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Research Article

Integrated Nitrogen, Farmyard Manure, and Vermicompost Improve Barley Productivity in the Central Highlands of Ethiopia

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Abstract

Soil fertility depletion caused by declining organic matter and imbalanced nutrient inputs is a major constraint to barley (Hordeum vulgare L.) production in the Ethiopian highlands. A field experiment was conducted during the 2022/2023 main cropping season at Holeta Agricultural Research Center, Ethiopia, to evaluate the effects of integrating nitrogen fertilizer, vermicompost, and farmyard manure on soil properties and barley productivity under a randomized complete block design with three replications. Initial soil analysis indicated clay-textured, moderately acidic soil with low organic carbon (1.22%), total nitrogen (0.12%), and available phosphorus, confirming nutrient limitations in the study area. Integrated nutrient application significantly ($P < 0.05$) improved soil chemical properties, yield components, and grain yield compared with sole application of organic or inorganic fertilizers. The combined application of 75% recommended vermicompost and 75% recommended nitrogen fertilizer produced the highest grain yield (4545.59 kg ha^{-1}), followed by 75% farmyard manure combined with 75% nitrogen fertilizer. Yield improvement was associated with increased spike length, grains per spike, and aboveground biomass production. Vermicompost-based treatments showed relatively greater yield advantages than farmyard manure treatments, likely due to faster nutrient mineralization and improved nutrient availability. Economic analysis also indicated higher net returns and marginal profitability under integrated nutrient management treatments. The results demonstrate that combining organic amendments with mineral nitrogen improves soil fertility and barley productivity and provides a sustainable nutrient management strategy for food barley production in the Ethiopian highlands.

Keywords

Barley Productivity, Integrated Nutrient Management, Nitisoil, Soil Fertility, Sustainable Agriculture

1. Background and Justification

Soil fertility depletion remains one of the major constraints to agricultural productivity in the Ethiopian highlands, where continuous cultivation, soil erosion, nutrient mining, and inadequate nutrient replenishment have accelerated the decline of soil organic matter and essential plant nutrients [1]. In the acidic highland soils of Welmera District, intensive farming practices and residue removal have substantially reduced soil quality and crop productivity [2]. Recent estimates indicate

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annual losses of approximately 122 kg N ha^{-1}, 13 kg P ha^{-1}, and 82 kg K ha^{-1}, together with a soil organic carbon deficit of nearly 3.7 t ha^{-1}, highlighting severe nutrient depletion in central Ethiopian agroecosystems [3]. Consequently, many cultivated soils in the region are no longer capable of sustaining optimum crop production without external nutrient inputs [4]. To maintain crop productivity, smallholder farmers increasingly depend on mineral fertilizers, particularly urea and diammonium phosphate [5]. Although inorganic fertilizers provide readily available nutrients and can substantially increase yields, their effectiveness is often limited by low nutrient-use efficiency, high costs, and the absence of site-specific nutrient management recommendations [4]. Moreover, continuous reliance on mineral fertilizers alone may contribute to soil acidification and deterioration of soil physical and biological properties, thereby threatening long-term agricultural sustainability [7].

Organic nutrient sources such as farmyard manure (FYM) and vermicompost (VC) have gained increasing attention as sustainable soil fertility management options because they improve soil physical, chemical, and biological properties while supplying essential macro- and micronutrients for crop growth [8]. Vermicompost, in particular, enhances nutrient mineralization, microbial activity, cation exchange capacity, and soil aggregation, leading to improved nutrient availability and crop performance. However, the use of organic amendments alone is often insufficient to satisfy crop nutrient demand because of their relatively slow nutrient release, labor-intensive handling, and limited availability under smallholder farming systems [9]. In many rural communities, organic materials are also diverted for livestock feed and household fuel, further restricting their agricultural application. As a result, sole application of organic nutrient sources rarely achieves optimum yields under intensive cereal production systems [10].

Barley (*Hordeum vulgare* L.) is one of the world's major cereal crops and an important food security crop in the Ethiopian highlands. Globally, it ranks fourth after wheat, rice, and maize in terms of production importance [11]. In Ethiopia, barley is widely cultivated and serves as a staple food crop for millions of households, particularly in highland areas where it is extensively used in traditional foods and beverages [12]. Despite its socioeconomic importance, barley productivity in Ethiopia remains substantially below its potential, mainly because of declining soil fertility and inadequate nutrient management practices [13].

Integrated nutrient management, which combines organic amendments with mineral fertilizers, has emerged as a promising strategy for improving nutrient-use efficiency, restoring soil fertility, and sustaining crop productivity in degraded agroecosystems. Although integrated nutrient management has been widely promoted, comparative evidence regarding the effectiveness of vermicompost and farmyard manure combined with reduced nitrogen fertilizer rates remains limited under the acidic highland conditions of central Ethiopia. Consequently, locally adapted nutrient management recommendations suitable for barley-based smallholder farming systems are still inadequate.

We hypothesized that the integrated application of vermicompost or farmyard manure with mineral nitrogen fertilizer would improve soil fertility and barley productivity more effectively than the sole application of either mineral fertilizer or organic amendments. Therefore, this study aimed to evaluate the effects of combined applications of vermicompost, farmyard manure, and nitrogen fertilizer on soil physicochemical properties and barley yield in the central highlands of Ethiopia.

2. Materials and Methods

2.1. Study Area

The field experiment was conducted during the 2022/2023 main cropping season at the Holeta Agricultural Research Center (HARC), located in Welmera District, Oromia Regional State, central Ethiopia, approximately 30 km west of Addis Ababa. The experimental site is situated between 09°01′- 09°03′ N latitude and 38°30′ - 38°32′ E longitude at an elevation of approximately 2,400 m above sea level. The study area is characterized by a cool sub-humid highland agroecology with a unimodal rainfall pattern.

Long-term climatic records from HARC indicate a mean annual rainfall of 1,067 mm, of which approximately 85% occurs between June and August. Mean annual minimum and maximum temperatures are 7.1°C and 23.3°C, respectively, with an average relative humidity of 65.8%. The topography is dominated by gently sloping plateau landscapes typical of the Ethiopian central highlands. The dominant soils in the area are Nitisols and Vertisols derived primarily from volcanic parent materials, including basalt, granite, schist, and gneiss. Nitisols are predominant and are characterized by deep clay profiles, moderate to poor drainage, stable blocky structure, and strong weathering [14]. The farming system in Welmera District integrates mixed crop-livestock production, where cereals including barley, wheat, teff, and maize constitute the major crops, while cattle, sheep, and goats are the dominant livestock species.

2.2. Preparation and Characterization of Organic Amendments

Vermicompost (VC) was prepared at HARC using a 1 m × 1 m × 1 m composting bin. Organic feedstocks consisted of crop residues, green plant materials, animal manure, pulse straw, and dry leaves arranged in successive layers comprising approximately 60% crop residues, 30% animal manure, and 10% topsoil. The earthworm species *Eisenia foetida* was introduced to facilitate decomposition, while castor leaves were periodically supplied as supplementary feed. Moisture content

was maintained at 60 -70% throughout the composting period, and the materials were manually turned every three days to ensure adequate aeration and uniform decomposition. Mature vermicompost was identified based on its dark brown to black coloration, granular structure, and earthy odor.

Farmyard manure (FYM) was obtained from the livestock unit of HARC and consisted primarily of decomposed cattle dung, urine, bedding materials, and straw residues. The manure was composted for approximately four months under partially aerobic conditions following the procedure described by Beyenesh and Nigussie [15]. Moisture content was maintained at approximately 15% during decomposition. Nutrient composition of FYM was within the range previously reported for well-decomposed cattle manure. Representative samples of VC and FYM were analyzed prior to field application to determine pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity using standard laboratory procedures.

2.3. Experimental Design and Treatments

The experiment was arranged in a randomized complete block design (RCBD) with three replications. Seventeen treatments consisting of different combinations of vermicompost, farmyard manure, and mineral nitrogen fertilizer were evaluated. Recommended application rates were 10 t ha^{-1} for both VC and FYM and 60 kg N ha^{-1} for mineral nitrogen fertilizer based on local fertilizer recommendations for barley production. The treatments included sole applications of VC, FYM, and nitrogen fertilizer, as well as integrated applications at varying proportions of the recommended rates (RR). The treatment combinations were as follows: Treatment Description. T1 - Unfertilized control; T2 -50% FYM + 25% N; T3 - 50% FYM + 50% N; T4 - 50% FYM + 75% N; T5 - 75% FYM + 25% N; T6 -75% FYM + 50% N; T7 - 75% FYM + 75% N; T8 - 50% VC + 25% N; T9 - 50% VC + 50% N; T10 - 50% VC + 75% N; T11 - 75% VC + 25% N; T12 -75% VC + 50% N; T13 - 75% VC + 75% N; T14 - 100% recommended N; T15 -100% recommended VC; T16 - 100% recommended FYM; T17 - Farmer practice (50% FYM + 25 kg N ha^{-1}). Treatments were randomly assigned within each block.

2.4. Field Management and Crop Husbandry

The experimental field measured 42 m x 11 m (462 m^2). Land preparation involved tractor plowing using a mouldboard plough followed by harrowing to obtain a fine seedbed. Individual plot size was 2 m x 3 m (6 m^2), with 0.5 m spacing between plots and 1 m spacing between blocks. Organic amendments were uniformly incorporated into the upper 0-20 cm soil layer one month before sowing to allow partial mineralization prior to crop establishment. Nitrogen fertilizer in the form of urea (46% N) was applied in two equal splits: half at planting and the remaining half at the mid-tillering stage. The improved food barley variety HB-1307 was sown manually in rows at a seed rate of 125 kg ha^{-1}. Weeding was performed manually at 32 and 54 days after sowing. All other agronomic practices, including field management and crop protection measures, were conducted in accordance with standard recommendations for barley production in the Ethiopian highlands.

2.5. Soil Sampling and Laboratory Analysis

Composite soil samples were collected from the 0-20 cm depth prior to treatment application and immediately after harvest. Five subsamples were collected diagonally from each experimental plot using an auger and thoroughly composited to obtain representative samples. Undisturbed core samples were additionally collected for bulk density determination. Soil samples were air-dried, ground, and passed through a 2-mm sieve prior to analysis, whereas samples for organic carbon and total nitrogen determination were sieved through a 0.5-mm mesh. Particle size distribution was determined using the hydrometer method [16]. Bulk density was measured using the core sampling method [17], while gravimetric procedures were used to determine soil moisture content [18]. Soil pH was measured in a 1: 2.5 soil-to-water suspension following McLean [19]. Soil organic carbon was determined using the Walkley-Black wet oxidation method [20] and total nitrogen was analyzed using the Kjeldahl digestion procedure [21]. Available phosphorus was extracted using the Bray II method [22]. Exchangeable acidity was determined using 1 N KCl extraction. Exchangeable Ca, Mg, K, and Na, as well as cation exchange capacity (CEC), were analyzed using ammonium acetate extraction at neutral pH [23]. Representative samples of VC and FYM were similarly analyzed for pH, organic carbon, total nitrogen, available phosphorus, and exchangeable cations using established analytical procedures.

2.6. Agronomic and Yield Measurements

Phenological observations included days to heading and days to physiological maturity. Days to heading were recorded when approximately 50% of plants in each plot had fully emerged spikes, whereas physiological maturity was recorded when nearly 90% of plants attained maturity. Growth and yield parameters were measured using five randomly selected and pre-tagged plants from the central rows of each plot. Plant height was measured from the soil surface to the tip of the spike, excluding awns. Productive tillers per plant and spike length were also recorded. Yield-related parameters included thousand-grain weight, aboveground biomass yield, grain yield, straw yield, and harvest index. Grain yield was adjusted to a standard moisture content of 12.5% prior to conversion to t ha^{-1}. Harvest index was calculated as the ratio of grain yield to total aboveground biomass following Biru [24].

2.7. Economic Analysis

Economic performance of the treatments was evaluated using partial budget analysis following the procedures outlined

by CIMMYT [25]. Variable production costs associated with fertilizer acquisition, transport, and application were considered in the analysis. Net benefits and marginal rates of return were calculated to identify economically viable nutrient management options for smallholder farmers.

2.8. Statistical Analysis

All measured variables were subjected to analysis of variance (ANOVA) using the generalized linear model (GLM) procedure in R statistical software version 4.3.3 [26]. Prior to analysis, assumptions of normality and homogeneity of variance were assessed using residual diagnostic tests. Treatment means were separated using Fisher's least significant difference (LSD) test at the 5% probability level. Pearson correlation analysis was performed to evaluate relationships among soil physicochemical properties and agronomic parameters. Statistical analyses were conducted using the agricolae and emmeans packages in R [27].

3. Results and Discussion

3.1. Pre-planting Soil Physicochemical Properties

The experimental soil was classified as clay, comprising 13.5% sand, 19% silt, and 67.5% clay, consistent with typical highland Nitisol characteristics. Such fine-textured soils are generally suitable for barley (*Hordeum vulgare* L.) production due to their relatively high water-holding capacity and nutrient retention potential. Soil bulk density (1.24 g cm^{-3}), total porosity (53.21%), and gravimetric moisture content (16.24%) indicated favorable physical conditions for root development. The bulk density was below the critical threshold for clay soils (~1.4 g cm^{-3}), suggesting minimal physical restriction to root penetration and aeration [28]. However, soil chemical properties revealed clear fertility constraints. Soil pH (5.38) indicated moderate acidity, which is known to increase exchangeable Al^{3+} and H^{+} activity and reduce nutrient availability. Given that optimal barley production occurs near neutral to slightly acidic conditions (pH 5.5-8.0), the observed acidity likely constrained nutrient use efficiency.

Soil organic carbon (1.22%) and total nitrogen (0.12%) were low, indicating depleted soil organic matter pools, likely driven by continuous cultivation and insufficient organic residue return. Available phosphorus was also low, suggesting strong P fixation under acidic conditions. Although cation exchange capacity (15.98 cmol (+) kg^{-1}) was moderate, nutrient supply capacity remained limited due to low organic matter. Exchangeable bases showed moderate Ca, low Mg, and variable K status, while micronutrients (Zn, Fe, Mn) were relatively adequate. Overall, the soil fertility status indicates a system constrained primarily by N, P, and organic matter deficiency rather than micronutrient limitation, necessitating integrated nutrient management interventions.

3.2. Chemical Composition of Organic Amendments

The pH of vermicompost (7.60) and farmyard manure (7.01) indicated near-neutral conditions, favorable for soil buffering upon application. Both amendments exhibited low carbon-to-nitrogen ratios, confirming advanced decomposition and suitability for direct field application. Vermicompost contained slightly higher total nitrogen (0.50%) compared with FYM (0.45%), whereas FYM had relatively higher organic carbon content. The higher phosphorus concentration in vermicompost suggests enhanced mineralization and microbial activity during vermi-processing, which improves nutrient transformation efficiency. Exchangeable cation concentrations and cation exchange capacity were higher in vermicompost than FYM, indicating superior nutrient retention and release potential. These differences suggest functional complementarity: FYM primarily contributes to gradual soil conditioning and structural improvement, while vermicompost provides more readily available nutrients and biologically active compounds. Thus, both amendments are suitable for integrated use with mineral nitrogen to enhance synchronized nutrient supply and soil fertility improvement.

3.3. Phenological Responses to Nutrient Management

Days to heading (DH) remained statistically similar across treatments, indicating that nutrient management had limited influence on the onset of reproductive growth. This finding agrees with Adane [29, 30], who reported relatively low sensitivity of barley heading to nutrient variation. In contrast, days to physiological maturity (DPM) varied significantly among treatments. The application of 75% FYM + 50% N and 75% VC + 50% N significantly shortened DPM compared with the control, suggesting improved nutrient availability during reproductive development, consistent with Adane [29]. Higher N rates generally accelerated physiological maturity, in agreement with Dinka [30], whereas sole applications of FYM or VC tended to delay maturity, likely due to their slower nutrient release and gradual nutrient availability (Nair et al., 2021). Overall, the results indicate that integrating mineral N with organic amendments can modify barley developmental timing through improved nutrient availability.

3.4. Growth Responses of Barley to Integrated Nutrient Management

The integrated application of N fertilizer, vermicompost (VC), and farmyard manure (FYM) significantly influenced barley growth parameters. Plant height (PH) varied significantly ($P < 0.05$), from 87.47 cm in the control to 107.47 cm

under 75% VC + 75% N (Appendix Table 4; Table 8), indicating enhanced vegetative growth with improved nutrient availability. The greater response under combined N and organic amendments agrees with [33], who reported increased barley plant height under integrated nutrient management.

Total tiller count (TT) also varied among treatments, with the lowest value (1.93) in the control and the highest (3.33) under 100% VC. Treatments receiving 75% FYM + 75% N and 75% VC + 50% N also increased tillering, suggesting that improved nutrient supply promotes canopy development. This agrees with Kumar [34], who reported enhanced tiller production with N fertilization.

Productive tillers (PT) responded particularly strongly to N availability, ranging from 1.33 in the control to 2.87 under 75% FYM + 75% N. Higher N treatments, including 75% VC + 75% N and 100% N, produced greater numbers of productive tillers, highlighting the importance of adequate N supply for yield formation. Similar responses were reported by [35], who demonstrated that integrated organic and mineral fertilization enhances productive tillering in barley.

Overall, integrated nutrient management improved key barley growth traits, particularly plant height, tillering, and productive tillers, demonstrating the potential of combining mineral N with organic amendments to enhance crop productivity and nutrient-use efficiency.

Table 1. *Effect of N fertilizer with VC and FYM on growth parameters of food barley.*

Treatments	PH	TT	PT
Control	87.47e	1.93e	1.33f
50%FYM+25%N	91.60 c-e	2.33b-e	1.73c-f
50%FYM+50%N	95.87 c-e	2.27c-e	1.67d-f
50%FYM+75%N	99.07a-d	3.13a-c	2.13c-e
75%FYM+25%N	94.87c-e	2.27c-e	1.80c-f
75%FYM+50%N	99.20a-d	2.67a-e	2.27b-d
75%FYM+ 75%N	101.87a-c	2.73a-e	2.87a
50%VC+ 25%N	99.40a-d	2.00 de	1.53ef
50%VC+50%N	99.53a-d	1.93e	1.60ef
50%VC+75%N	99.27a-d	2.80a-e	2.07c-e
75%VC+25%N	93.87c-e	2.67a-e	1.93c-f
75%VC+50%N	99.47a-d	3.27ab	2.33a-c
75%VC+75%N	107.47a	2.80a-e	2.80ab
100%N	106.53ab	2.80a-e	2.07c-e
100%VC	90.33de	3.33a	2.00c-e
100%FYM	96.33b-e	3.07a-c	2.00c-e
50%FYM+25kg N	98.13a-d	2.93a-d	2.13c-e
LSD (0.05)	8.95	0.81	0.54
CV (%)	5.51	18.34	15.98

PH= plant height, TT= total number of tillers, PT= productive tillers, FYM=farm yard manure, VC=vermicompost, N=nitrogen, LSD= least significant difference, CV=coefficient variation

3.5. Yield and Yield Responses of Barley to Integrated Nutrient Management

The combined application of N fertilizer with FYM and VC significantly influenced spike length (SL), grains per spike (GPS), and thousand-grain weight (TGW) ($P < 0.05$; Appendix Table 4). Spike length increased from 5.67 cm in the control to 7.47 cm under 75% FYM + 75% N and 7.30 cm under 75% VC + 75% N, indicating enhanced spike development under integrated nutrient supply. Similar improvements in barley growth under combined organic and inorganic fertilization were reported by [36, 37]. Grains per spike also increased substantially, from 32.80 in the control to 46.87 under 75% VC + 75% N, consistent with the findings of [38]. In contrast, TGW was comparatively stable, ranging from 37.70 g in the control to 41.53 g under 75% VC + 75% N, supporting reports that grain weight is less responsive to nutrient management than other yield components (39). Organic amendments may further enhance nutrient availability through improved microbial activity and soil conditions (Singh et al., 2022; Chen et al., 2018; Selim, 2020).

Biomass yield (BY), grain yield (GY), straw yield (SY), and harvest index (HI) also responded significantly to integrated nutrient management. Biomass yield increased from 3296.29 kg ha^{-1} in the control to 11,460.74 kg ha^{-1} under 75% VC + 75% N and 10,745.75 kg ha^{-1} under 75% FYM + 75% N (Table 9). Similarly, grain yield increased from 1539.15 kg ha^{-1} in the control to 4545.59 and 4215.61 kg ha^{-1} under 75% VC + 75% N and 75% FYM + 75% N, respectively. These improvements likely resulted from complementary nutrient supply, improved soil conditions, and enhanced microbial activity associated with integrated fertilization [39]. Straw yield followed a similar trend, increasing from 1757.14 kg ha^{-1} in the control to 10,061.82 kg ha^{-1} under 75% VC + 75% N and 6530.14 kg ha^{-1} under 75% FYM + 75% N.

Harvest index, however, showed a different response. The highest HI (52.00%) was recorded under 75% FYM + 50% N, whereas 75% VC + 75% N and 50% VC + 25% N recorded lower values of 32.57% and 31.28%, respectively. This indicates that greater biomass production does not necessarily result in proportional grain accumulation, emphasizing the importance of balancing vegetative and reproductive growth [32]. Overall, integrated application of N fertilizer with FYM and VC substantially improve crop yield and biomass production, while also offering potential benefits for soil health and long-

term production sustainability [6, 31].

Table 2. Effect of N fertilizer with vermicompost and farm yard manure on yield and yield parameters of food barley.

Treatments	SL	BY	GY	SY	GPS	TGW	HI
Control	5.67d	3296.29f	1539.15f	1757.14d	32.80f	37.70a	46.69ab
50%FYM+25%N	6.27cd	5886.24e	2247.62e	3638.62cd	40.53b-e	39.67a	38.17b-d
50%FYM+50%N	6.60bc	8668.42b-d	3890.21b-d	4778.21bc	41.13b-d	40.53a	45.13ab
50%FYM+75%N	6.60bc	9350.44bc	4130.95a-c	5219.49bc	41.67b-d	40.40a	44.39a-c
75%FYM+25%N	6.53bc	6084.66de	2380.95e	3703.70cd	37.33d-f	39.27a	38.98b-d
75%FYM+50%N	6.73a-c	8176.19b-e	4134.04a-c	4042.15cd	39.40c-e	39.73a	52.00a
75%FYM+ 75%N	7.30ab	10745.75b	4215.61ab	6530.14b	44.73ab	41.53a	39.27b-d
50%VC+ 25%N	6.53bc	7142.85c-e	2230.95e	4911.90bc	40.93b-e	40.13a	31.28d
50%VC+50%N	6.20cd	7226.03c-e	3617.90cd	3608.13cd	40.53b-e	39.73a	50.63a
50%VC+75%N	6.33cd	8323.27b-e	3876.36b-d	4446.90bc	43.33a-c	39.20a	47.23ab
75%VC+25%N	6.60bc	6812.17c-e	2367.72e	4444.45bc	39.80b-e	38.93a	35.19cd
75%VC+50%N	6.73a-c	8446.21b-e	3884.80b-d	4561.40bc	40.33b-e	38.67a	46.31ab
75%VC+75%N	7.47a	114607.40a	4545.59a	10061.82a	46.87a	41.47a	32.57d
100%N	7.00a-c	9286.45bc	3529.29d	5757.16bc	43.00a-c	40.67a	38.02b-d
100%VC	6.93a-c	6216.93de	2182.53e	4034.39cd	41.27b-d	39.13a	35.16cd
100%FYM	6.60b-c	6481.48de	2493.39e	3988.09cd	35.93ef	38.13a	38.43b-d
50%FYM+25kg N	6.80a-c	6547.62de	2562.17e	3985.45cd	38.27c-e	27.33b	39.02b-d
LSD (0.05)	0.75	2270.95	488.65	2108.96	4.31	8.33	12.12
CV (%)	6.81	17.41	9.28	27.13	6.41	12.86	11.89

SL= spike length, BY=total biomass yield (kgha^{-1}), GY= grain yield (kgha^{-1}), SY= straw yield (kgha^{-1}), GPS= grain per spike, TGW= thousand grain weight, HI= harvest index FYM=farm yard manure, VC=vermicompost, N=nitrogen, LSD= least significant difference, CV=coefficient variation

The yield advantage over the control reflects synergistic interactions between mineral nitrogen and organic amendments, improving nutrient availability, microbial activity, and soil physical conditions. Biomass and straw yields followed similar trends, indicating enhanced vegetative growth under integrated nutrient supply. However, harvest index varied inversely with biomass accumulation, suggesting that excessive vegetative growth under high nutrient supply may reduce proportional allocation to grain under certain conditions. Overall, the results confirm that integrated nutrient management optimizes both source (photosynthetic capacity) and sink (grain formation) processes in barley.

3.6. Economic Feasibility of Integrated N, VC, and FYM Management

Economic analysis showed clear differences in the profitability of nutrient management treatments based on yield performance and associated costs and returns. Treatments combining organic amendments with mineral N generally produced higher gross benefits (GB) and gross benefit per yield (GBY), demonstrating greater economic potential. Notably, 75% VC + 75% N and 75% FYM + 50% N achieved positive net benefits (NB), indicating favorable returns from integrated nutrient management. In contrast, sole applications such as 100% FYM or 100% N showed less consistent economic performance, with some treatments recording negative marginal rates of return (MRR), suggesting that additional input costs were not adequately compensated by increased returns.

Overall, the results demonstrate that integrating N fertilizer

with VC or FYM can improve both productivity and economic returns compared with reliance on individual nutrient sources. Such combinations provide a practical strategy for balancing input costs, yield gains, and profitability while supporting sustainable barley production. These findings highlight the potential of integrated nutrient management to contribute to economically viable and resource-efficient food barley production.

Table 3. *Effects of Nfertilizer farm yard manure and vermicompost rates on economic feasibility of food barley production.*

Trt	Gy (kg/ha)	Ad. Gy (kg/ha)	GBY (birr)	GBS (birr)	GFB (birr)	TVC	NB	MRR
Control	1539	1385	107741	5271	113012	277	112735	6172
100%FYM	2493	2244	174537	11964	186501	1449	185053	D
50%FYM+25%N	2248	2023	157333	10916	168249	2630	165620	40627
50%FYM+25kg N	2562	2306	179352	11956	191308	2686	188622	D
75%FYM+25%N	2381	2143	166667	11111	177778	2904	174874	922
50%FYM+50%N	2624	2361	183648	8635	192282	4322	187960	14987
75%FYM+50%N	3434	3091	240383	11626	252009	4718	247291	118
75%FYM+ 75%N	4082	3674	285759	18990	304750	28960	275790	119
100%N	3429	3086	240050	17571	257622	7417	250205	D
50%VC+ 25%N	2231	2008	156167	14736	170902	17627	153276	2347
50%VC+50%N	2885	2596	201920	11624	213544	19369	194175	D
75%VC+25%N	2368	2131	165741	13333	179074	25401	153673	3663
75%VC+50%N	3318	2986	232270	14384	246654	27197	219457	D
50%VC+75%N	3176	2859	222345	12541	234886	28547	206339	43341
50%FYM+75%N	3264	2938	228500	13258	241759	28563	213196	D
75%VC+75%N	4546	3821	297191	21085	318277	6489	311787	D
100%VC	2183	1964	152777	12103	164881	31393	133488	425

Trt =Treatment, Ad. Gy=adjusted grain yield, Gy=grain yield, GBS= gross straw benefits, GBY= gross yield benefit, GFB= *Gross Field Benefit*, TVC= *Total Variable Cost*, NB= net benefits, MRR= marginal rates of return, D= dominant

4. Conclusion and Recommendation

Integrated application of nitrogen fertilizer with organic amendments significantly improves soil fertility and barley productivity in degraded highland soils of Ethiopia. The system is constrained by low organic carbon, nitrogen, and phosphorus, and responds strongly to combine nutrient inputs due to improved nutrient synchronization and soil functional recovery. The highest productivity was achieved with 75% vermicompost + 75% recommended nitrogen, indicating superior efficiency of vermicompost-based integration over farmyard manure. Integrated nutrient management therefore provides a scalable strategy for improving yield and nutrient use efficiency in nutrient-depleted agroecosystems, although multi-location validation is required for broader recommendation.

Author Contributions

Berhanu Disassa: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Investigation

Tesfaye Wakgari: Conceptualization, Methodology, Supervision, Writing – review & editing

Negessa Gadisa: Conceptualization, Supervision, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Zeleke, G., Agegnehu, G., Abera, D., and Rashid, S. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. 13(03), 39-45. https://doi.org/10.13140/RG.2.1.3632.5846

[2] Van Beek, C. L., Elias, E., Yihenew, G. S., Heesmans, H., Tsegaye, A., Feyisa, H., and Mengist, S. (2016). Soil nutrient balances under diverse agro-ecological settings in Ethiopia. Nutrient Cycling in Agroecosystems, 106(3), 257-274. https://doi.org/0.1007/s10705-016-9803-0

[3] Assa ye, Y., Desta, G., Molla, E., Adimassu, Z., and Kindu, M. (2025). Effects of land uses on runoff, soil, and nutrient losses in the middle Beles River Basin, Northwest Ethiopia. International Journal of River Basin Management, 1-18. https://doi.org/10.1080/15715124.2025.2547954

[4] Agegnehu, G., Amede, T., Erkossa, T., Yirga, C., Henry, C., Tyler, R,. and Sileshi, G. W. (2021). Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. Acta Agriculturae Scandina vica, Section B-Soil & Plant Science, 71(9), 852-869. https://doi.org/10.1080/09064710.2021.1954239

[5] Singh, U. (2006). Integrated nitrogen fertilization for intensive and sustainable agriculture. Journal of Crop improvement, 15(2), 259-288. https://doi.org/10.1300/J411v15n02_08

[6] Singh, V. K., Malhi, G. S., Kaur, M., Singh, G., and Jatav, H. S. (2022). Use of organic soil amendments for improving soil ecosystem health and crop productivity. Ecosystem Services. 8(6), 343-348. https://doi.org/10.1016/j.ecoser.2022.101452

[7] Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., and Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. In Microbiota and biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs (pp. 1-20). Cham: Springer International Publishing.

[8] Parama, V. R., & Biswas, D. R. (2009). Assessment, safer disposal and utilization of agricultural and industrial wastes. Journal of the Indian Society of Soil Science, 57(4), 502-512.

[9] Bedada, W. (2015). Compost and fertilizer-alternatives or complementary? management feasibility and long-term effects on soil fertility in an Ethiopian village.

[10] Abera, T., Abera, D., Abera, Y., Gurmu, G., and Shimbir, T. (2016). Soil fertility management in Ethiopia: Research findings, challenges, opportunities and prospects. Agricultural Research for Ethiopian Renaissance.

[11] Asefa, D. H. (2024). Effect of Row Spacing and Weeding Frequency on Weed Abundance and Agronomic Performances of Malt. https://doi.org/10.20372/nadre:6149

[12] Asfaw, Z. (2000). The barleys of Ethiopia. Genes in the field: On-farm conservation of crop diversity, 57, 77-108.

[13] Agegnehu, G., Liben, M., Molla, A., Feyissa, A., Bekele, A., and Getaneh, F. (2011). Research achievements in soil fertility management in relation to barley in Ethiopia. Barley research and development in Ethiopia, 137. ICARDA, Aleppo, Syria.

[14] Regassa, A. (2015). Revisiting nitic horizon properties of Nitisols in SW Ethiopia. Geoderma. 69-79. https://doi.org/10.1016/j.geoderma.2014.12.021

[15] Nigussie, A., Dume, B., Ahmed, M., Mamuye, M., Ambaw, G., Berhiun, G., and Aticho, A. (2021). Effect of microbial inoculation on nutrient turnover and lignocellulose degradation during composting: A meta-analysis. Waste Management, 125, 220-234. https://doi.org/10.1016/j.wasman.2021.02.043

[16] Day, P. R. (1965). Particle fractionation and particle-size analysis. Methods of soil analysis: part 1 physical and mineralogical properties, including statistics of measurement and sampling, 9, 545-567. https://doi.org/10.2134/agronmonogr9.1.c43

[17] Blake, G. R. (1965). Bulk density. Methods of soil analysis: Part 1 physical and mineralogical properties, including statistics of measurement and sampling, 9, 374-390. https://doi.org/10.2134/agronmonogr9.1.c30

[18] Reynolds, S. G. (1970). The gravimetric method of soil moisture determination Part IA study of equipment, and methodological problems. Journal of Hydrology, 11(3), 258-273. https://doi.org/10.1016/0022-1694(70)90066-X

[19] McLean, E. O. (1982). Soil pH and lime requirement. Methods of soil analysis, in part, 2. https://doi.org/10.2134/agronmonogr9.2.2ed.c12

[20] Walker, A., and Black, I. (1934). An examination of the different method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science, 37(1), 29-38. https://doi.org/10.1097/00010694-193401000-00003

[21] Nelson, D. W., and Sommers, L. E. (1973). Determination of total nitrogen in plant material 1. Agronomy journal, 65(1), 109-112. ttps://doi.org/10.2134/agronj1973.00021962006500010033x

[22] Bray, R., and Kurtz, L. (1945). Determination of total, organic and available forms of phosphorous in soil. Soil science Journal, 59(1): 39-45.

[23] Chapman, H. (1965). Cation exchange capacity by ammonium saturation. 9: Incorporated 891-901. https://doi.org/10.2134/agronmonogr9.2.c6

[24] Biru Abebe. (1979). Agronomy research manual. Part III. Formula and tables. Institute of Agricultural Research. Addis Ababa.

[25] CIMMYT (International center for wheat and maize improvement). (1988). from agronomic data to farmer recommendations: An economics training manual. Completely revised edition. Mexico, D. F.

[26] R Core Team. (2021). R: a language and environment for statistical computing; R Core team: Vienna, Austria, 2022. Available at: www.R-project.org (Accessed February 17(1), 2022).

[27] De Mendiburu, F. (2016). Agricolae: statistical procedures for agricultural research. R package version. 1(1), 2-4. https://doi.org/0.32614/CRAN.package.agricolae

[28] Brady, N. and Weil, R. (2008). The nature and properties of soils, 14th edition. Prentice Hall, Upper Saddle River. 992.

[29] Adane, M., Misganaw, A., and Alamnie, G. (2020). Effect of combined organic and inorganic fertilizer on yield and yield components of food barley (Hordeum Vulgare L.). Food Science and Quality Management, 95(1), 1-8. https://doi.org/10.7176/FSQM/95-01

[30] Tariku, B, Tolera A. and Ermiyas, H. (2018). Effect of Integrated Nutrient Management on Growth and Yield of Food Barley (Hordeum vulgare L.) Variety in Toke Kutaye District, West Showa Zone, Ethiopia. Advances in Crop Science and Technology, 6(1): 1-8. https://doi.org/10.4172/2329-8863.1000365

[31] Negessa, G., and Tesfaye, W. (2021). Nitrogen uptake and use efficiency of wheat (Triticum aestivum L.) varieties as influenced by combined application of vermicompost and nitrogen fertilizer rate. American Journal of Bioscience and Bioengineering,9(1),169-178. https://doi.org/10.11648/j.bio.20210906.14

[32] Choudhary, V. K., Datta, A., and Singh, A. K. (2020). Integrated nutrient management in wheat: An effective strategy for enhancing productivity and soil fertility. Journal of Plant Nutrition, 43(10), 1523-1535.

[33] Tilahun, A., and Tamado, T. (2019). Growth, yield component and yield response of durum wheat (Triticum turgidum L. var. Durum) to blended NPS fertilizer supplemented with N rates at Arsi Negelle, Central Ethiopia. African Journal of Plant Science 13(1), 9-20. https://doi.org/10.5897/AJPS2018.1697

[34] Kumar, A. (2019). Impact of nitrogen fertilization on growth, yield attributes and yield of barley (Hordeum vulgare L.) varieties. International Journal of Chemical Studies,7(3), 560-564.

[35] Molla, B. (2021). Response of yield and quality of malt barely (hordeum distichon l.) varieties to rates and time of nitrogen fertilizer applications in farta district, northwestern Ethiopia (Doctoral dissertation, Bahir Dar University).

[36] Shafi, M., Khan, Z., Khan, M. O., Haseeb, A., Bakht, J., and Anwar, S. (2018). Enhancing wheat yield through integrated nitrogen and weed management practices. Pakistan Journal of Weed Science Research, 24 (3). https://doi.org/10.28941/24-3(2018)-1

[37] Ali, S., Rizwan, M., Qayyum, M. F., Ok, Y. S., Ibrahim, M., Riaz, M., and Irshad, M. K. (2018). Biochar soil amendment on alleviation of drought and salt stress in plants: A critical review. Environmental Science and Pollution Research, 25(10), 8616-8642. https://doi.org/10.1007/s11356-017-8904-x

[38] Zhang, C., Ouyang, Z., Li, Z., Huang, X., Wang, X., and Peng, J. (2016). Effect of nitrogen fertilizer management on grain yield and nitrogen use efficiency of maize. Scientific Reports, 6(1), 1-9.

[39] Liu, X., Herbert, S. J., Hashemi, A. M., Zhang, X., and Ding, G. (2018). Effects of agricultural management on soil organic matter and carbon transformation - a review. Plant, Soil and Environment, 54(12), 531-543. https://doi.org/10.17221/3544-PSE