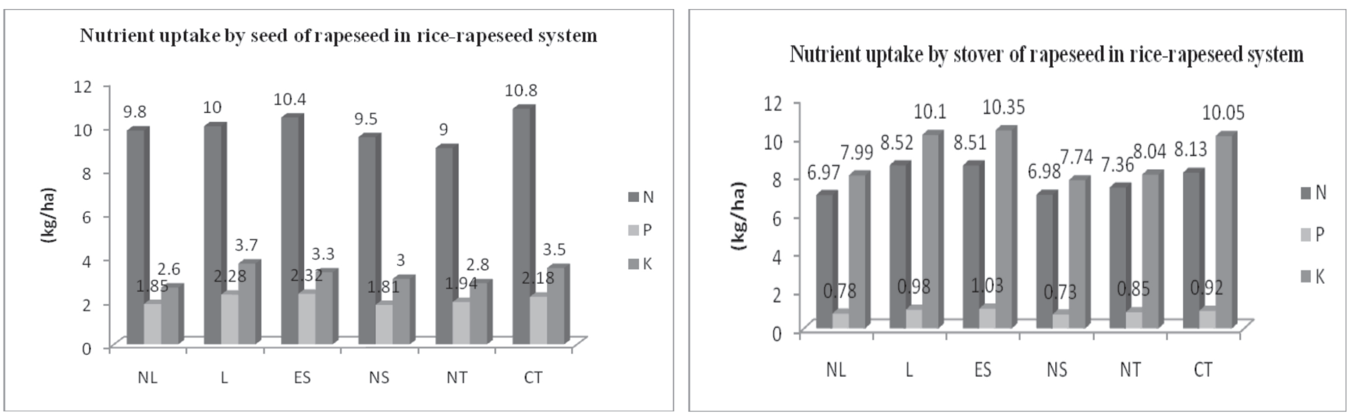

Fig. 3. Nutrient uptake (kg/ha) of rapeseed in rice–rapeseed system as influenced by liming and planting time to rice and tillage practices to rapeseed

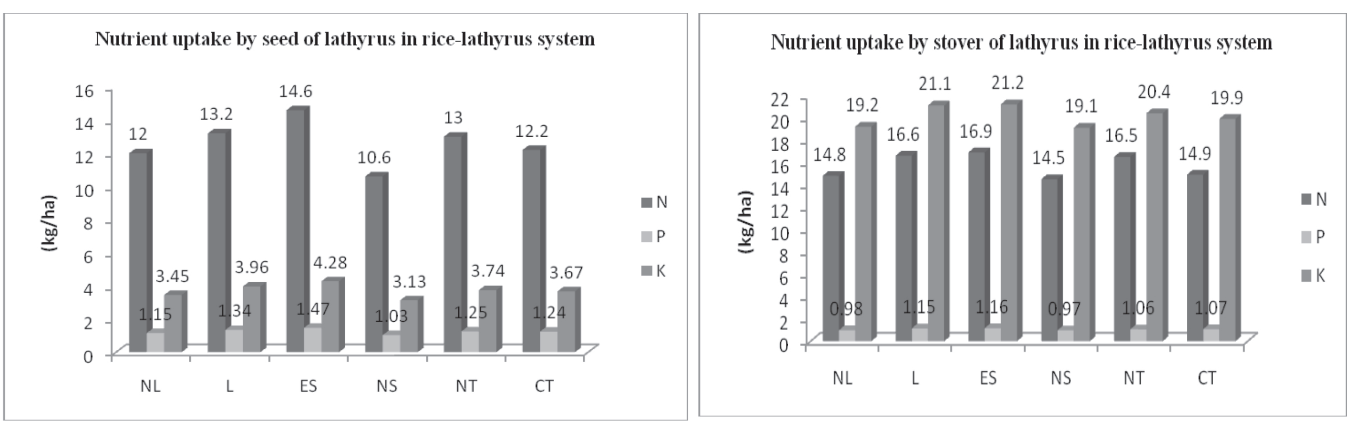

Fig. 4. Nutrient uptake (kg/ha) of lathyrus in rice-lathyrus system as influenced by liming and planting time to rice and tillage practices to lathyrus

(NL, No liming; L, liming; ES, early sowing; NS, normal sowing; NT, no tillage; CT, coventional tillage)

Table 3. Efficiency indices, productivity and profitability of rice-based cropping system as influenced by liming and planting time to rice and tillage practices to rapeseed and lathyrus (pooled data of 2 years)

Treatment	Land-use efficiency (%)	Production efficiency (kg/ha/day)	Nutrient-use efficiency (kg REY/kg of nutrient applied)			Water-use efficiency (kg/ha-mm)	Partial factor productivity (kg grain/kg NPK)	Rice equivalent yield (t/ha)	Cost of cultivation (×10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Benefit: cost ratio
			N	P	K						
Liming											
No liming	62.2	26.2	70.2	113.2	152.6	18.0	26.6	5.91	31.9	36.1	1.15
Liming	62.2	28.0	74.7	120.6	162.5	20.0	28.3	6.30	36.4	36.0	1.00
SEm±	–	0.6	1.6	2.5	3.4	0.5	0.7	0.13	–	1.5	0.04
CD (P=0.05)	–	NS	5.4	NS	NS	1.7	NS	0.45	–	NS	0.14
Planting Time											
Early	63.1	28.8	78.1	126.1	170.0	19.1	29.5	6.57	34.2	41.4	1.24
Normal	61.3	25.4	66. 8	107.7	145.0	18.9	25.4	5.63	34.2	30.6	0.91
SEm±	–	0.6	1.6	2.5	3.4	0.5	0.7	0.13	–	1.5	0.04
CD (P=0.05)	–	2.0	5.4	8.7	11.8	NS	2.4	0.45	–	5.1	0.14
Tillage											
NT	62.1	27.1	76.1	152.2	202.9	19.2	31.8	6.09	31.5	38.6	1.23
CT	62.3	27.1	68. 8	81.6	112.1	18.8	23.1	6.12	36.9	33.5	0.91
SEm±	–	0.1	0.3	1.1	1.5	0.05	0.1	0.03	–	0.3	0.01
CD (P=0.05)	–	NS	1.1	3.7	4.8	0.16	0.3	NS	–	1.0	0.03
Rabi crops											
Rapeseed	60.1	27.8	68.0	125. 8	160.9	18.6	27.5	6.05	33.0	36.6	1.12
Lathyrus	64.2	26.4	76. 9	108.0	154.2	19.5	27.5	6.15	35.3	35.5	1.02
SEm±	–	0.1	0.4	0.8	1.0	0.05	0.07	0.03	–	0.4	0.01
CD (P=0.05)	–	0.4	1.3	2.3	3.0	0.15	NS	0.09	–	1.1	0.03

nent crops in the sequence. Significantly higher system WUE of 19.12 kg/ha-mm obtained under early planting than normal sowing (18.92) could be attributed to lower evapotranspiration resulting from more soil-water retention during the *rabi* crop growing season. Hence early planting could be noted as superior in terms of water use under the moisture-stress situation. Since early planted crops in the system yielded higher than normal planted crop with same level of nutrient use, PFP for nutrient use was also higher under early planting. The LUE was recorded higher under early planting than normal planting. This was owing to higher crop duration which in turn recorded the highest LUE and efficient utilization of land over normal planting. Similarly, N-, P-and K-use efficiencies were higher under early planting.

Effect of tillage on performance of rice-based cropping systems

The system productivity in terms of REY was significantly affected by tillage treatments as because, both the *rabi* crops to which tillage treatments were applied resulted in significantly higher seed yields (Table 3). However, no tillage (NT) was found to be superior to conventional tillage (CT) in terms of WUE and PFP for nutrient use, as it recorded significantly higher values of WUE and PFP over CT. One reason for higher PFP under no tillage might be the lower dose of fertilizer nutrients received by the treatment. Tillage treatment had significant effect on production efficiency, but there is no change in LUE due to same crop duration of the cropping system.

Effect of rabi crops on performance of rice-based cropping systems

Two *rabi* crops rapeseed and lathyrus were grown after rice crop in the sequence. Rice–rapeseed cropping sequence recorded significantly higher REY than rice–lathyrus sequence owing to higher average seed yield of rapeseed (0.54 t/ha) than lathyrus (0.34 t/ha). Mondal *et al.* (2004) reported significantly highest rice-equivalent yield under rice–linseed as *utera* followed by rice–lathyrus *utera* cropping system. Significantly higher WUE of rice–lathyrus sequence over rice–rapeseed sequence were recorded. This might be due to less water requirement by lathyrus crop than rapeseed crop. There was no significant effect on PFP of the crops. Higher LUE was recorded from rice–lathyrus sequence than rice–rapeseed sequence indicating that land was efficiently utilized under rice–lathyrus cropping system (Table 3).

Interaction effects

The significant interaction effect between planting time and tillage on REY of the cropping system could be attributed to seed yield of rapeseed in no-tilled soil under early planting, wherein CT was found better under normal planting. Early planting favoured both the *rabi* crops in the sequence, but lathyrus was superior to rapeseed. Rapeseed preferred CT more than NT, but lathyrus could perform at par with both tillage practices (Table 4). Mondal *et al*. (2004) observed better yield of lathyrus as *utera* crop comparing to conventional tillage. Under early planting, either of the tillage practices and either of the *rabi* crops in the crop sequence could perform at par, might be due to the fact that major advantage of NT is advancement of planting time which might have been suppressed by the earliness given in the planting time treatment itself. Under normal planting time, lathyrus with NT performed comparable to rapeseed with CT. It was an indicative of preferential adaptation of the crops to different tillage systems.

Table 4. Interaction effects on rice-equivalent yield (t/ha) of the cropping system (pooled data of 2 years)

Tillage practices	Crop	
	Rapeseed	Lathyrus
NT	5.98	6.20
CT	6.13	6.10
SEm±	0.05	
CD (P=0.05)	0.15	
Planting time	**Tillage practices**	
	NT	CT
Early	6.62	6.52
Normal	5.56	5.71
SEm±	0.04	
CD (P=0.05)	0.13	
Planting time	**Crop**	
	Rapeseed	Lathyrus
Early	6.45	6.69
Normal	5.65	5.61
SEm±	0.05	
CD (P=0.05)	0.15	

NT, No tillage; CT, conventional tillage

Energy analysis of the systems

Liming treatment to rice recorded higher system-energy input than no liming. However, liming did not have pronounced influence on total energy output and energy productivity of the system. No difference in energy-input requirement of the system due to different planting times was noted. System maximum total energy output was produced under early planting and the least value under normal planting time. This might be due to higher grain and by-products yields of both the component crops obtained under early planting. Early planting emerged as the most efficient in energy use with highest energy productivity of 0.843 kg/MJ and energy intensiveness of 5.402 MJ/₹. The highest input energy was consumed by CT and the lowest was required by NT practices. Compared to NT, energy input of CT was higher by 12.39%. This could be attributed to more tillage operations under CT during the *rabi* crop season. Though gross energy output was more in CT, net energy output was maximum under NT. This might be due to fewer amounts of inputs required under NT. Maximum energy-use efficiency and energy intensity in economic terms were recorded under NT. This mainly owed to use of less energy input under NT. The CT registered the lowest values of energy-use efficiency and energy intensity in economic terms. Lower value of energy-use efficiency was due to higher energy input requirement for tillage operation and chemical fertilizer especially N (Table 5). Jha *et al*. (2011) reported similar results. The energy input, gross energy output and net energy output were marginally higher by 1.06%, 0.79% and 0.76%, respectively, under rice–rapeseed cropping system than rice–lathyrus cropping system. Energy-use efficiency of both the systems did not differ statistically. Maximum energy intensity in economic terms was recorded under rice–rape-

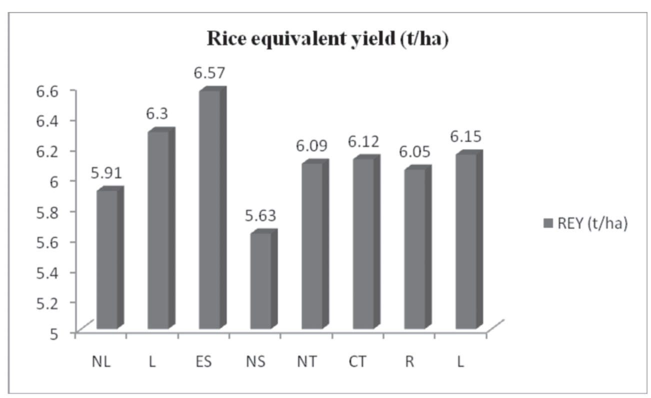

Fig. 5. Effect of liming and planting time to rice and tillage practices to rapeseed on rice-equivalent yield (REY) t/ha (pooled) (NL, No liming; L, liming; ES, early sowing; NS, normal sowing, NT, no tillage; CT, conventional tillage)

Table 5. Effect of liming and planting time to rice and tillage practices to rapeseed and lathyrus on energy-use efficiency of rice-based cropping systems (pooled mean data of 2 years)

Treatment	Energy input (× 10^3 MJ/ha)	Gross energy output (× 10^3 MJ/ha)	Net energy output (× 10^3 MJ/ha)	Energy-use efficiency (%)	Energy productivity (kg/MJ)	Energy intensity in physical terms (MJ/kg)	Energy intensity in economic terms (MJ/₹)
Liming							
No liming	15.94	168.96	153.02	10.75	0.782	0.953	5.274
Liming	16.27	179.15	162.88	11.10	0.807	1.017	4.878
SEm±		3.65	3.65	0.23	0.017	0.020	0.147
CD (P=0.05)		NS	NS	NS	NS	NS	NS
Planting Time							
Early	16.11	184.62	168.51	11.60	0.843	0.952	5.402
Normal	16.11	163.49	147.39	10.25	0.747	1.018	4.750
SEm±		3.65	3.65	0.23	0.017	0.020	0.147
CD (P=0.05)		12.63	12.63	0.80	0.059	NS	0.509
Tillage							
NT	15.17	173.32	158.15	11.59	0.844	0.909	5.353
CT	17.05	174.79	157.74	10.25	0.745	1.060	4.799
SEm±		0.30	0.30	0.03	0.002	0.003	0.101
CD (P=0.05)		0.98	0.98	0.10	0.007	0.010	0.329
Rabi_crops							
Rapeseed	16.19	174.74	158.55	10.93	0.789	0.991	5.412
Lathyrus	16.02	173.37	157.35	10.92	0.801	0.978	5.010
SEm±		0.35	0.35	0.02	0.002	0.002	0.100
CD (P=0.05)		1.05	1.05	NS	0.006	0.006	0.300

NT, No tillage; CT, conventional tillage

seed cropping system. This was mainly due to more dry-matter yield of rapeseed in the system which led to more energy generation. The lathyrus required high amount of input i.e. seed and this input, contributed to most of the input energy requirement.

System economics

Application of liming was found not to be a profitable business in terms of net returns and benefit: cost ratio (Table 3). Though liming recorded significantly higher amount of gross return over no liming, but it failed to record even higher benefit: cost ratio than no liming. High cost incurred on purchasing liming materials and its application and not so much impressive increase in yield due to liming made the treatment non-remunerative. The early planting was also found to be more remunerative, as evident from higher net returns along with higher benefit: cost ratio than normal planting. The NT also recorded significantly higher net returns and benefit: cost ratio over CT, as less cost of cultivation was incurred. The rapeseed crop in the sequence was found to be more remunerative in terms of net return (₹36,581/ha) and benefit: cost ratio than lathyrus crop in the sequence, because higher cost of cultivation mainly seed cost incurred by lathyrus crop. Singh *et al.* (2002) reported the highest benefit: cost ratio in rice–mustard cropping sequence in eastern Uttar Pradesh.

Advancing the planting time of rice from the first week of July to middle of June had pronounced effect on growth, productivity and profitability of the rice-based cropping systems in rainfed lowland agro-ecosystem. Establishment of *rabi* crops under conventional tillage was found better under normal planting time, whereas both the conventional and no-tillage practices performed at par under early planting in terms of system productivity. Rapeseed could be chosen as *rabi* crop in the rice-based cropping system under normal planting time of rice and conventional tillage to rapeseed considering productivity and profitability of the system. Alternatively, lathyrus could be chosen as *rabi* crop in the rice-based cropping system in lowland under early planting time of rice and no tillage considering gross system productivity and use of nutrient and water by the system.

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