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Substitution of mineral fertilizer in transplanted rice through nutrient and weed management with herbicide-*comlizer* mixture

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ABSTRACT

Field experiments were conducted to evaluate the effect of herbicide-compost-fertilizer mixture on nutrient supply and efficacy of herbicide in different transplanted rice ecosystems, e.g. *Sali*, *boro* and *ahu* rice. Biofertilizer-incubated vermicompost 2 t ha^{-1} and 60, 75 and 90% of recommended fertilizer doses instant mixture (*comlizer*) were compared with recommended practice for nutrient (RP) and weed management in rice crop. The 60%RFD-VC (*comlizer*-60), 75%RFD-VC (*comlizer*-75) and 90%RFD-VC (*comlizer*-90) were applied at 3, 30 and 60 days after transplanting (DAT) of rice seedlings and pretilachlor 750 g ha^{-1} was applied by mixing with the *comlizer* at 3 DAT (P) followed by one hand weeding at 30 DAT (HW). The *comlizer* treatments were compared with unfertilized (UF) + pretilachlor applied as sand mixture [UF-P(S)-HW], RP without weed management (weedy) [RP-weedy], RP with recommended weed management practice [RP-P(S)-HW], and RP + pretilachlor as compost mixture + HW [RP-P(M)-HW]. The population of bacteria in the vermicompost significantly reduced due to mixing with fertilizer, but the same was unaffected by herbicide mixing with *comlizer*. Hand weeding at 30 DAT following use of herbicide, irrespective of application with sand, compost or *comlizer*, significantly reduced weed density and dry weight at 30 and 60 DAT compared to weedy. Application of *comlizer*-75(P)-HW recorded longest panicle length, highest filled grains panicle^{-1}, grain yield, and nutrient uptake (N, P, K) by rice crop. The available P and K contents differed significantly due to the fertilizer treatments. Irrespective of rice crops, *comlizer*-75(P)-HW recorded highest benefit over per rupee invested for cultivation.

Keywords: Compost-fertilizer mixture, Compost enrichment, Biofertilizer, Puddle rice

INTRODUCTION

Transplanted rice occupies highest cultivated area among the different rice ecosystems in Assam, and except summer (*bodo*) rice the crop is grown under rainfed condition. Weed management in transplanted rice becomes a major challenge under intermittent flooding (Tuong *et al.,* 2005), especially in rainfed areas owing to rainfall aberrations. The approach to weed management in transplanted rice had changed with increasing reliance on herbicides, than mechanical or manual methods, due to non-availability and wage hike of agricultural labour. However, the efficacy of herbicide varies depending upon the methods adopted for herbicide application with standing water in the field just after transplanting. The area under high yielding variety of *Sali*, *boro* and *ahu* rice has increased little more than five times during 2007-08 to 2016-17

(Anonymous, 2019) with a remarkable corresponding increase in commercial fertilizer consumption in Assam. Loss of both native and applied plant nutrients from soil through leaching and runoff water has gained importance in recent years (Cao *et al.*, 2004; Wang *et al.*, 2004; Tian *et al.*, 2007) and reduction in fertilizer rate especially at early growth stage had been suggested as possible option to curb it (Tian *et al.*, 2007). The judicious use of plant nutrients is one of the factors for high productivity in system of rice intensification (Stoop *et al.*, 2002). Split application of reduced doses of fertilizer as mixture with compost (*comlizer*) before application had been shown to improve yield and curtail cultivation cost under upland condition (Uddin, 2012). Similar success in transplanted rice would reduce both consumption of and investment in commercial chemical fertilizers. Besides, addition of lower than recommended dose of fertilizers with compost may facilitate enhancing or sustain soil fertility. Feasibility of applying herbicide by mixing with *comlizer* offers an area of interest in terms of its effectiveness and saving of manpower. Accordingly, the present investigation was planned to evaluate herbicide-compost-fertilizer mixture on weed intensity, growth and yield of transplanted rice crops and soil fertility.

MATERIALS AND METHODS

Location and season

The field experiments were conducted in the Instructional cum Research farm of Assam Agricultural University, Jorhat, Assam during July 2012 to June 2013.

Transplanted rice was grown in three different seasons, viz. winter rice locally known as *Sali* rice with June/July sowing followed by transplanting in July/August, summer rice with sowing time November to December followed by transplanting in January to February (*Boro* rice), and autumn rice that is sown in February/March and transplanted in the main field during late March/April (*Ahu* rice). The variety used, seedling age, dates of transplanting and harvest, spacing and recommended fertilizer dose for each rice crop and physico-chemical properties of the soils of the experimental sites are shown in Table 1.

Experimental design and treatments

The experiment was conducted with individual plot size of 5m x 3m in a completely randomized block design with seven treatments, each replicated thrice. The different treatments for weed and nutrient management were – unfertilized (UF) + pretilachlor 750 g ha^{-1} as sand mixture [P(S)] + hand weeding at 30 DAT (HW) [UF-P(S)-HW], recommended fertilizer dose (RFD) with farmyard manure (FYM) 2 t ha^{-1} (RP) without weed management [RP – weedy], RP-P(S)-HW, RP + pretilachlor 750 g ha^{-1} as vermicompost (200 kg ha^{-1}) mixture P(M) + HW [RP-P(M)-HW], 60% RFD-vermicompost 2 t ha^{-1} (VC) mixture at 3, 30 and 60 DAT (*Comlizer*-60), pretilachlor 750 g ha^{-1} mixed with the first split (P) + HW [*Comlizer*-60(P)-HW], 75%RFD-VC mixture at 3, 30 and 60 DAT (*Comlizer*-75) + (P) + HW

Table 1. Physico-chemical properties of soils of the experimental sites and other technical details

Parameter	*Sali* rice	*Boro* rice	*Ahu* rice
Texture	cl	scl	scl
pH	5.2	5.4	5.4
Organic carbon (g kg^{-1})	6.1	8.1	8.2
Available N (kg ha^{-1})	188.0	282.5	202.6
Available P (kg ha^{-1})	6.4	9.2	5.6
Available K (kg ha^{-1})	120.5	128.2	125.3
NH_4-N (mg kg^{-1})	42.1	38.6	46.2
NO_3-N (mg kg^{-1})	12.5	15.8	14.6
Variety	Ranjit	Kanaklata	Luit
Date of transplanting in the main field	11-08-12	05-02-13	10-04-13
Age of seedlings at transplanting (days)	25	20	25
Spacing (row x plant) cm	20 x 15	20 x 20	20 x 15
Recommended fertilizer dose [N:P_2O_5:$K_{-2}O$ (kg ha^{-1})]	60:20:40	40:20:20	40:20:20
Date of harvest	24-12-12	05-06-13	21-06-13
Previous crop	Fallow	*Sali* rice	*Sali* rice

[*Comlizer*-75(P)-HW], 90%RFD-VC mixture at 3, 30 and 60 DAT (*Comlizer*-90) + (P) + HW [*Comlizer*-90(P)-HW].

The pre-emergence herbicide pretilachlor was applied at 3 DAT. In case of RFD, the P and K fertilizers and half of N fertilizer were applied at the time of transplanting and the other half of N fertilizer in two equal splits at 25 days after transplanting and at panicle initiation stage. Vermicompost was incubated with *Azospirillum* and phosphate solubilizing bacteria (PSB) culture (10^5 to 10^7 cfu g^{-1}) 2 g kg^{-1} of compost for two weeks (25±1%, w/w moisture content) and used for application in various treatments. Requisite quantities of fertilizers were mixed with biofertilizer-incubated compost before application. The single super phosphate (SSP), used as P fertilizer, was mixed first with vermicompost. The muriate of potash (MOP) and urea were added to the vermicompost-SSP mixture one by one, as sources of N and K, respectively. In each instance, required quantity of fertilizer was added to a smaller amount of compost or compost-fertilizer mixture, and the same was then added to the rest of compost or compost-fertilizer mixture. In case of comlizer, the herbicide was mixed once the sequential mixing of the fertilizers with vermicompost had been completed. The *comlizer* or herbicide-*comlizer* was applied in the field immediately, without delay or storage, once the mixing process was completed.

Weed density and dry weight

A 50 cm x 50 cm quadrate was placed randomly in each plot at 30 and 60 days after transplanting (DAT) of rice crop in each season, and the weeds inside the quadrate were collected for further observation. The species-wise count was made and the value was converted into number per square metre. The weight of weeds for each species, after oven during at 55±1 ^{0}C till constant weight, was recorded and expressed as gram per square metre.

Nutrient uptake by weed and crop

The samples of weed and crop, collected at various growth stages, were analysed for total nutrient concentration (N, P and K) following procedures outlined elsewhere (Baruah and Barthakur, 1996). The nutrient uptake by weed or crop was calculated using nutrient concentration and weed dry weight or crop dry matter accumulation (grain + straw), and expressed as g ha^{-1} or kg ha^{-1}, respectively.

Growth, yield attributes and yields of crops

At the time of harvest, five hills were collected through random selection. The lengths of the panicles were measured and the number of panicles and the number of grains were counted in each hill. The mean value for each parameter was calculated from the observations recorded for five hills. The number of panicles m^{-2} was recorded by placing a 50 cm x 50 cm quadrate randomly in each plot and the panicles were counted and converted into per m^2. The grain yield and straw yield were obtained by harvesting the crop in a plot excluding the border rows, and expressing the result as kg ha^{-1}.

Vermicompost and comlizer analysis

The vermicompost in each season was analyzed for total nutrient content following standard protocol. The bacterial count was done in the compost before and after inoculation with biofertilizer cultures, and in the *comlizer* after mixing with fertilizer following standard procedures and as reported elsewhere (Borah *et al.*, 2014; Borah *et al.,* 2017). The samples for vermicompost, *comlizer* or herbicide-*comlizer* were analysed in triplicate and the data were analyzed in a completely randomized design for statistical significance among the treatment means.

Soil sampling and analysis

Representative surface (0-15 cm) soil samples were collected from individual plots at specific crop growth stages, and processed and analysed for various parameters following methods described by Baruah and Barthakur (1996). The ammonical nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) in soil were estimated in a 1 N Na_2SO_4-phenylmercuric acetate extract using a uv-*vis* spectrophotometer (Onken and Sunderman, 1977).

Statistical analysis

A one way ANOVA was calculated to verify the significance of the difference between treatment means at 5% probability level ($P < 0.05$) using SPSS computer software for Windows (version 9.05).

RESULTS AND DISCUSSION

Quality of *comlizer*

The various parameters of *comlizer* (compost-fertilizer mixture) and herbicide-*comlizer* mixture are presented in Table 2. Inoculation PSB and *Azospirillum* biofertilizer into vermicompost significantly increased the population of bacteria after 15 days incubation. The pH of the vermicompost remained unaffected due to incubation with bacteria or mixing with fertilizer and herbicide. The population of *Azospirillum* and PSB significantly decreased after mixing with mineral fertilizer (*comlizer*), irrespective of their doses. Among the *comlizers*, the lowest population for both the bacteria was recorded for 90%comlizer. Mixing of pretilachlor with *comlizer* further reduced population of both the bacteria, but the difference was not significant. Similar decline in the population of bacteria after mixing of vermicompost with mineral fertilizer was earlier reported (Borah *et al*., 2020), which was ascribed to toxicity of urea to microbes through complex undefined mechanism (Veverka *et al*., 2007). Contrary to that, ammonium addition had been shown to have little effect on the composition of the microbial community during 28 days of incubation (Avrahami *et al.,* 2003*a*), but resulted in community shifts after 16 weeks of incubation (Avrahami *et al.,* 2003b).

Weed flora, density and dry matter accumulation

Weed flora

Alternathera philoxeroides (Mart.) Griseb., *Marsilea minuta* L. among the broadleaved, *Echinochloa crusgalli* (L.), *Sacciolepis interrupta* (Willd.) Stapf among the grasses and *Cyperus iria* L., *Scirpus juncoides* Roxb. among the sedges dominated the weed flora both at 30 and 60 DAT in all the rice ecosystems. Similar weed flora in transplanted rice ecosystem and aquatic environment of the state had been observed in our previous work (Deka *et al*., 2013). Fragmentation of stolons was reported to enhance *Alternathera philoxeroides* sprouting irrespective of burial orientation and node number (Peng *et al*., 2017) and the relative abundance of the weed observed in this study may be ascribed to this phenomenon.

Echinochloa spp. have ability to germinate both under aerobic and anaerobic environment, while germination of *Scirpus* spp. is enhanced in anaerobic condition following burial (Pons *et al*., 1982), which might be the reasons for their observed abundance under different rice ecosystems in the present study. The absence of otherwise common species like *Fissendocarpa linifolia* (Vahl) Bennet., *Paspalum conjugatum* P.J. Bergius and *Isachne himalaica* Hook. f. was also observed in our earlier work due to shift in weed flora over time with crop management practices (Rajkhowa *et al*., 2006). On the other hand, the absences of weeds like *Monochoria vaginalis* (Burm. f.) C. Presl, *Leersia hexandra* Swartz., and *Eleocharis acutangula*(Roxb.) Schult in boro rice were attributed to seasonal variation in germination (Chen and Kuo, 1999) due to temperature (Athira *et al*., 2019) and water regime (Juraimi *et al*., 2012) fluctuations. The diversity and specificity of weed flora in different rice ecosystems was due to differences among the species in seed size (Sonkoly *et al*., 2020) and habitat.

Table 2. Changes# in pH and population (–log 10^{-5} cfu g^{-1}) of *Azospirillum* and phosphate solubilizing bacteria (PSB) of vermicompost after mixing with fertilizer and/or herbicide

Treatment	pH (1:2.5)		PSB		*Azospirillum*	
	Sali	*Boro/ Ahu*	*Sali*	*Boro/ Ahu*	*Sali*	*Boro/ Ahu*
Vermicompost (pre-incubation)	5.35	5.12	18.3	20.5	5.8	7.1
Vermicompost (post-incubation)	5.05	5.18	28.3	26.8	9.8	10.2
Comlizer-60	5.27	5.23	20.2	20.5	6.8	6.4
Comlizer-75	5.41	5.36	20.0	20.8	6.9	6.3
Comlizer-90	5.31	5.36	17.0	16.6	5.4	5.2
P(M)	5.16	5.11	25.2	24.6	7.4	8.8
Comlizer-60(P)	5.45	5.26	20.1	20.2	6.6	6.3
Comlizer-75(P)	5.18	5.32	19.8	19.6	6.5	6.3
Comlizer-90(P)	5.47	5.34	16.6	15.2	5.1	5.0
$CD_{P = 0.05}$	NS	NS	2.7	3.2	0.8	1.1
CV (%)	2.1	3.6	8.6	9.8	8.2	10.1

#One hour after mixing of fertilizer or herbicide or both

Table 3. Diversity of weed flora in different rice crops

Sali (winter) rice	Boro (summer) rice	Ahu (autumn) rice
	30 days after transplanting	
Broadleaved weeds	**Broadleaved weeds**	**Broadleaved weeds**
Monochoria vaginalis (Burm. f.) C. Presl, *Sagittaria guayanensis* (D. Don) Bogin, *Alternathera philoxeroides* (Mart.) Griseb., *Marsilea minuta* L.	*Alternanthera philoxeroides* (Mart.) Griseb., *Cuphea balsamona* Cham. & Schltdl., *Eichhornia crassipes* (Mart.) Solms., *Hydrolea zeylanica* (L.) Vahl, *Marsilea minuta* L.*Spilanthes paniculata* Wall. *ex* DC.	*Marsilea minuta* L., *Monochoria vaginalis* (Burm. f.) C. Presl, *Alternanthera philoxeroides* (Burm. f.) C. Presl
Grasses	**Grasses**	**Grasses**
Echinochloa crusgalli (L.) Beauv., *Leersia hexandra* Swartz., *Sacciolepis interrupta* (Willd.) Stapf	*Echinochloa crusgalli* (L.) Beauv., *Sacciolepis interrupta* (Willd.) Stapf	*Echinocloa crusgalii* (L.) Beauv., *Sacciolepis interrupta* (Willd.) Stapf, *Leersia hexandra* Swartz.
Sedges	**Sedges**	**Sedges**
Cyperus iria L., *Scirpus juncoides* Roxb., *Eleocharis acutangula* (Roxb.) Schult	*Cyperus iria* L., *Scirpus juncoides* Roxb.	*Eleocharis accutangula* (Roxb.) Schult, *Cyperus iria* L.*Scirpus juncoiides* Roxb.
	60 days after transplanting	
Broadleaved weeds	**Broadleaved weeds**	**Broadleaved weeds**
Alternathera philoxeroides (Mart.) Griseb., *Marsilea minuta* L.	*Alternanthera philoxeroides* (Mart.) Griseb., *Cuphea balsamona* Cham. & Schltdl., *Eichhornia crassipes* (Mart.) Solms., *Hydrolea zeylanica* (L.) Vahl, *Marsilea minuta* L.*Spilanthes paniculata* Wall. *ex* DC.	*Cuphea balsamona* Cham. & Schltdl., *Hydrolea zeylanica* (L.) Vahl, *Eichhornia crassipes* (Mart.) Solms., *Marsilia minuta* L., *Spilanthus peniculata* Wall. *ex* DC., *Alternanthera philoxeroides* (Mart.) Griseb.
Grasses	**Grasses**	**Grasses**
Echinochloa crusgalli (L.) Beauv., *Leersia hexandra* Swartz., *Sacciolepis interrupta* (Willd.) Stapf	*Echinochloa crusgalli* (L.) Beauv., *Sacciolepis interrupta* (Willd.) Stapf	*Echinocloa crusgalii* (L.) Beauv., *Sacciolepis interrupta* (Willd.) Stapf
Sedges	**Sedges**	**Sedges**
Cyperus iria L., *Scirpus juncoides* Roxb., *Eleocharis acutangula* (Roxb.) Schult	*Cyperus iria* L., *Scirpus juncoides* Roxb.	*Cyperus iria* L., *Scirpus juncoides* Roxb.

Weed density and dry weight

The weed population and dry matter accumulation per unit area in rice crops are presented in Table 3 and 4, respectively. Irrespective of methods, pretilachlor 750 g ha^{-1} with hand weeding at 30 DAT significantly reduced number of weed density compared to weedy plot (Table 3). There was no significant difference in weed density among the weed management practices, except for higher weed density at 30 DAT in *boro* rice due to *comlizer* application. The observed difference in *comlizer* applied plots compared to unfertilized plot was due to population of *Cyperus iria* L. and *Scirpus juncoides* Roxb. (data not presented here).

Cyperus inflexus seeds were reported usually to remain dormant at maturity during autumn and germinate during early summer post ripening during winter season (Baskin and Baskin, 1978). On the other hand, storage of seeds under moist-cool environment in comparison to dry-warm or dry-cool environment was reported to enhance germination of *Scirpus* spp (Larson, 1997). This might be the reason for observed higher population of *Scirpus juncoides* and *Cyperus iria* in *boro* rice, transplanted succeeding a cool and moist soil condition, compared to *Sali* and *ahu* rice, where the ambient temperature was higher prior to and post transplanting period. Composting of cattle manure through vermicomposting method increased germination of *Rumex obtusifolius* seeds compared to conventional or biodynamic method (Zaller, 2007) and the same might had influenced relatively higher emergence of weeds in the *comlizer* treatments.

The dry weight significantly decreased due to weed management practice compared to weedy plot, irrespective of rice ecosystems or growth stages (Table 4). Among the methods of herbicide application, no difference in weed dry weight was recorded between pretilachlor-sand and pretilachlor-compost mixture, while applying it with *comlizer* caused significant variation with sand or compost mixture in few occasions.

The species-wise distribution of weed dry weight at 30 DAT and 60 DAT in different rice crops is depicted in Fig. 1 and 2 (a, b, c). Irrespective of the treatments, the percent share of total weed dry weight

Table 3. Weed density (number m^{-2}) at various crop growth stages in different rice crops

Treatments	Weed density at 30 DAT			Weed dry weight at 60 DAT		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	28.0	18.3	16.0	18.3	39.7	21.0
RP-weedy	110.7	36.3	33.3	86.3	64.7	49.3
RP-P(S)-HW	27.3	21.7	15.7	21.0	40.3	20.7
RP-P(M)-HW	27.7	16.7	22.0	17.0	34.7	19.7
Comlizer-60(P)-HW	31.7	25.7	18.0	22.7	39.0	20.3
Comlizer-75(P)-HW	29.0	27.0	18.0	18.7	37.7	23.7
Comlizer-90(P)-HW	29.3	24.7	20.3	24.7	40.3	26.0
$CD_{P = 0.05}$	8.7	5.5	4.8	5.5	6.2	6.6
CV (%)	12.9	9.9	13.8	10.9	9.6	14.7

Table 4. Weed dry weight (g m^{-2}) at various crop growth stages in different rice crops

Treatments	Weed dry weight at 30 DAT			Weed dry weight at 60 DAT		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	21.9	17.2	11.8	12.3	27.4	17.9
RP-weedy	69.1	43.7	20.0	74.8	58.8	48.3
RP-P(S)-HW	25.2	19.7	12.9	14.5	26.0	19.3
RP-P(M)-HW	23.1	16.9	16.9	16.0	23.3	18.4
Comlizer-60(P)-HW	19.7	19.2	15.2	17.5	26.0	21.2
Comlizer-75(P)-HW	17.8	18.7	14.3	12.5	25.2	17.8
Comlizer-90(P)-HW	23.7	19.5	15.7	18.4	25.6	22.7
$CD_{P = 0.05}$	7.1	3.2	4.1	5.0	4.5	3.3
CV (%)	14.9	9.6	15.8	15.6	9.7	7.7

in *Sali* and *boro* rice at 30 DAT and in all rice crops at 60 DAT was relatively higher for broadleaved weeds (Fig 1 and 2). In *ahu* rice at 30 DAT grasses shared relatively higher proportion of total weed dry weight (Fig 1c). In *boro* rice, the percent share of weed dry weight was relatively higher both at 30 and 60 DAT (Fig 1b and 2b). Application of *comlizer*-75(P)-HW recorded relatively equal proportions of BLW, grass and sedges, irrespective of growth stages and rice crops (Fig 1 and 2).

Paul and Banerjee (2007) and Saha and Rao (2012) observed dominance of broadleaf weed followed by sedges at 30 DAT which shifted to dominance of grasses at later stage of crop growth. In *boro* and *ahu* rice the percent share of grasses in the total weed dry weight was relatively higher than *Sali* rice both at 30 and 60 DAT. The *boro* and *ahu* rice after transplanting was subjected to intermittent flooding due to less rainy days and rainfall intensity compared to *Sali* rice. Dorji *et al*. (2013) reported decline in biomass accumulation of weeds with increase in flooding depth and pretilachlor dose (300 g ha^{-1}), which might be the reason for proportionate lower weed dry weight recorded for grasses at 30 DAT in *Sali* rice with uniform flooding depths compared to *boro* and *ahu* rice.

Majrashi *et al.* (2012) observed that sedges like *Scirpus grossus* L. showed better growth with application of fertilizer than unfertilized soil which might explain the relatively higher dry weight of sedges both at 30 and 60 DAT. Flooding after herbicide application or weeding or hoeing could help reduce future weed growth or once the canopy of rice has closed, shading and interference from the crop are likely to suppress weed growth (Chauhan, 2012). In the present study, application of *comlizer*-75(P)-HW had positive effect on weed control *vis-à-vis* crop growth and resulted in significant decrease in nutrient uptake by weeds compared to other treatments.

Nutrient uptake by weeds

The nutrient uptake by weeds at 30 DAT and 60 DAT is presented in Fig. 3 (a, b), 4 (a, b) and 5 (a, b) for nitrogen, phosphorous and potassium, respectively. The highest uptake of N, P and K was recorded in weedy plot and differed significantly to the rest of the treatments both at 30 and 60 DAT in all the rice crops. The lowest uptake of nutrients at was observed due to application of *comlizer*-75(P)-HW both at 30 and 60 DAT, which was at par with

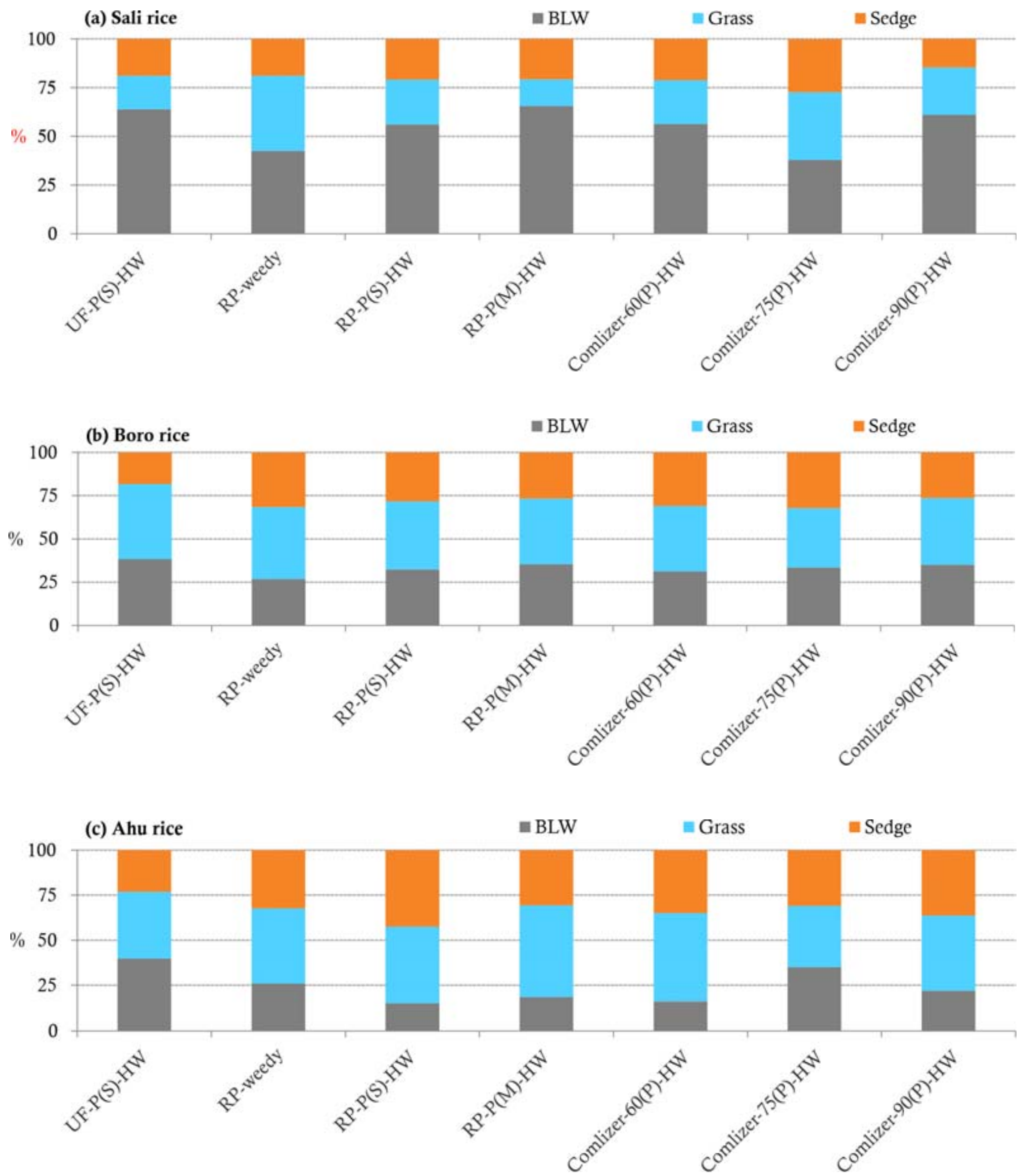

Figure 1. Percent share of total weed dry weight at 30 DAT among the broadleaved weed (BLW), grasses and sedges in (a) *Sali*, (b) *Boro* and (c) *Ahu* rice

UF-P(S)-HW but differed significantly to rest of the treatments.

The nutrient uptake by weeds observed in the present study was higher compared to uptake of 2.5 kg N, 1.0 kg P and 3.0 kg K per hectare by weeds in weedy plot in transplanted rice reported elsewhere (Jacob and Syriac, 2005), which was due to difference in weed flora and soil fertility status. The significant difference in nutrient uptake by weeds between unfertilized plots or *comlizer*-75(P)-HW and other treatments may be attributed to relatively higher weed and nutrient management efficiency in the former. Under unfertilized condition, weeds population density and biomass accumulation was low following application of herbicide and hand weeding and thus rice plants competed better than the weeds. In case of *comlizer*-75(P)-HW, possibly balanced supply of nutrients throughout the early vegetative stage coupled with effective weed management facilitated efficient nutrient uptake by crops rather than by the weeds. Thus, *comlizer*-75(P)+HW showed better performance in terms of reducing nutrient share to weeds compared to lower [*comlizer*-60(P)-HW] or higher [*comlizer*-90(P)-HW or RP] doses of fertilizers applied to rice crops.

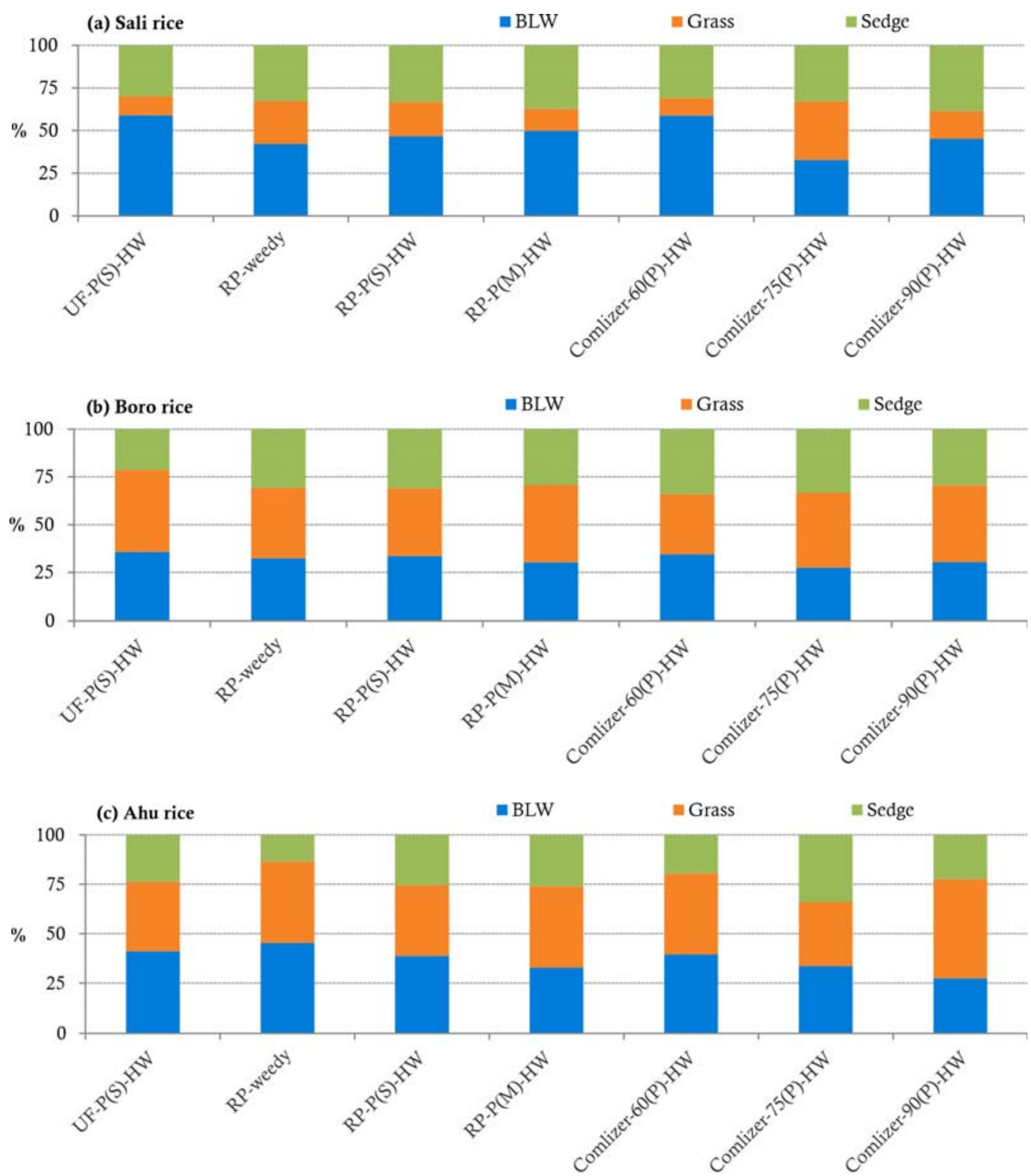

Figure 2. Percent share of weed dry weight at 60 DAT among the broadleaved weed (BLW), grasses and sedges in (a) *Sali*, (b) *Boro* and (c) *Ahu* rice

Crop growth and yield

Growth and yield attributing characters

The plant height and number of panicles m^{-2} at harvest of rice crops are shown in Table 5.

The plant height was not affected by the treatments in all the rice crops. The numbers of panicles m^{-2} in unfertilized and weedy plots were significantly lower than all other treatments in all the rice crops. The panicle length and number of filled grins panicle^{-1} are shown in Table 6. The panicle length of rice plants receiving both weed and nutrient management practices, significantly increased compared to weedy or unfertilized crop, except in *Sali* rice. In case of number of grains panicle^{-1}, the values were significantly lower in weedy or unfertilized crop compared to weed and nutrient management practices, irrespective of rice ecosystem.

Grain yield and economics of production

The grain yield and benefit: cost ratio of rice cultivation is presented in Table 7 for all the rice crops.

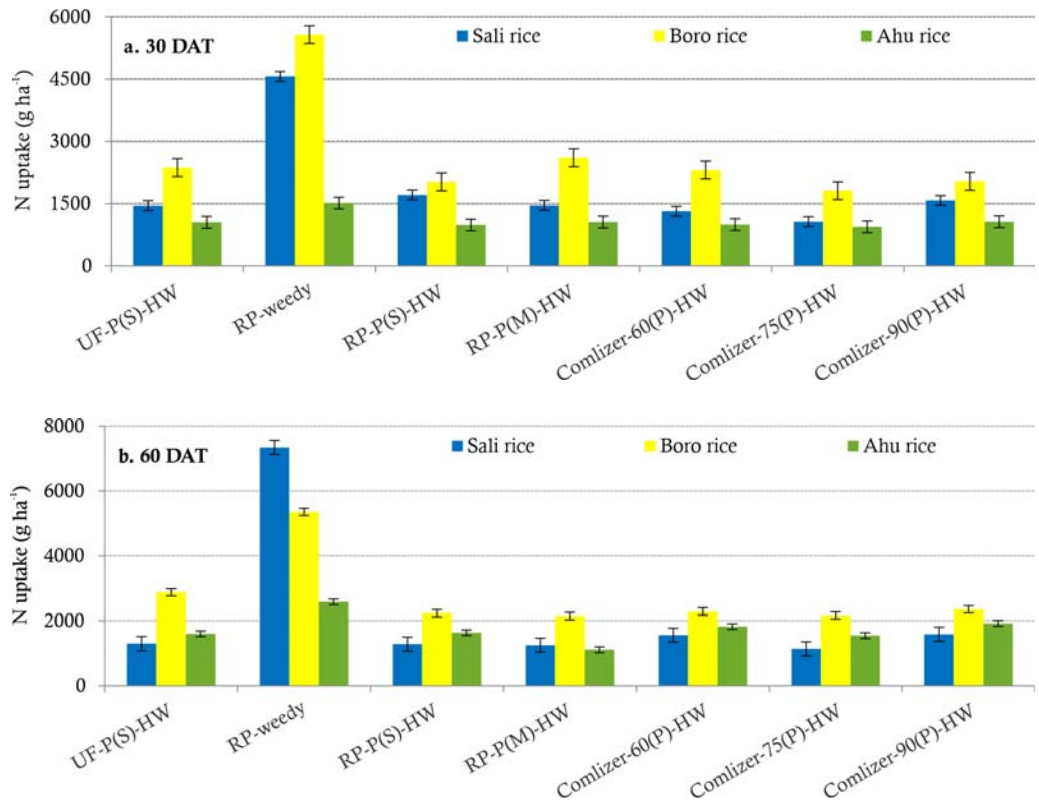

Figure 3. Nitrogen uptake by weed in different rice crops at (a) 30 DAT and (b) 60 DAT

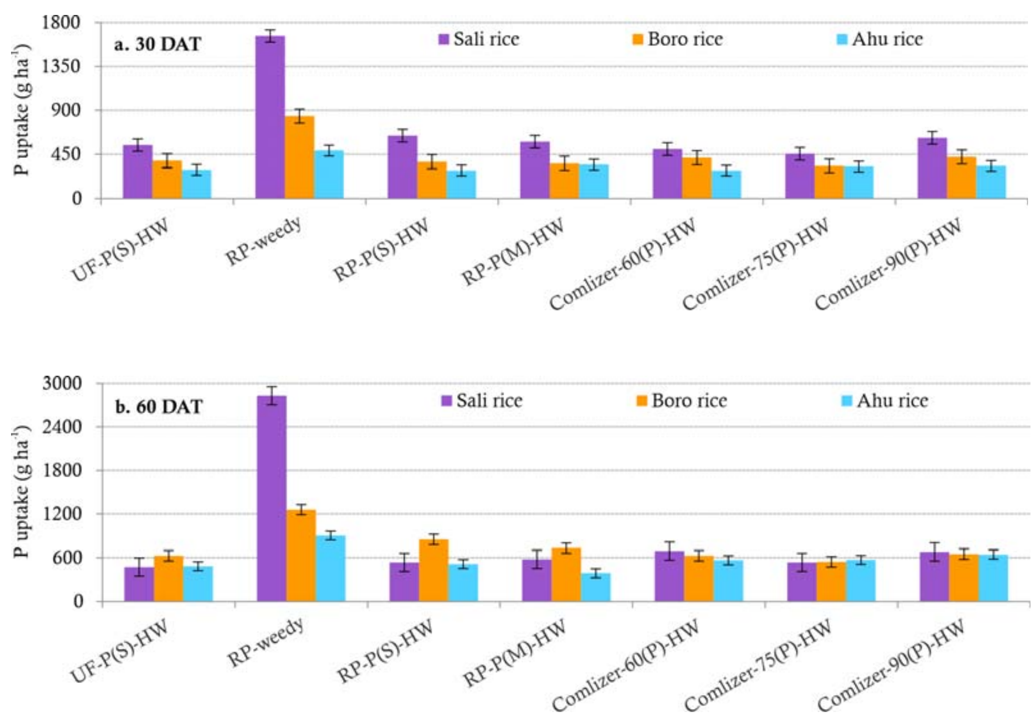

Figure 4. Phosphorous uptake by weed in different rice crops at (a) 30 DAT and (b) 60 DAT

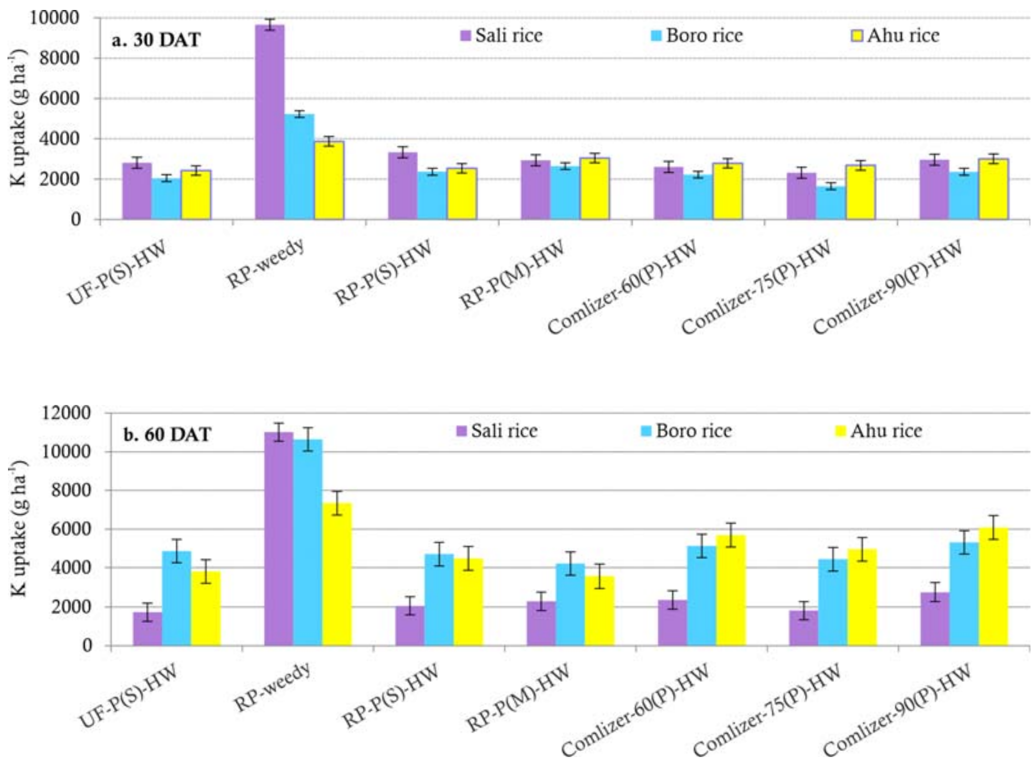

Figure 5. Potassium uptake by weed in different rice crops at (a) 30 DAT and (b) 60 DAT

Table 5. Growth and yield parameters of winter rice under different treatments

Treatment	Plant height (cm)			Number of panicle (m^{-2})		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	94.3	101.3	86.9	96	95	71
RP-weedy	95.4	99.9	85.5	92	91	70
RP-P(S)-HW	95.5	104.7	86.5	121	123	84
RP-P(M)-HW	95.3	102.7	84.5	122	117	86
Comlizer-60(P)-HW	94.3	103.9	90.7	131	119	89
Comlizer-75(P)-HW	95.9	104.5	91.3	138	131	95
Comlizer-90(P)-HW	95.0	103.7	90.6	125	124	91
$CD_{P = 0.05}$	NS	NS	NS	22	18	11
CV (%)	3.8	5.0	4.2	10.4	5.1	9.3

The highest grain yield and net return per rupee invested (B:C ratio) was recorded with *comlizer*-75(P)-HW for all the rice crops (Table 7). The grain yield in weedy and unfertilized plots was significantly lower than treatments receiving weed and nutrient management practices, irrespective of rice crops. In *Sali* rice, the grain yield in weedy plot was significantly higher than that in unfertilized plot, which may be due to competitive ability of Ranjit variety against weeds compared to Kanaklata or Luit varieties. This is because, the weed dry weight at 30 and 60 DAT, nutrient uptake by weeds (barring N uptake at 30 DAT) was highest in *Sali* rice for the weedy plot among the treatments. Possibly, the availability of nutrients from native and applied source was effectively absorbed and translocated within the plants in fertilized but weedy plot. Thus, the nutrient availability was limiting to growth and yield of *Sali* rice crop in unfertilized plot in spite of lower density, dry matter accumulation and nutrient uptake, compared to weedy plot.

The grain yield in *comlizer*-75(P)-HW was significantly higher over the treatments where RFD and vermicompost were applied separately in all the rice crops, over *comlizer*-90(P)-HW in *Sali* rice, both *comlizer*-60(P)-HW and *comlizer*-90(P)-HW in *boro* rice, and at par with *comlizer*-60(P)-HW and *comlizer*-90(P)-HW in *ahu* rice (Table 7). These observed effects might be due to differences in fertilizer application methods, and nutrient uptake pattern and crop duration among the rice varieties. Except for *ahu* rice, the yields obtained in the present study for Ranjit and Kanaklata varieties were much below the average yields of about 5000 to 5500 kg ha^{-1} and 4500 to 5000 kg ha^{-1}, respectively cultivated in typical lowlands with medium to high soil fertility and long-term submergence of about 5±1 cm water depth. Thus, in case of Ranjit, the highest grain yield was achieved with application of 75%RFD through *comlizer*. On the other hand, the nutrients supplied through *comlizer*-75 with 75%RFD matched the crop growth with uptake of released nutrients compared to *comlizer*-60 or *comlizer*-90 for Kanaklata variety during vegetative stage under lower ambient temperature than *Sali* rice. Further, the positive effect of *comlizer* over RFD-VC through separate applications may be due to better retention and release of applied nutrients synchronized with crop growth.

Enhanced crop growth in terms of panicle number, panicle length, grain per panicle in rice due to better weed management through pre-emergence herbicide or due to integration of synthetic fertilizer with organic manure including vermicompost had been reported (Barik *et al.*, 2006; Sunil *et al.*, 2010; Siavoshi *et al.,* 2011; Larijani *et al.,* 2012). Suppression of weeds at early growth stage coupled with supply of adequate quantity of nutrients throughout the crop growth period facilitated desirable growth in crop in terms of tiller numbers, increased grains per panicle resulting in better yield compared to treatments with relatively poor weed management and low nutrient content. A variation in nutrient uptake, dry matter accumulation and allocation of translocates among different parts of rice plants with application of different combinations of mineral and organic fertilizers had earlier been reported (Moe *et al.*, 2019).

Nutrient uptake by crop

The total nutrient uptake by crop at harvest is presented in Table 8. Application of 75% *Comlizer*-P(C) + HW recorded highest uptake of nutrient in all the rice crops. The lowest values for nutrient uptake were observed for either weedy or unfertilized plots.

Table 6. Panicle length and number of grains per panicle at harvest of rice crops

Treatment	Panicle length (cm)			Number of grains panicle^{-1}		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	19.4	21.0	19.1	90.6	94.5	89.6
RP-weedy	21.1	20.7	18.3	93.3	92.7	86.3
RP-P(S)-HW	22.3	23.7	20.4	106.7	102.2	97.4
RP-P(M)-HW	22.0	22.9	20.6	103.3	100.7	96.8
Comlizer-60(P)-HW	23.0	23.9	20.7	103.0	103.3	98.6
Comlizer-75(P)-HW	23.3	24.1	21.1	108.8	105.2	103.1
Comlizer-90(P)-HW	21.3	24.0	20.6	106.3	104.2	98.2
$CD_{P = 0.05}$	1.9	1.5	1.1	9.4	6.1	6.5
CV (%)	5.1	4.4	4.1	10.4	7.1	8.5

Table 7. Grain yield and benefit: cost (B:C) ratio in different rice crops

Treatment	Grain yield (kg ha^{-1})			B:C ratio		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	1775	1934	1601	0.51	0.61	0.36
RP-weedy	2125	1853	1448	0.63	0.48	0.36
RP-P(S)-HW	2825	2719	2179	0.72	0.84	0.39
RP-P(M)-HW	2817	2692	2053	0.75	0.76	0.38
Comlizer-60(P)-HW	3033	2751	2312	0.54	0.74	0.33
Comlizer-75(P)-HW	3292	3094	2642	0.88	0.98	0.50
Comlizer-90(P)-HW	2900	2810	2388	0.44	0.78	0.34
$CD_{P = 0.05}$	280	171	387			
CV (%)	7	9	11			

The variation in nutrient uptake by different rice crops and among the treatments might be due to corresponding differences in yield of grain and straw (data not presented) observed in this experiment. Xing *et al.* (2009) observed that in spite of applying recommended dose of fertilizers rice crop suffered from deficit of N, P and K, while balanced nutrient application accelerated higher nutrient uptake by rice crop.

Soil fertility status

Nutrient content after application of fertilizer

The NH_4-N and NO_3-N in soil at 45 days after transplanting is presented in Table 9. The highest NH_4-N and NO_3-N in all the rice crops was recorded for soil fertilized with *comlizer*-75 and was significantly higher compared to all other treatments (Table 9). Increase in population of bacteria (Othman *et al.*, 2013) and their activity in flooded rice rhizosphere with increasing nitrogen content (Das and Saha, 2003) was reported. The increase in content of inorganic N-fractions observed in the present study may be attributed to enhanced activity of microorganisms resulting in mineralization of the nutrient.

The available P and K contents in soil at 45 days after planting are shown in Table 10. The highest content of available P at 45 DAT in all the rice crops was observed for *Comlizer*-75 and differed significantly to rest of the treatments, except *Comlizer*-90 in *Sali* rice. But, the available P status in soils among the fertilized plots was at par in *boro* and *ahu* rice.

The observed values for available potassium in this study was possibly due to difference in time of fertilizer application in *Sali* and *ahu* or *boro* rice. In *Sali* rice the fertilizers were applied in submerged soils but the soil remained under intermittent flooding during fertilizer application in *boro* and *ahu* rice. In P-deficient acid soils, phosphorous applied to moist soils (prior to flooding) through mineral and organic fertilizers is added more to Al-P and Fe-P compared to application in flooded soil (Shinde *et al.*, 1978). Similarly, Seng *et al.* (2006) observed that under continuous flooding rice crop responded to P application even after 6 weeks of planting. The significant increase in available potassium content

Table 8. Total nutrient uptake (kg ha^{-1}) by rice at harvest

Treatments	Nitrogen			Phosphorous			Potassium		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	19.2	25.6	17.4	6.1	8.1	5.6	39.3	50.8	34.3
RP-weedy	24.0	23.7	17.1	8.0	7.0	4.9	45.6	46.8	33.5
RP-P(S)-HW	30.6	30.9	20.8	10.6	9.0	6.0	60.2	60.4	39.5
RP-P(M)-HW	31.6	30.6	21.3	9.9	9.4	6.5	63.0	60.7	40.5
Comlizer-60(P)-HW	29.9	31.6	26.2	8.8	9.2	7.5	57.8	62.2	49.3
Comlizer-75(P)-HW	37.4	36.3	30.2	13.0	12.1	10.0	71.6	70.1	57.2
Comlizer-90(P)-HW	28.8	31.4	25.7	9.5	10.1	8.1	57.5	62.1	48.5
$CD_{P = 0.05}$	6.5	4.7	3.3	2.6	2.0	1.3	7.7	7.4	7.0
CV (%)	13.1	10.3	8.2	15.8	14.3	10.4	7.8	8.3	9.1

Table 9. Ammonical nitrogen and nitrate nitrogen in soil at 45 days after transplanting

Treatment	NH_4-N (mg kg^{-1})			NO_3-N (mg kg^{-1})		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	40.9	36.2	47.7	10.8	16.7	13.2
RP-weedy	44.0	40.3	52.5	13.0	20.3	15.4
RP-P(S)-HW	46.1	41.1	54.8	12.9	20.8	15.2
RP-P(M)-HW	44.2	42.0	53.6	12.1	19.9	14.9
Comlizer-60(P)-HW	50.0	48.4	59.0	13.7	21.8	16.1
Comlizer-75(P)-HW	57.4	56.4	68.4	16.7	25.4	19.7
Comlizer-90(P)-HW	50.3	50.4	59.9	13.6	20.4	16.0
$CD_{P = 0.05}$	3.7	5.7	4.0	1.8	2.9	1.6
CV (%)	5.3	7.6	6.8	9.2	7.9	8.2

Table 10. Available phosphorous and potassium content in soil at 45 days after transplanting

Treatment	Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	6.4	7.8	6.5	118.8	128.7	131.0
RP-weedy	7.3	9.1	7.3	141.8	143.8	142.7
RP-P(S)-HW	7.2	9.4	7.6	137.6	143.2	145.0
RP-P(M)-HW	7.5	9.6	7.3	135.3	142.5	140.6
Comlizer-60(P)-HW	7.6	9.7	7.5	136.8	137.8	147.1
Comlizer-75(P)-HW	8.2	10.9	8.2	141.6	144.4	145.7
Comlizer-90(P)-HW	7.9	10.1	7.8	135.3	141.9	146.7
$CD_{P = 0.05}$	0.6	1.7	0.8	10.0	8.6	9.2
CV (%)	5.4	8.1	5.9	5.1	4.5	5.6

Table 11. Available nutrient status (kg ha^{-1}) in soil after harvest of rice crops

Treatments	Nitrogen			Phosphorous			Potassium		
	Sali	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*	*Sali*	*Boro*	*Ahu*
UF-P(S)-HW	177.9	272.9	227.7	6.6	9.3	7.8	123.4	136.6	118.4
RP-weedy	183.6	291.9	241.9	6.9	10.1	9.0	132.9	154.6	135.5
RP-P(S)-HW	175.0	266.4	216.1	6.6	10.2	8.4	121.7	150.9	133.4
RP-P(M)-HW	189.9	278.6	234.6	7.2	10.2	8.6	118.4	153.4	128.7
Comlizer-60(P)-HW	181.1	276.1	220.7	7.6	10.8	9.4	117.2	146.3	127.1
Comlizer-75(P)-HW	179.1	261.8	228.4	7.3	11.2	9.8	119.7	143.1	125.8
Comlizer-90(P)-HW	180.0	267.7	227.7	7.6	11.2	9.2	124.3	145.4	128.0
$CD_{P = 0.05}$	NS	NS	NS	NS	1.2	1.1	NS	NS	9.7
CV (%)	6.9	5.6	7.6	8.5	6.6	7.3	4.7	5.8	4.8

of fertilized soils, compared to unfertilized plot, was due to increased soluble K following mineral fertilizer application.

Available nutrient status after harvest of crop

The soil pH and organic carbon content after harvest of rice crops were not affected by the treatments (data not presented). The contents of available nutrients (N, P and K) in soil after harvest of rice crops are shown in Table 11.

The available nitrogen content in soil after harvest of rice crops was not influenced by the treatments. This might be due to almost equal amounts of removal and addition of the nutrient in the respective treatments. The relatively lesser uptake of nutrients in unfertilized and weedy plots coupled with addition from recycling or previous crop residue complemented the available nitrogen status in soil at harvest of rice. The available phosphorous content was not significant among the fertilized plots, but was higher in *comlizer* applied plots compared to unfertilized soil in *boro* and *ahu* rice, but the effect was not observed in *Sali* rice. This might be due to difference in time of P-estimation in *Sali* and *boro* or *ahu* rice. The *Sali* rice was harvested during winter in aerobic soil long time after flood water was drained out. But, the *boro* and *ahu* rice crops were harvested during rainy season in saturated soils, where the flooding had influence on the effect of treatments and possibly decomposition of the previous rice crop residues. Thus the effects were conspicuous after harvest of *boro* and *ahu* rice crops compared to *Sali* rice. The significantly higher available K contents in fertilized compared to unfertilized soil was due to higher soluble K in the former following mineral and organic fertilizer application.

CONCLUSION

Application of 75% of the recommended fertilizer doses of N, P and K with 2 t ha^{-1} biofertilizer enriched vermicompost as mixture produced higher grain yield and net benefit in different transplanted flooded rice ecosystems. The studied soil and crop parameters could partially explain the differences in grain yields and soil fertility parameters observed with different treatments. Further study may be aimed with inclusion of additional soil and crop growth parameters like soil enzyme activities, N and P fractions, leaf chlorophyll content, root growth characteristics *etc*. at specific crop growth stages.

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Conflict of Interest

The authors declare that they have no competing interests.

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