



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(9): 63-70
Received: 22-07-2026
Accepted: 29-08-2026

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Intensifying food–forage production on medium land in Assam through teosinte–ricebean intercropping, integrated nutrient management, and relay rapeseed

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i9Sa.6489>

Abstract

A two-year field experiment was conducted during 2016–17 and 2017–18 at Assam Agricultural University, Jorhat, to evaluate an intensive food–forage cropping system under medium-land conditions. The study examined sole teosinte, sole ricebean and teosinte–ricebean intercropping in 3:2 and 3:3 row ratios under four nutrient-management treatments: 100% recommended dose of fertilizer (RDF), 50% nitrogen (N) through RDF + 50% N through farmyard manure (FYM), 50% N through RDF + 50% N through vermicompost, and an organic combination of FYM and vermicompost. The effects of these treatments on succeeding rice and relay rapeseed, system productivity and economics were also assessed. The 3:2 arrangement produced the highest teosinte forage yield among intercrops, whereas the 3:3 arrangement produced superior ricebean forage yield and overall intercropping performance, with land equivalent ratios of 1.37 and 1.40 and the highest green-forage-equivalent yields of 859.19 and 901.79 q ha⁻¹ during the two years. The application of 50% N through RDF + 50% N through vermicompost consistently improved forage production, nutrient uptake, succeeding rice and relay rapeseed yields and economic returns. Economically, sole ricebean followed by rice and relay rapeseed generated the highest net returns (Rs. 73, 896 and Rs. 80, 312 ha⁻¹) and benefit–cost ratios (1.41 and 1.53) in the two years, ahead of the 3:3 teosinte–ricebean system (Rs. 71, 244 and Rs. 77, 634 ha⁻¹; B:C 1.16 and 1.27), while cultivation cost and profitability were most favourable under 50% N through RDF + 50% N through vermicompost (B:C 1.37 and 1.55) compared with sole inorganic fertilization or full organic substitution. Overall, 3:3 teosinte + ricebean followed by rice with recommended integrated nutrient management and relay rapeseed, combined with 50% RDF-N and 50% vermicompost-N in the forage phase, was identified as a suitable and economically viable intensive cropping strategy for medium-land situations of Assam, while sole ricebean–rice–rapeseed offered the greatest net profitability among the systems tested.

Keywords: Food–forage system, teosinte, ricebean, intercropping, integrated nutrient management, relay rapeseed, land equivalent ratio

Introduction

Livestock production is an important component of smallholder farming systems in India, particularly in the northeastern region, where crop residues, green fodder, and livestock manure are closely integrated with crop production. However, the availability of cultivated forage remains inadequate in relation to livestock requirements. This shortage is aggravated by limited land resources, seasonal variation in forage supply, increasing competition between food and fodder crops, and the need to maintain household income from small holdings. Under these conditions, intensifying production through suitable food–forage cropping systems offers an opportunity to increase total output without requiring additional land. Food–forage systems can be intensified through both spatial and temporal diversification. Spatial diversification involves growing cereal and legume crops together, while temporal diversification involves growing successive crops within the same year. Intercropping cereals with legumes can improve land-use efficiency through differences in canopy structure, rooting pattern, nutrient requirement, and growth duration. A cereal component generally contributes high biomass production, whereas the legume component can improve forage protein content and contribute to biological nitrogen fixation. The productivity advantage of intercropping is commonly evaluated using the land

equivalent ratio (LER), with values greater than one indicating that the intercrop uses land more efficiently than the corresponding sole crops ^[1, 2].

Teosinte (*Euchlaena mexicana* Schrad.) is a fast-growing cereal forage crop with considerable biomass-producing ability and adaptability to warm, humid conditions. Ricebean (*Vigna umbellata* (Thunb.) Ohwi & Ohashi) is a forage legume that can complement cereal crops by contributing protein-rich biomass and improving the biological diversity of the cropping system. Earlier studies have demonstrated the potential of teosinte and legume mixtures, including teosinte–ricebean combinations, but the performance of an intercrop depends strongly on the relative proportion and spatial arrangement of the component crops. An inappropriate row ratio may intensify interspecific competition, reduce the yield of one component, and weaken the residual benefits to subsequent crops. Therefore, identifying a suitable row arrangement is essential for obtaining a balance between cereal forage production, legume contribution, total biomass, and subsequent crop performance.

The nutrient-management strategy is equally important in an intensive food–forage sequence. Continuous removal of biomass can accelerate nutrient depletion, particularly when forage crops are harvested at an immature stage and large quantities of nutrients are removed from the field. Exclusive dependence on mineral fertilizers may sustain short-term productivity but may not adequately improve soil organic matter and nutrient-retention capacity. Conversely, organic sources such as farmyard manure (FYM) and vermicompost release nutrients more gradually and can improve soil physical, chemical, and biological properties, but nutrient release may not coincide with the rapid nutrient demand of high-yielding forage crops. Integrated nutrient management (INM), which combines mineral fertilizers with organic nutrient sources, may therefore provide a more synchronized supply of nutrients while maintaining soil fertility ^[3, 4].

The residual effects of nutrient management are particularly important in a multi-season system. In the medium-land situations of Assam, a summer forage crop may be followed by transplanted rice during the kharif season and a short-duration oilseed crop after rice. Ricebean in the first crop may benefit the succeeding rice crop through biological nitrogen fixation, residue return, and improved nutrient cycling. Similarly, organic nutrient sources applied to the forage phase may continue to influence rice growth and the performance of a relay crop. A relay rapeseed crop established in standing rice can use residual soil moisture and nutrients while reducing the fallow period between rice and the next cropping season. However, the success of relay rapeseed depends on the fertility remaining after the preceding crops and on the ability of the entire system to maintain timely crop establishment.

Assam has substantial potential for such intensified systems because rice is the dominant crop and many medium-land fields remain available for a pre-rice crop and a post-rice relay crop. Nevertheless, high rainfall, acidic sandy-loam soils, low to medium soil fertility, and limited access to costly external inputs create challenges for sustained production. A suitable system must therefore be evaluated using multiple criteria, including forage yield, grain and oilseed yield, land-use efficiency, nutrient uptake, residual soil fertility, economic return, and energy productivity. Assessment of individual crop yield alone may fail to identify the most appropriate system for farmers who depend simultaneously on food production, livestock feeding, and soil fertility maintenance.

The present study was conducted to evaluate an intensive food–forage cropping system comprising summer teosinte and ricebean, succeeding kharif rice, and relay rapeseed under the medium-land conditions of Assam. The specific objectives were to: (i) assess the growth, forage yield, quality of sole and intercropped teosinte and ricebean; (ii) determine the effects of row ratio and integrated nutrient management on succeeding rice; (iii) quantify residual effects on relay rapeseed grown without additional fertilizer; and (iv) compare the systems in terms of land equivalent ratio, green-forage-equivalent yield and economics. It was hypothesized that a suitable teosinte–ricebean row ratio combined with integrated application of mineral fertilizer and organic manure would improve total system productivity and enhance the residual fertility available to succeeding rice and relay rapeseed.

Materials and Methods

A two-year field experiment was conducted during 2016–17 and 2017–18 at the Instructional-cum-Research Farm of Assam Agricultural University, Jorhat. The summer phase used a split-plot design with three replications. Main plots contained sole teosinte, sole ricebean, teosinte + ricebean in a 3:2 row ratio, or teosinte + ricebean in a 3:3 row ratio. Subplots received: 100% recommended dose of fertilizer (RDF); 50% of nitrogen (N) through RDF + 50% N through farmyard manure (FYM); 50% N through RDF + 50% N through vermicompost (VC); or an organic treatment supplying 50% N through VC + 50% N through FYM. Rice was grown in the kharif season in a split-split arrangement with either a recommended integrated nutrient management (INM) package or the same package with 50% organic manure (OM). Rapeseed was broadcast as a relay crop after rice without additional fertilizer. Crop growth, forage yield and quality, rice and rapeseed performance, land equivalent ratio (LER), soil properties, economics, and energy indices were measured. Data were subjected to analysis of variance appropriate to the split-split-plot design, and treatment means were compared at $P = 0.05$.

Results and Discussion

Teosinte–Ricebean Intercropping Performance

Plant height and dry matter accumulation: Sole teosinte and sole ricebean produced taller plants and greater per-plant dry matter than either intercropped combination, due to reduced inter-plant competition (Tables 1–2). Among intercrops, the 3:3 ratio outperformed 3:2 for both components. INM-wise, 50% N (RDF) + 50% N (VC) gave the best growth, followed by 50% N (RDF) + 50% N (FYM), RDF alone, and fully organic, reflecting the benefit of combining readily available and slow-release nutrient sources.

Forage yield: Sole teosinte produced the highest green forage yield, recording 233.73 and 238.65 q ha⁻¹ during 2016–17 and 2017–18, respectively. Among the intercrops, the 3:2 teosinte–ricebean row ratio produced greater teosinte forage yield than the 3:3 ratio, with yields of 163.74 and 170.74 q ha⁻¹. In contrast, ricebean performed better in the 3:3 arrangement, producing 127.75 and 136.50 q ha⁻¹ green forage compared with 98.73 and 111.03 q ha⁻¹ in the 3:2 arrangement. Sole ricebean produced the highest ricebean forage yield, at 194.06 and 201.06 q ha⁻¹ (Table 3).

Land equivalent ratio (LER): Both intercropping ratios recorded LER > 1, confirming a land-use advantage (Table 2).

The 3:3 arrangement recorded the highest LER, with values of 1.37 and 1.40 in the two years, indicating a land-use advantage of 37–40% over sole cropping. The 3:2 arrangement also recorded LER values greater than one, but its performance was lower than that of the 3:3 system, due to more balanced use of light, space, moisture and nutrients between the cereal and legume. INM had no significant effect on LER, showing that cropping geometry, not nutrient source, drove the advantage —

consistent with established intercropping theory ^[1, 2].

Competition indices: Ricebean was the more competitive/dominant component in both ratios, shown by its positive aggressivity and competitive ratio > 1, especially under 3:2 (Table 4). Teosinte's competitive ratio stayed below 1 in both arrangements, indicating milder dominance under the more balanced 3:3 system.

Table 1: Plant height (cm) of teosinte and ricebean at different growth stages as influenced by cropping system and integrated nutrient management

Treatment	2016		2017		2016		2017	
	Teosinte		Teosinte		Ricebean		Ricebean	
	80 DAS	Harvest	80 DAS	Harvest	80 DAS	Harvest	80 DAS	Harvest
Cropping System (C)								
Teosinte sole	122.90	123.65	130.60	131.60	-	-	-	-
Ricebean sole	-	-	-	-	119.03	120.44	121.86	123.78
Teosinte + Ricebean (3:2)	113.28	114.03	121.98	123.32	112.26	114.41	117.21	119.57
Teosinte + Ricebean (3:3)	118.83	119.83	126.37	127.53	115.68	117.22	119.79	121.02
S.Em±	1.34	1.31	0.77	0.65	0.56	0.59	0.64	0.80
C.D. (P=0.05)	5.23	5.10	3.01	2.55	2.19	2.32	2.52	3.15
Integrated Nutrient Management (M)								
RDF (inorganic)	116.43	117.32	125.26	126.03	114.04	114.18	117.56	120.62
50% RDF-N + 50% FYM-N	118.81	119.69	126.65	128.09	116.53	117.98	120.55	121.64
50% RDF-N + 50% VC-N	124.67	125.56	131.50	132.61	122.27	124.49	123.53	125.43
100% organic (VC + FYM)	113.46	114.12	121.86	123.19	109.77	112.77	116.84	118.12
S.Em±	1.48	1.46	0.91	0.90	1.42	1.43	0.92	1.15
C.D. (P=0.05)	4.41	4.34	2.72	2.67	4.22	4.24	2.74	3.41
Interaction (C × M)								
S.Em±	2.57	2.53	1.58	1.56	2.46	2.48	1.60	1.99
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Dry matter accumulation (DMA, g/plant) of teosinte and ricebean at different growth stages and land equivalent ratio (LER) as influenced by cropping system and INM

Treatment	2016		2017		2016		2017		2016	2017
	Teosinte DMA		Teosinte DMA		Ricebean DMA		Ricebean DMA			
	80 DAS	Harvest	80 DAS	Harvest	80 DAS	Harvest	80 DAS	Harvest		
Cropping System (C)										
Teosinte sole	94.62	132.01	99.45	138.51	-	-	-	-	1.00	1.00
Ricebean sole	-	-	-	-	21.09	28.48	22.59	30.05	1.00	1.00
Teosinte + Ricebean (3:2)	79.18	103.26	83.85	113.68	19.98	26.80	21.48	28.22	1.24	1.30
Teosinte + Ricebean (3:3)	84.34	113.22	89.84	123.30	20.37	27.39	21.95	29.20	1.37	1.40
S.Em±	2.11	1.91	1.31	1.90	0.19	0.22	0.29	0.33	0.06	0.04
C.D. (P=0.05)	8.24	7.47	5.11	7.45	0.74	0.80	1.14	1.29	0.20	0.19
Integrated Nutrient Management (M)										
RDF (inorganic)	81.13	108.13	85.79	116.80	20.39	27.46	21.89	29.93	1.13	1.14
50% RDF-N + 50% FYM-N	86.22	117.21	90.33	123.99	20.72	27.86	22.33	29.61	1.08	1.11
50% RDF-N + 50% VC-N	101.68	140.73	105.02	147.17	21.38	28.84	23.22	30.59	1.10	1.12
100% organic (VC + FYM)	75.15	98.58	83.04	112.69	19.42	26.08	21.03	27.72	1.29	1.34
S.Em±	2.05	2.06	2.07	1.58	0.24	0.32	0.38	0.35	0.06	0.06
C.D. (P=0.05)	6.09	6.12	6.15	4.70	0.72	0.85	1.14	1.04	NS	NS
Interaction (C × M)										
S.Em±	3.55	3.57	3.59	2.74	0.42	0.56	0.66	0.61	0.12	0.10
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Green forage yield (GFY) and dry matter yield (DMY) of teosinte and ricebean as influenced by cropping system and INM

Treatment	Teosinte GFY(q/ha)		Teosinte DMY(q/ha)		Ricebean GFY (q/ha)		Ricebean DMY(q/ha)	
	2016		2016		2016		2016	
	2016	2017	2016	2017	2016	2017	2016	2017
Cropping System (C)								
Teosinte sole	233.73	238.65	53.12	55.68	-	-	-	-
Ricebean sole	-	-	-	-	194.06	201.06	47.30	49.31
Teosinte + Ricebean (3:2)	163.74	170.74	37.21	39.83	98.73	111.03	23.78	27.57
Teosinte + Ricebean (3:3)	150.03	157.78	34.12	36.83	127.75	136.50	31.18	33.48
Integrated Nutrient Management (M)								
RDF (inorganic)	171.19	176.52	38.90	41.17	140.89	150.33	33.83	36.85
50% RDF-N + 50% FYM-N	203.46	209.01	46.26	48.79	142.03	151.14	34.48	37.09
50% RDF-N + 50% VC-N	205.58	214.58	46.78	50.10	160.89	167.67	39.31	41.58
100% organic (VC + FYM)	149.78	156.11	34.13	36.40	116.91	128.97	28.73	31.64

Table 4: Aggressivity and competitive ratio of teosinte and ricebean as influenced by cropping system and INM

Treatment	Aggressivity Teosinte		Aggressivity Ricebean		Competitive Ratio Teosinte		Competitive Ratio Ricebean	
	2016	2017	2016	2017	2016	2017	2016	2017
Cropping System (C)								
Teosinte + Ricebean (3:2)	-0.09	-0.18	0.09	0.18	0.98	0.92	1.07	1.17
Teosinte + Ricebean (3:3)	-0.05	-0.04	0.05	0.04	0.99	0.99	1.06	1.04
Integrated Nutrient Management (M)								
RDF (inorganic)	-0.09	-0.09	0.09	0.09	0.61	0.63	0.77	0.76
50% RDF-N + 50% FYM-N	-0.04	-0.06	0.04	0.06	0.68	0.63	0.73	0.71
50% RDF-N + 50% VC-N	-0.04	-0.09	0.04	0.09	0.66	0.63	0.64	0.74
100% organic (VC + FYM)	-0.01	-0.06	0.01	0.06	0.69	0.64	0.69	0.73

Residual Effects on Succeeding Rice

Plant height and yield attributes: Rice grown after sole ricebean recorded the tallest plants, most panicles/m², and most grains and filled grains per panicle, followed by the 3:3 intercrop, the 3:2 intercrop, and sole teosinte (lowest) (Table 5), reflecting the residual nitrogen and improved soil fertility left by the legume [5, 6].

Grain yield, straw yield and harvest index: Grain and straw yield followed the same order: highest after sole ricebean (47.24–49.62 and 76.14–79.26 q ha⁻¹), then the 3:3 intercrop,

then 3:2, lowest after sole teosinte (Table 6), consistent with reported cereal-yield benefits after legumes [7, 8, 9]. Residually, 50% N (RDF) + 50% N through VC again gave the highest grain and straw yield, ahead of the FYM combination and inorganic-only treatment, due to vermicompost's slow nutrient release, improved P availability, and better soil water-holding capacity [10, 11, 12]. The recommended rice INM package outperformed the 50%-organic package, showing that adequate direct nutrition remains essential alongside residual benefit. Harvest index did not differ significantly across treatments.

Table 5: Residual effects of cropping system and integrated nutrient management on plant height, panicles/m² and grains/panicle of rice

Treatment	2016		2017		2016		2017	
	Plant ht.(cm)		Plant ht.(cm)		Panicles/m ²		Grains/panicle	
	100 DAT	Harvest	100 DAT	Harvest	Panicles/m ²	Grains/panicle	Panicles/m ²	Grains/panicle
Cropping System (C)								
Teosinte sole–Rice	121.96	123.33	123.12	124.67	261.01	166.87	270.53	169.62
Ricebean sole–Rice	131.71	132.92	133.29	134.29	293.13	173.37	305.93	177.47
Teosinte + Ricebean (3:2)–Rice	125.54	126.66	127.09	127.83	277.32	171.10	286.55	174.14
Teosinte + Ricebean (3:3)–Rice	127.87	129.13	129.04	130.88	283.38	172.29	292.96	176.77
S.Em±	1.27	1.14	1.16	1.09	5.76	1.26	6.61	1.51
C.D. (P=0.05)	4.41	3.95	4.02	3.76	19.94	4.35	22.87	5.21
Integrated Nutrient Management (M)								
RDF (inorganic)	121.61	122.99	122.86	124.37	260.79	162.51	269.76	168.17
50% RDF-N + 50% FYM-N	127.82	129.11	129.41	130.61	286.61	173.11	297.75	176.42
50% RDF-N + 50% VC- N	131.44	132.65	132.77	134.19	297.41	179.98	308.32	182.47
100% organic (VC + FYM)	126.21	127.29	127.51	128.50	270.02	168.04	280.15	170.95
S.Em±	1.00	1.19	1.17	1.15	5.01	2.68	4.68	1.91
C.D. (P=0.05)	2.98	3.49	3.41	3.35	14.62	6.95	13.66	5.56
INM Package to Rice (I)								
I1: Recommended INM package	128.14	129.56	129.51	130.99	283.73	172.80	294.82	176.13
I2: Recommended + 50% OM	125.40	126.47	126.76	127.84	273.69	169.02	283.16	172.87
S.Em±	0.94	0.90	0.84	0.79	3.42	1.28	3.16	0.97
C.D. (P=0.05)	2.72	2.60	2.41	2.28	9.86	3.70	9.09	2.79
Interaction (C×M, C×I, M×I, C×M×I)								
All interactions	NS	NS	NS	NS	NS	NS	NS	NS

Table 6: Residual effects of cropping system and integrated nutrient management on grain yield, straw yield and harvest index of rice

Treatment	Grain Yield (q/ha)		Straw Yield (q/ha)		Harvest index (%)	
	2016	2017	2016	2017	2016	2017
Cropping System (C)						
Teosinte sole–Rice	38.53	40.30	66.39	68.11	36.73	37.15
Ricebean sole–Rice	47.24	49.62	76.14	79.26	38.27	38.52
Teosinte + Ricebean (3:2)–Rice	42.86	44.15	72.15	72.74	37.29	37.72
Teosinte + Ricebean (3:3)–Rice	43.32	45.04	72.50	73.32	37.46	38.02
S.Em±	1.14	1.62	1.85	2.09	0.53	0.53
C.D. (P=0.05)	3.93	5.61	6.40	7.23	NS	NS
Integrated Nutrient Management (M)						
RDF (inorganic)	39.96	39.97	67.81	66.64	37.10	37.49
50% RDF-N + 50% FYM-N	43.87	45.51	73.53	74.50	37.35	37.91
50% RDF-N + 50% VC-N	46.40	50.52	75.48	80.88	38.03	38.39
100% organic (VC + FYM)	41.72	43.11	70.36	71.41	37.26	37.63
S.Em±	0.97	1.26	1.58	1.48	0.54	0.43
C.D. (P=0.05)	2.83	3.67	4.62	4.31	NS	NS

INM Package to Rice (I)						
I1: Recommended INM package	44.62	46.60	73.27	74.52	37.87	38.42
I2: Recommended + 50% OM	41.34	42.95	70.32	72.20	37.01	37.29
S.Em±	0.86	0.99	0.99	0.79	0.37	0.40
C.D. (P=0.05)	2.47	2.84	2.86	2.28	NS	NS
Interaction (C×M, C×I, M×I, C×M×I)						
All interactions	NS	NS	NS	NS	NS	NS

Residual Effects of Cropping System and INM on Relay Rapeseed

Plant height: Plant height of rapeseed responded significantly to the residual effect of the preceding cropping system at both the 80 days-after-sowing (DAS) and at-harvest stages in both years (Table 7). Plots that had carried sole ricebean–rice in the previous season produced the tallest rapeseed plants (82.55 cm and 85.68 cm at harvest in 2016-17 and 2017-18, respectively), followed by the 3:3 teosinte + ricebean intercrop, while sole teosinte–rice left the shortest plants. Because ricebean is a legume, its residue and root biomass add fixed nitrogen and organic matter to the soil, and this carry-over nutrient pool, rather than any fresh input, appears to be what pushed vegetative growth of the following rapeseed ahead of the non-legume sequences.

A similar pattern held for the residual effect of integrated nutrient management: plant height was tallest where the preceding crop had received 50% N through RDF together with 50% N through vermicompost, closely followed by the FYM-substituted treatment, and shortest under 100% inorganic fertilization (RDF alone). Organic amendments evidently leave behind more than just nutrients — their slow mineralization and associated micronutrient supply continue to support crop growth well after the manure itself was applied to the previous crop. The INM package carried to rice also left a significant residual imprint, with the recommended package producing taller rapeseed than the same package diluted with 50% organic matter, in both years. None of the two- or three-way interactions

among cropping system, INM, and the INM package to rice were significant for plant height in either season, indicating that each factor exerted its residual influence largely independently of the others.

Siliquae per plant and seeds per siliqua: Yield-attributing characters followed the same broad trend as plant height. The number of siliquae per plant and seeds per siliqua were both significantly higher where rapeseed followed sole ricebean–rice, and lowest under sole teosinte–rice, in both years of the study (Table 7). Reproductive development appears to be shaped by the nitrogen economy the preceding crop leaves behind: a stronger residual nitrogen and organic-matter pool translates into more pods setting per plant and more seeds filling within each pod. Residual INM produced the same ranking seen for growth: the vermicompost-substituted treatment gave the highest siliquae/plant and seeds/siliqua (21.65 and 18.70 in 2016-17; 22.11 and 18.32 in 2017-18), ahead of the FYM-substituted treatment, while sole RDF gave the fewest of both — a difference of roughly 55–60% between the best organic-substituted treatment and inorganic-only fertilization. The recommended INM package carried to rice again outperformed its 50% organic-matter variant for both attributes in both years. As with plant height, the C × M × I interaction was non-significant, so the residual gains from cropping system, INM, and the rice-level INM package are best read as additive rather than mutually dependent.

Table 7: Residual effects of cropping system and integrated nutrient management on plant height, siliquae/plant and seeds/siliqua of rapeseed

Treatment	2016-17		2017-18		2016-17		2017-18	
	Plant ht.(cm)		Plant ht.(cm)					
	80 DAS	Harvest	80 DAS	At Harvest	Siliquae/plant	Seeds/siliqua	Siliquae/plant	Seeds/siliqua
Cropping System (C)								
Teosinte sole–Rice–Rapeseed	77.33	81.45	79.29	83.08	17.88	15.14	18.13	15.47
Ricebean sole–Rice–Rapeseed	78.76	82.55	80.51	85.68	19.48	16.41	20.23	16.82
Teosinte + Ricebean (3:2)–Rice–Rapeseed	77.72	81.76	79.72	83.60	19.16	15.58	18.62	16.07
Teosinte + Ricebean (3:3)–Rice–Rapeseed	78.13	82.09	80.13	84.30	19.07	16.11	19.28	16.32
S.Em±	0.23	0.20	0.18	0.40	0.33	0.26	0.41	0.24
C.D. (P=0.05)	0.81	0.71	0.62	1.39	1.16	0.89	1.43	0.83
Integrated Nutrient Management (M)								
RDF (inorganic)	77.06	81.13	78.94	83.25	13.77	12.05	13.89	13.26
50% RDF-N + 50% FYM-N	78.08	82.14	80.04	84.18	20.05	16.47	20.30	16.79
50% RDF-N + 50% VC-N	78.98	82.91	80.94	85.33	21.65	18.70	22.11	18.32
100% organic (VC + FYM)	77.81	81.68	79.73	83.89	19.12	16.02	19.95	16.31
INM Package to Rice (I)								
I1: Recommended INM package	78.30	82.39	80.17	84.43	19.18	16.32	19.76	16.81
I2: Recommended + 50% OM	77.67	81.54	79.65	83.89	18.11	15.30	18.36	15.53
Interaction (C×M, C×I, M×I, C×M×I)								
All interactions	NS	NS	NS	NS	NS	NS	NS	NS

Seed yield and stover yield: Seed yield of rapeseed mirrored the growth and yield-attribute trends closely (Table 8). Sole ricebean–rice gave the highest residual seed yield (3.34 q/ha in 2016-17 and 3.70 q/ha in 2017-18), an advantage of roughly 44% and 25% over sole teosinte–rice in the respective years, with the 3:3 teosinte + ricebean intercrop placed second. The

legume component in the preceding sequence therefore does more than support its own productivity — the nitrogen it fixes, and the organic matter it returns to the soil, carry through rice and into the following rapeseed crop, lowering the fertilizer burden the rotation as a whole has to bear while still sustaining seed yield of the third crop in the sequence. Residual INM

effects on seed yield followed the identical ranking recorded for the yield-attributing characters: 50% N of RDF substituted with vermicompost gave the highest seed yield in both years, followed by the FYM-substituted treatment, with sole RDF the lowest. Likewise, the recommended INM package to rice produced significantly higher residual seed yield of rapeseed than the same package with 50% organic matter. Stover yield tracked seed yield throughout — highest under sole ricebean–rice and the vermicompost-substituted, recommended-package treatments, lowest under sole teosinte–rice and RDF-only fertilization. None of the interaction effects reached significance for either seed or stover yield in either year.

Harvest index: Harvest index followed a comparable but flatter pattern than seed and stover yield: it differed significantly with cropping system, residual INM and the INM package to rice in both years, again favouring the sole ricebean–rice sequence, the vermicompost-substituted INM treatment, and the recommended INM package to rice, though the spread between the best and poorest treatments was narrower than for the yield components themselves, indicating that the residual inputs raised seed and stover yield roughly in step with one another rather than skewing partitioning strongly toward either sink.

Oil content and oil yield: Oil content of the seed itself proved far less responsive to residual treatment effects than the other characters examined. The preceding cropping system, the residual INM, and the INM package carried to rice all failed to produce a statistically significant difference in oil content in either year (Table 8), even though the numerical values still tracked the same direction as the other traits — highest under sole ricebean–rice and vermicompost substitution, lowest under sole teosinte–rice and RDF alone. Oil content behaves as a largely genotype-fixed trait that residual soil fertility can nudge only marginally. Oil yield, by contrast, is the arithmetic product of oil content and seed yield, and it inherited the significance of the seed-yield differences that drove it. Sole ricebean–rice gave the highest residual oil yield (103.53 kg/ha in 2016-17 and 114.31 kg/ha in 2017-18), and 50% N of RDF through vermicompost gave the highest oil yield among the INM treatments (104.99 kg/ha and 119.22 kg/ha), both significantly ahead of their respective lowest-yielding counterparts. The INM package to rice, however, did not significantly affect oil content or oil yield of rapeseed in either year, and no interaction among the three factors was significant for either trait — so the oil-yield advantage carried over from a legume-based, organically-managed preceding system is essentially a seed-yield effect rather than a change in seed quality.

Table 8: Residual effects of cropping system and integrated nutrient management on seed yield, stover yield, harvest index (H.I.), oil content and oil yield of rapeseed

Treatment	2016-17			2017-18			2016-17		2017-18	
	Seed yield (q/ha)	Stover yield (q/ha)	H.I. (%)	Seed yield (q/ha)	Stover yield (q/ha)	H.I. (%)	Oil content 2016-17 (%)	Oil yield 2016-17 (kg/ha)	Oil content 2017-18 (%)	Oil yield 2017-18 (kg/ha)
Cropping System (C)										
Teosinte sole–Rice– Rapeseed	2.32	6.42	26.57	2.96	8.06	26.87	29.79	69.14	30.11	89.36
Ricebean sole–Rice– Rapeseed	3.34	8.57	27.88	3.70	9.57	27.90	30.79	103.53	30.88	114.31
Teosinte + Ricebean (3:2)–Rice–Rapeseed	2.97	8.05	26.95	3.18	8.50	27.13	30.21	90.68	30.48	97.52
Teosinte + Ricebean (3:3)–Rice–Rapeseed	3.04	8.07	27.38	3.34	8.75	27.49	30.55	92.10	30.60	102.32
C.D. (P=0.05)	0.59	1.36	0.73	0.48	0.97	0.44	NS	19.72	NS	16.02
Integrated Nutrient Management (M)										
RDF (inorganic)	2.57	6.93	26.91	2.88	7.80	26.94	29.25	75.21	29.61	85.28
50% RDF-N + 50% FYM-N	3.18	8.44	27.27	3.47	9.07	27.55	30.33	96.79	29.95	104.07
50% RDF-N + 50% VC-N	3.34	8.78	27.56	3.77	9.82	27.76	31.49	104.99	31.46	119.22
100% organic (VC + FYM)	2.59	6.96	27.03	3.05	8.19	27.14	30.28	78.45	31.06	94.95
C.D. (P=0.05)	0.53	1.42	0.26	0.40	1.18	0.61	NS	14.86	NS	12.36
INM Package to Rice (I)										
I1: Recommended INM package	3.27	8.55	27.60	3.57	9.38	27.55	30.86	101.34	30.95	110.90
I2: Recommended + 50% OM	2.57	7.01	26.79	3.02	8.06	27.15	29.81	76.39	30.09	90.86
C.D. (P=0.05)	0.34	0.90	0.27	0.24	0.71	0.34	NS	10.80	NS	7.64
Interaction (C×M, C×I, M×I, C×M×I)										
All interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

System Productivity and Economics of the Whole System

System production (GFEY): The teosinte + ricebean (3:3)–rice–rapeseed sequence gave the highest green forage equivalent yield (859.19 and 901.79 q/ha), followed by sole ricebean–rice–rapeseed, due to the added legume fodder component boosting biomass (Table 9). Among nutrient treatments, 50% N of RDF + 50% N through vermicompost gave the highest GFEY (891.42 and 958.10 q/ha), while the fully organic treatment gave the lowest — showing that a balanced inorganic–organic combination outperforms either extreme. The recommended INM package to rice also gave higher GFEY than its 50% organic-substituted version. Interaction effects were non-significant.

Economics: Among cropping systems, the highest cost of

cultivation (Rs. 57, 665/ha) was incurred under teosinte + ricebean (3:2)–rice–rapeseed, while the highest gross return (Rs. 1, 28, 879/ha and Rs. 1, 35, 269/ha during 2016- 17 and 2017-18) came from teosinte + ricebean (3:3), consistent with its superior GFEY; however, sole ricebean–rice–rapeseed gave the highest net return (Rs. 73, 896/ha and Rs. 80, 312/ha) and B:C ratio (1.41 and 1.53) due to its lower cultivation cost, followed by teosinte + ricebean (3:3) (B:C 1.24 and 1.36), while sole teosinte gave the lowest (B:C 0.88 and 0.98), agreeing with ^[13] on the higher economic efficiency of legume-based sequences over sole cereal-fodder systems. Among nutrient treatments, the 100% organic treatment (50% VC + 50% FYM) was the costliest (Rs. 60, 955/ha), whereas 50% N of RDF + 50% N through vermicompost gave the highest gross return, net return (Rs. 77, 271/ha and Rs. 87, 273/ha), and B:C ratio (1.37 and

1.55); the fully organic treatment gave the lowest net return and B:C ratio (0.83 and 0.93), even below RDF alone (1.22 and 1.28), showing that full organic substitution is less economically efficient than a balanced inorganic–vermicompost combination. Likewise, for the INM package to rice, the recommended package, though marginally costlier (Rs. 56, 881/ha) than its 50% organic-substituted counterpart, gave a higher gross return,

net return (Rs. 68, 214/ha and Rs. 74, 235/ha), and B:C ratio (1.21 and 1.32), indicating better residual economics under the full recommended schedule. Overall, sole ricebean–rice–rapeseed with 50% N of RDF + 50% N through vermicompost and the recommended INM package to rice proved most remunerative, while full organic substitution, despite its soil-health benefits, was the least profitable option.

Table 9: Green forage equivalent yield (GFEY) of the system as influenced by cropping system and integrated nutrient management

Treatment	GFEY (q/ha)	
	2016-17	2017-18
Cropping System (C)		
Teosinte sole–Rice–Rapeseed	705.23	744.00
Ricebean sole–Rice–Rapeseed	843.06	885.83
Teosinte + Ricebean (3:2)–Rice–Rapeseed	828.05	868.51
Teosinte + Ricebean (3:3)–Rice–Rapeseed	859.19	901.79
S.Em±	21.62	22.62
C.D. (P=0.05)	74.80	78.27
Integrated Nutrient Management (M)		
RDF (inorganic)	761.20	781.08
50% RDF-N + 50% FYM-N	843.09	879.07
50% RDF-N + 50% VC-N	891.42	958.10
100% organic (VC + FYM)	739.82	781.87
S.Em±	15.23	15.77
C.D. (P=0.05)	44.45	46.04
INM Package to Rice (I)		
I1: Recommended INM package	833.97	874.10
I2: Recommended + 50% OM	783.80	825.96
S.Em±	11.04	8.39
C.D. (P=0.05)	31.81	24.16

Table 10: Economics of the whole system under cropping system and integrated nutrient management

Treatment	Cost of Cultivation (Rs/ha)	2016-17			2017-18		
		Gross Return (Rs/ha)	Net Return (Rs/ha)	B:C Ratio	Gross Return (Rs/ha)	Net Return (Rs/ha)	B:C Ratio
Cropping System (C)							
Teosinte sole–Rice–Rapeseed	56, 660	1, 05, 784	49, 124	0.88	1, 11, 600	54, 940	0.98
Ricebean sole–Rice–Rapeseed	52, 563	1, 26, 459	73, 896	1.41	1, 32, 875	80, 312	1.53
Teosinte + Ricebean (3:2)– Rice–Rapeseed	57, 665	1, 24, 208	66, 543	1.16	1, 30, 276	72, 611	1.27
Teosinte + Ricebean (3:3)– Rice–Rapeseed	57, 635	1, 28, 879	71, 244	1.24	1, 35, 269	77, 634	1.36
Integrated Nutrient Management (M)							
RDF (inorganic)	51, 307	1, 14, 180	62, 873	1.22	1, 17, 163	65, 856	1.28
50% RDF-N + 50% FYM-N	55, 818	1, 26, 463	70, 645	1.27	1, 31, 861	76, 043	1.37
50% RDF-N + 50% VC-N	56, 443	1, 33, 714	77, 271	1.37	1, 43, 716	87, 273	1.55
100% organic (VC + FYM)	60, 955	1, 10, 973	50, 018	0.83	1, 17, 281	56, 326	0.93
INM Package to Rice (I)							
I1: Recommended INM package	56, 881	1, 25, 095	68, 214	1.21	1, 31, 116	74, 235	1.32
I2: Recommended + 50% OM	55, 381	1, 17, 570	62, 189	1.13	1, 23, 895	68, 514	1.25

Summary of Findings

The 3:2 arrangement maximized the teosinte component, whereas the 3:3 arrangement was the strongest overall intercrop: its LER was 1.37 in 2016 and 1.40 in 2017. The 3:3 system produced 859.19 and 901.79 q ha⁻¹ green- forage-equivalent yield (GFEY) across the two years. Among nutrient treatments, 50% N through RDF + 50% N through VC consistently improved forage biomass, rice performance through residual effects, rapeseed yield and net return. Rice following sole ricebean yielded 47.24 and 49.62 q ha⁻¹, while the 3:3 intercrop was the strongest intercropping predecessor, producing 43.32 and 45.04 q ha⁻¹. Relay rapeseed following the sole ricebean–rice sequence yielded 3.34 and 3.70 q ha⁻¹; the 3:3 intercrop–rice sequence yielded 3.04 and 3.34 q ha⁻¹. Across the complete system, sole ricebean–rice–rapeseed generated the highest net returns (Rs. 73, 896 and Rs. 80, 312 ha⁻¹) and benefit–cost ratios (1.41 and 1.53), while the 3:3 intercrop produced the highest

GFEY and the highest energy productivity ratio among the intercropping options. The strongest combined recommendation was 3:3 teosinte + ricebean, with 50% N from RDF + 50% N from VC in the forage phase, recommended INM in rice, and relay rapeseed on residual fertility.

Conclusion

For medium-land situations of Assam, a 3:3 teosinte–ricebean intercrop followed by rice and relay rapeseed can intensify food and forage output without sacrificing system-level productivity. Integrating inorganic fertilizer with vermicompost was more reliable than either sole inorganic fertilizer or the fully organic combination tested. The results support a system-level approach in which forage, grain, oilseed, soil condition, profitability, and energy performance are optimized together rather than crop by crop.

Acknowledgement

The author(s) gratefully acknowledge the Department of Agronomy, Assam Agricultural University, Jorhat, for providing the experimental facilities used to conduct this study.

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