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Research Article

Nitrogen Fertilizer and Precursor Crops Effects on the Productivity of Tef and Soil Fertility in East Gojam zone, North West Ethiopia

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Abstract

Development of appropriate cropping sequence and optimization of nitrogen fertilizer is a cost effective approach to improve soil fertility and productivity of tef. Field experiments were carried out in Dejen and Enemay districts of East Gojjam Zone for two consecutive cropping years of 2021 and 2022 to determine the effects of precursor crops on nitrogen requirement of the succeeding tef yield and soil properties. Experiments were laid out in split plot design having three precursor crops (chick pea, grass pea and tef) as main plots and five nitrogen rates (0, 23, 46, 69 and 92 kg ha^{-1}) as sub plots with three replications. In both locations precursor crops (chick pea and grass pea) showed significant increase grain yield of tef. In Dejen experimental site, growing of tef following grass pea and chick pea resulted better yield advantage more than 20% compared to continuously tef planting. Similarly, in Enemay experimental location grain yield of tef was maximized by 17.31% and 16.84% when tef was planted after chick pea and grass pea respectively over tef-tef cropping sequence. Grain yield of tef tended to increase with increasing nitrogen rates in both locations. Application of 92 kg N ha^{-1} resulted the highest grain yield and maximum net benefit with acceptable marginal rate of return. Overall, growing tef following pulse precursor crops like chick pea and grass pea with optimum fertilizer is desirable to maintain soil fertility and maximize yield of tef in the sudy areas.

Keywords

Cropping Sequence, Grain Yield, Optimum Fertilizer, Precursor Crop

1. Introduction

Tef (*Eragrostis tef*), a cereal grain included in grass family of Poaceae, diversified and endemic to Ethiopia supports more than 70-75% of Ethiopia's population as staple and co-staple food [1]. In Ethiopia tef (*Eragrostis Tef*) is one of the most important cereal crops which plays a great role in terms of food security, nutrition, and income generation for small-holder farmers [2]. It is also the most desirable crop which provides protein, carbohydrate and minerals. Beside to this, its straw used as a source of cattle feed [3].

Tef is widely grown in different part of the country under diverse agro-ecological conditions in the altitude ranging from 1800 to 2100 meters above sea level. The major Tefproducing areas in Ethiopia are Amhara, Oromia, Tigray and South nation and nationality regional people of Ethiopia [4]. The national land coverage, production and productivity of tef was estimated about 2,932,670.03 ha, 5.6 metric ton and

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1.91 ton ha^{-1} respectively [5]. In Amhara region tefis the leading cereal crop in terms area coverage and the second in its volume of production following maize. East Gojjam is the leading Zone which contributes about 28% of total production of tef in the region [5].

Despite its importance and large area coverage, its productivity is very low which 1.91 t ha-^{1}. Soil fertility depletion pose a serious threat to tef production in high lands of Ethiopia which are characterized by high rainfall, soil acidity, soil erosion, leaching and the attendant non availability of plant nutrients to the crop [6]. Moreover, soil fertility decline as results of different factors and blanket fertilizer application throughout the country without considering soil types and agro-ecological are among the bottleneck to obtain sustainable desired yield [7]. According to [8] continuously growing the same crops or closely related crops for many years on the same land will generate degradation of soil quality and then cause an ecological imbalance, greatly impacting crop yield and quality. Crop rotation is one of the mostcommon management tools used to enhance soil nutrient and water availability, control weedsand pests, and improve the ecological and economic sustainability of cropping systems [9, 10]. Pulse crops in cereal based cropping system has become a widely accepted and useful agronomic practice to increase crop diversification and biologically fixed nitrogen in agro ecosystem [11]. In the high land vertisols of Ethiopia, farmers commonly used lentil (Lens culinaris medikus), chick pea (Cicer aritienum), wheat (Triticum aestivum L.) and tef (Eragrostis tef) as precursor crop to produce tef [12]. However, crops differ in their effect on the subsequent crops as they vary in its N_2 fixing ability [13, 14]. In a rotation system selecting the right type of pulse crops and incorporate at an appropriate frequency is very important to achieve the potential ecological and economic benefits [11].

However, there is no enough research conducted regarding the importance of pulse crops in rotation system and the amount of nitrogen fertilizer applied to the subsequent tef crop in our study area. Therefore, a cropping system study was initiated to determine the effects of precursor crops on N requirement of the succeeding tef yield and soil properties under rain fed conditions in East Gojjam Zone of North West Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted in Dejen and Enemay districts of East Gojjam Zone for two consecutive years of 2021 and 2022. Dejen district testing site is located at 10°11’34” North latitude and 38°82’26”East longitude with altitude of 2448 meter above sea level. The minimum and maximum temperatures of the study site is 10.21 and 21.3 °Crespectively with average annual rain fall of 756.80 mm. Whereas, Enemay district experimental site located between latitude 10° 39' 59.99" North and longitude 38° 00' 0.00"East at an altitude of 2454meters above sea level.

2.2. Treatments and Experimental Design

The experimental treatments were comprised three preceding crops (tef, chick pea and grass pea) as main plots and five nitrogen fertilizer rates (0, 23, 46, 69 and 92) kg ha^{-1} as sub plots with a total of 15 factorial treatment combinations. Split plot design with three replications was used. The gross plot area was 2.5 m x 3.6 m having a total of 18 rows. The spacing between blocks, plots and rows was 1.5, 0.5 and 0.2 m respectively. The two outer most rows from both sides and 0.25 m length from the top and bottom sides were excluding during data collection and harvesting.

2.3. Experimental Procedure

During the first cropping season (2021) preceding crops tef, chick pea and grass pea were planted with recommended nitrogen and phosphorous rates of the area. Other agronomic practices were uniformly applied based on recommendation. After harvesting the preceding crops, the crop residues purposefully left in each main plot field were incorporated into the soil during land preparation. In the second cropping season (2022), each main plot was sown with tef variety dagem [DZ-Cr-438(RIL No.91A)] at a 15 kg ha^{-1} seed rate. Nitrogen fertilizer (0, 23, 46, 69, and 92) kg ha^{-1} was applied half after emergence and the remaining half at time of tillering. Phosphorous fertilizer 20 kg ha^{-1} was uniformly applied for each plot during sowing time. Each nitrogen fertilizerwas applied half after emergence and the remaining half at time of tillering. Other agronomic practices were uniformly applied based on recommendation of the area.

2.4. Soil Samples and Analysis

Soil samples of (0-20 cm depth) were collected from experimental sites before sowing and after harvesting the experiment. The samples were analyzed for pH, total N, available phosphorous and organic C. Soil pH was determined based on pH meter with a soil to waterratio of 1:2.5Organic carbon was analyzed by the method of [15]. The Kjeldahl method's procedures were used to calculate the total nitrogen [16]. Available P was determined by the Bray II method [17].

2.5. Data Collection

Plant height (cm): It was measured from the base of the main stem to the top of the panicle from 10 representative selected samples in each net plot area.

Panicle length (cm): The lengths of panicles from ten earlier tagged plants were measured starting from the first panicle branch to the top of the panicle.

Number of productive tillers per plant: Number of productive tillers was determined by counting from 10 randomly selected plants in the net plot area.

Above ground biomass (kg ha^{-1}): Plants in the net plot area were harvested at ground level and tied into bundles. After sun-drying to a constant weight, above ground biomass yield was recorded.

Grain Yield (kg ha^{-1}): Grain yield was measured using sensitive balance after threshing and cleaning the seed.

2.6. Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS version 9.0 Statistical Software (SAS, 2002). Whenever the ANOVA results show significant differences among treatments, means were compared using least significance difference (LSD) test at 0.05 probability level of significant.

2.7. Economic Analysis

Economic analysis was carried out based on the procedures of [18]. The cost of fertilizer (Urea), which varied between treatments, was taken in account for the partial budget analysis. The average grain and straw yield of tef was adjusted to 10% downwards to narrow the yield gabs between experimental plots and farmers fields. The average selling price of tef grainduring (January-March (2015) atDejen and Enemay districts were (Eth- Birr 64.80 and 65.33 kg^{-1}) respectively. Similarly the price of straw was estimated to be (Eth- Birr 2.32 and 2.20 kg^{-1}) in Dejen and Enemay experimental sites were used for partial budget analysis. The cost of urea during sowing time was (Birr 36.60 and 37.10 kg^{-1}) in Dejen and Enemay districts respectively. All costs and benefits were calculated on hectare basis in Birr. The dominance analysis was carried after arranging the treatments in its increasing order of TVC. A treatment considered as dominated if it has higher total variable cost but lower net benefit than a previous treatment was excluded from marginal rate of return analysis. Marginal rate of return (MRR %) was estimated the change in the net benefit to the change in total variable costs.

3. Results and Discussion

Soil properties result before and after rotation of precursor crops

3.1. Soil Properties Before to Sowing

The pre sowing soil results showed that the soil pH, organic carbon, total N and available P were 6.33, 0.67%, 0.06% and 7.8 mg kg^{-1} respectively from Dejen trial site. In Enemya location, the pH, organic carbon, total N and available P were 7.37, 0.53%, 0.06% and 9.33 mg kg^{-1} respectively (Table 1).

Table 1. *Physicochemical properties of the soils from both sites before to sowing.*

Location	(pH)	OC (%)	TN (%)	AP (mg kg^{-1})
Dejen	6.33	0.67	0.06	7.80
Enemay	7.37	0.53	0.06	9.33

Note: OC: organic carbon; TN: total nitrogen; AP: available phosphorous; CEC: cation exchange capacity

3.2. Soil Properties After Precursor Crops

The soil result after precursor crops showed slight improvement on different soil properties (Table 2). Accordingly, the soil pH was ranged from 6.38 to 6.56 in Dejen and 7.67to 7.93 in Enemay location, which is slightly acidic to moderately alkaline respectively. Soil organic carbon was found 0.63% to 0.82% and 0.58% to 0.82% in Dejen and Enemay experimental sites respectively. Thus, the organic carbon content of the trial sites rated as very low [19]. Total nitrogen after precursor crops presented in Table 2 indicated as it is low in both locations [20]. The available phosphorous content from the soil analysis after precursor crops found within the range of medium to very high [21]. Based on the soil result, there were deficiencies on total nitrogen and soil organic carbon which is might be due to the result of mono cropping practice in the area. Long term crop rotation with pulse and oil crops is desirable to improve the soil fertility and increase productivity.

Table 2. *Soil laboratory results after precursor crops from both sites.*

	Dejen			Enemay		
Parameters	Chick pea	Gras pea	Tef	Chick pea	Gras pea	Tef
pH (H_2O)	6.40	6.56	6.38	7.80	7.93	7.67
Organic C (%)	0.78	0.82	0.63	0.74	0.82	0.58
Total N (%)	0.063	0.071	0.059	0.064	0.057	0.056
Ava. P (ppm)	21.587	16.798	13.195	25.990	19.586	11.192

	Dejen			Enemay		
Parameters	Chick pea	Gras pea	Tef	Chick pea	Gras pea	Tef
CEC ($Cmol_c$ kg^{-1})	43.02	42.42	42.16	61.42	61.42	60.88

Note: OC: organic carbon; TN: total nitrogen; AP: available phosphorous; CEC: cation exchange capacity

3.3. Effect of Precursor Crops on Growth and Yield Components of Tef

Plant height (cm)

Plant height was significantly (P<0.01) affected by the main effects of precursor crops and nitrogen fertilizer rates at both experimental sites (Tables 3 and 4). However, there was non significant interaction between precursor crops and N fertilizer rate for any of measured traits. Seeding of tef following chick pea and grass pea gave the highest plant height compared to tef sowing year after year without rotation at both experimental sites. This might be due to importance pulse crops which can fix N_2 in the soil system and thus increase the growth and development of plants. The results demonstrated by [22, 23] revealed that the cropping sequence of pulse to cereals significantly increase the plant height due to their property in fixation of nitrogen.

Application of 92 kg N ha^{-1} resulted the maximum plant height (93.71 cm) in Dejen and (80.88 cm) Enemay experimental site. Whereas, the minimum plant height (67.57 cm) and (64.52 cm) were observed from nil application of nitrogen fertilizer in Dejen and Enemay experimental locationsrespectively (Tables 3 and 4). The increased in plant height with nitrogen fertilizer could be the role of N in stimulating cell division and elongation [24]. The current result is consistent with the study of [25] who, reported that the maximum plat height was recorded from the highest nitrogen fertilizer applications. Likewise, [13] and [26] showed that plant height increased with nitrogen fertilizer application rate.

Panicle length

Analysis of variance revealed that panicle length was significantly (P<0.001) influenced by the main effects of precursor crops and nitrogen fertilizer rate in Enemay district. In Dejen experimental site, panicle length was significantly (P<0.001) affected by nitrogen fertilizer rates but not by precursor crops (Table 3). In both locations, panicle length of tef was tended to increase with increasing nitrogen rates (Tables 3 and 4). In Enemay experimental location, the maximum panicle length (28.19 cm) was recorded when tef was sown after chick pea. However, it was statistically on par with grass pea to tef cropping sequence (Table 4). Closely confirmed with the current result, [23] reported that the highest spike length was recorded from pulse precursor crops thancontinuous wheat cropping plot.

The maximum panicle length of tef in Dejen (30.35 cm) and Enemay (28.34 cm) was recorded from the highest 92 kg N ha^{-1} applications. Whereas, the minimum panicle length (25.33 cm) and (28.19 cm) was obtained in Dejen and Enemay locations respectively from unfertilized treatments. Similar to the present result [27] and [25] reported significantly higher and lower mean panicle length of tef was obtained from the highest and control treatments of nitrogen fertilizer applications respectively.

Number of productive tillers

Number of productive tillers of tef was significantly (P<0.01) influenced by the main effects of precursor cropsin Enemay location (Table 4). However, it was non significantly influenced by both factors in Dejen experimental site (Table 3). Significantly, maximum number of productive tillers per plant (4.95) was counted from tef following chick pea cropping sequence while, the minimum (2.88) recorded from continuous growing of tef. In contrary with the current result, non significant variation on number of finger head was observed between precursor crops [28].

Biomass yield (kg ha^{-1})

Precursor crops and nitrogen fertilizer rate significantly (P<0.01) affect biomass yield of tef at both locations (Tables 3 and 4). The cropping sequence of pulse crops to tef significantly increase biomass yield of tef compared to continuously growing of tef. The maximum biomass yield of tef in Dejen (4016.70 kg ha^{-1}) and Enemay (5100 kg ha^{-1}) was obtained to the sequence of chick pea to tef. However, it was not statistically different from the results obtained tef following grass pea (Tables 3 and 4). This probably due to the effect of crop sequence with precursor crops such as chick pea and grass pea which provide additional benefit of residual fertility in addition to the applied inorganic nitrogen and resulted exuberant crop growth consequently increase biological yield [29]. The minimum biomass yield (3266.66 kg ha^{-1}) and (4116.70 kg ha^{-1}) was recorded in the continuous tef treatments in Dejen and Enemay locations respectively. Biomass yield advantage of 18.67% and 14.48% was obtained in Dejen experimental site as a result of precursor crops chick pea and grass pea respectively. Likewise, in Enemay location sowing of tef following chick pea and grass pea gave additional biomass yield 19.28% and 17.94% respectively compared to continuous tef cultivation. Pulse precursor crops improve biomass yield of tef from both heavy and light vertisols over cereal-cereal cropping sequence [12]. The present result was also closely confirmed with the study of [28] who, reported that the highest biomass yield of finger millet was obtained from finger millet following lupine and niger seed than cereal precursors. The effect of pulse precursor crops on biological yield of the subsequent crop over cereal-cereal rotation was reported by [13, 23, 30].

Biomass yield of tef was increased as nitrogen fertilizer increased at both locations. The highest biomass yield in Dejen (5183.30 kg ha^{-1}) and Enemay (6166.70 kg ha^{-1}) was obtainedfrom the application of 92 kg N ha^{-1}. Whereas, the lowest (2266.70 kg ha^{-1}) and (3333.30 kg ha^{-1}) was recorded from unfertilized treatments in Dejen and Enemay locations respectively (Tables 3 and 4). In Dejen trial site, application of 69 kg N ha^{-1} was statistically similar with 92 kg ha^{-1} nitrogen fertilizer applications. The difference in biomass yield might be due to the role of nitrogen fertilizer which enhance vegetative growth of the crop and thus in turn increase biological yield [31]. Application of 92 kg N ha^{-1} provide better biomass yield benefit of 56.39% and 45.95% in Dejen and Enemay locations respectively over unfertilized treatment. In harmony with the present result [25, 26] statedthat biomass yield of tef tended to increase with nitrogen rates. Likewise, biomass yield increase with increasing N rate on different cereal crops were reported by [13, 30, 32].

Grain yield (kg ha^{-1})

Analysis of variance revealed that grain yield was significantly (P<0.01) influenced by the main effects of precursor crops and nitrogen fertilizer rates at both experimental sites (Tables 3 and 4). The yield of tef was improved as a result of rotations made with chick pea and grass pea at both locations than continuously growing tef. In Dejen experimental site, growing of tef following grass pea and chick pea resulted better yield advantage of 21.12% and 21.02% respectively compared to continuously tef planting without rotation (Table 3). Similarly, in Enemay experimental location grain yield of tef was maximized by 17.31% and 16.84% when tef was planted after chick pea and grass pea respectively (Table 4). The current result was consistent with the study of [12], who, reported that precursor pulse crops significantly increase the grain yield of tef over cereal to cereal rotations. Beside to this, finger millet based rotation experiment conducted by [28] showed that significantly higher grain yield was recorded from lupine and niger seed precursors compared to cereal precursors. Beside to these, different authorsreported that pulse precursor crops improve the yield of subsequent crops [33, 13, 30, 23].

At both sites, the grain yield of tef maximized as the nitrogen rate increased (Tables 3 and 4). Applications of 92 kg N ha^{-1} produced the highest grain yields in Dejen (1622.69 kg ha^{-1}) and Enemay (1915.80 kg ha^{-1}). On the other hand, the minimum grain yield (828.58 kg ha^{-1}) and (1189.20 kg ha^{-1}) was recorded from nil applications of nitrogen fertilizer in Dejen and Enemay trial sites respectively (Tables 3 and 4). The increased in grain yield due to nitrogen fertilizer could be ascribed to the role of N enhanced vegetative growth of plants, increase photosynthetic activity and consequently produced maximum yield [24]. Application of 46, 69 and 92 kg N ha^{-1} gave additional yield advantage of 32.76%, 40.83% and 48.94% respectively over the control in Dejen location. Similarly, in Enemay experimental site application of 46, 69 and 92 kg N ha^{-1} provide additional yield benefit of 24.35%, 31.52% and 37.93% respectively over unfertilized treatments. In conformity of the present study [25] reported application of 92 kg N ha^{-1}increased grain yield of tef by 131.01%, 87.78% and 182.23% in Sekota, Sayda and lasta-Lalibela districts respectively compared to the control treatment. Moreover, different studies confirmed that grain yield tended toincrease with increasing nitrogen rates [29, 34, 30].

Table 3. *Main effects of precursor crops and N fertilizer rateon growth, yield and yield related traits oftef in Dejen experimental site.*

Treatments	Plantheight (cm)	Paniclelength (cm)	Productivetillers/plant	Biomassyield (kg ha^{-1})	Grainyield (kg ha^{-1})
Precursor crops					
Chick pea	82.51a	28.30	3.71	4016.70a	1308.13a
Grass pea	82.82a	27.89	3.66	3819.69a	1309.44a
Tef	78.23b	27.32	3.47	3266.66b	1033.16b
LSD (0.05)	2.45**	NS	NS	399.50**	147.64**
N rate (kg ha^{-1})					
0	67.57e	25.33c	3.24	2266.70d	828.58c
23	75.68d	26.57c	3.39	2961.10c	1000.77c
46	82.83c	28.21b	3.86	3544.40b	1232.22b
69	86.14b	28.73b	3.64	4669.40a	1400.28b
92	93.71a	30.35a	3.92	5183.30a	1622.69a
LSD	3.16***	1.50***	NS	515.75**	190.60**

Treatments	Plantheight (cm)	Paniclelength (cm)	Productivetillers/plant	Biomassyield (kg ha^{-1})	Grainyield (kg ha^{-1})
CV (%)	4.03	5.59	20.66	14.33	16.22

Note: Means with the same column followed by the same letter (s) are not significantly different at 5% significant level. Where NS: Non significant; LSD: Least Significant Difference; CV: coefficient of variation in percent

Table 4. Main effects of precursor crops and N fertilizer rate on growth, yield and yield related traits of tef in Enemay experimental site.

Treatments	Plant height (cm)	Panicle length (cm)	Productive tillers/plant	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Precursor crops					
Chick pea	75.57a	28.19a	4.95a	5100.00a	1685.84a
Grass pea	73.44a	25.14b	3.21b	5016.70a	1676.25a
Tef	67.94b	23.54c	2.88b	4116.70b	1393.96b
LSD (0.05)	4.27**	1.52***	0.51**	555.11**	162.85**
Nitrogen rate (kg ha^{-1})					
0	64.52d	23.64c	3.43	3333.30d	1189.20d
23	67.54cd	24.39c	3.57	4389.90c	1513.30c
46	71.67bc	25.03bc	3.71	4527.80c	1571.90bc
69	76.98ab	26.70ab	3.74	5305.6b	1736.60ab
92	80.88a	28.34a	3.93	6166.70a	1915.80a
LSD	5.51***	1.96***	NS	716.65***	210.24***
CV (%)	7.89	7.92	18.64	15.64	13.73

Note: Means with the same column followed by the same letter (s) are not significantly different at 5% significant level. Where NS: Non significant; LSD: Least Significant Difference; CV: coefficient of variation in percent

Partial budget analysis

Based on partial budget analysis, application of different N rates regardless of precursor crops resulted net benefit with acceptable marginal rate of return in both experimental sites, except in Enemay location at application of 46 kg N ha^{-1} which was un acceptable MRR (Table 5). Increasing nitrogen fertilizer 0 to 92 kg ha^{-1} increase the net benefit correspondingly in both locations. Application of 92 kg N ha^{-1} gave the highest net benefit ETB (94,749.75) in Dejen and (113,639.88) in Enemay working sites with acceptable marginal rate of return. In line with the current study sowing of tef with the application of maximum nitrogen gave the highest net benefit with acceptable marginal rate of return [25].

Table 5. Partial budget analysis of tef as influenced by N rates across sites.

Treatments	Adjusted gain yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Gross benefit ETB ha^{-1}	TVCETB ha^{-1}	Net benefit ETB ha^{-1}	MRR (%)
Dejen district						
0	745.72	1,294.29	51,325.41	0.00	51,325.41	-
23	900.69	1,764.27	62,457.82	1,830	60,627.82	508.33
46	1109.00	2,080.98	76,691.07	3,660	73,031.70	677.81

Treatments	Adjusted gain yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Gross benefit ETB ha^{-1}	TVCETB ha^{-1}	Net benefit ETB ha^{-1}	MRR (%)
69	1,260.25	2,942.28	88,490.29	5,490	83,000.28	544.73
92	1,460.42	3,204.54	102,069.75	7,320	94,749.75	642.05
Enemay district						
0	1070.28	1929.78	74,166.91	0.00	74,166.91	-
23	1361.97	2588.04	94,671.19	1855	92,816.19	1005.35
46	1414.71	2660.31	98,275.69	3710	94,565.69	94.31
69	1562.94	3212.10	109,173.49	5565	103,608.49	487.48
92	1724.22	3825.72	121,059.88	7420	113,639.88	540.78

Notes: ETB=Ethiopian birr; MRR; marginal rate of return; TVC= total variable cost

4. Conclusion and Recommendation

The present study clearly notified that precedingpulse crops improve the yield of subsequent tef yield. Yield and yield components of tef were increased linearly with nitrogen fertilizer application. This suggests that the amount of nitrogen fertilizer applied on tef following pulse crops may not be enough. Therefore, in order to improve productivity and sustain soil fertility, long-term rotation experiments must be carried out.

Generally, using appropriate pulse crops in a rotation system combined with optimum fertilizer improve soil fertility and maximize crop productivity.

Abbreviations

ANOVA	Analysis of Variance
AP	Available Phosphorous
CEC	Cation Exchange Capacity
CIMMYT	Centre for International Maize and Wheat Improvement
LSD	Least Significance Difference
MRR	Marginal Rate of Return
OC	Organic Carbon
SAS	Statistical Analysis System
TVC	Total Variable Cost

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Conflicts of Interest

The authors declare no conflicts of interest.

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