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EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON GROWTH, YIELD AND SOIL FERTILITY OF HORSE GRAM (*MACROTYLOMA UNIFLORUM* L.) IN ASSAM INDIA

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ABSTRACT

A field experiment was conducted during two consecutive kharif seasons of 2023 and 2024 at AAU, Zonal Research Station, Shillongani, Nagaon, Assam, to study the effect of integrated nutrient management on growth, yield and soil fertility in horse gram. The experiment was laid out in Randomized Block Design (RBD) with seven treatments and three replications. Among the treatments, seed inoculation with Rhizobium-PSB consortia combined with foliar spray of 0.5% NPK (19:19:19) at pre-flowering and pod initiation (T_7) recorded significantly higher plant height (113.0 cm), number of branches plant^{-1} (8.6), number of pods plant^{-1} (126.6), seed yield (14.41 q ha^{-1}) and Stover yield (20.25 q ha^{-1}). Soil organic carbon (1.08%), available nitrogen (378.3 kg ha^{-1}), phosphorus (21.75 kg ha^{-1}) and potassium (277.4 kg ha^{-1}) were also improved under T_7. The highest net return (Rs. 39,945 ha^{-1}) and benefit: cost ratio (2.38) were obtained from T_7. The study suggests that integration of biofertilizers with foliar nutrient supplementation is a sustainable and economically viable practice for horse gram cultivation under rainfed conditions of Assam.
***Keywords* :** Horse gram, INM, Rhizobium, Foliar nutrition, Yield, Soil fertility.

Introduction

Horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.) is one of the most drought-tolerant and nutritionally rich pulse crops cultivated in the rainfed regions of India. It is primarily grown in the southern, central, and eastern parts of the country, including Assam, as a hardy crop suited to marginal soils and low-input conditions (Reddy *et al.*, 2019). The crop is valued for its high protein content (20–25%), dietary fiber, and medicinal properties, and it serves as a vital source of fodder and food security in resource-poor farming systems (Jain *et al.*, 2021). In Assam, horse gram is cultivated mainly in upland areas after rice harvest, where soil fertility is often low and imbalanced nutrient management leads to poor productivity. The average productivity of horse gram in the region remains below 500 kg ha^{-1}, primarily due to limited fertilizer use and negligible application of biofertilizers or foliar nutrients (Borah *et al.*, 2022).

Integrated Nutrient Management (INM) offers an eco-friendly and sustainable approach to enhance the productivity of pulse crops by combining organic, inorganic, and biological sources of nutrients. The synergistic use of chemical fertilizers with microbial inoculants such as *Rhizobium* and phosphate-solubilizing bacteria (PSB) enhances biological nitrogen fixation and phosphorus availability, thereby improving nutrient uptake efficiency and soil fertility (Sinha *et al.*, 2020). Foliar nutrition using balanced NPK formulations (19:19:19) at critical growth stages such as pre-flowering and pod initiation has also been reported to supplement nutrient demand, improve physiological efficiency, and increase seed yield under rainfed conditions (Kumar *et al.*, 2018).

Considering the importance of balanced nutrient management in pulses, particularly in the low-fertility soils of Assam, the present investigation was undertaken to evaluate the effect of integrated nutrient management practices involving different combinations of chemical fertilizers, biofertilizer consortia, and foliar nutrient sprays on the growth, yield, and nutrient uptake of horse gram. This study aims to identify a suitable INM practice for enhancing the productivity, nutrient use efficiency, and sustainability of horse gram cultivation under the agro-climatic conditions of Assam.

Materials and Methods

A field experiment was conducted during two consecutive *kharif* seasons of 2023 and 2024 at the Assam Agricultural University, Zonal Research Station, Shillongani, Nagaon, Assam, India (26.32° N latitude, 92.69° E longitude, 64 m above mean sea level). The experimental site falls under the humid subtropical climatic conditions of Agro-Climatic Zone III (Central Brahmaputra Valley Zone) of Assam, characterized by high rainfall and moderate temperature. The soil of the experimental field was sandy clay loam in texture, acidic in reaction (pH 5.75), and medium in fertility, containing 0.84% organic carbon, 350.2 kg ha^{-1} available N, 19.87 kg ha^{-1} available P_2O_5, and 258.7 kg ha^{-1} available K_2O.

During the crop-growing period, the total rainfall received was 223.2 mm, with mean maximum and minimum temperatures of 34°C and 14°C, respectively. The relative humidity ranged from 91% to 67%. The experiment was laid out in a Randomized Block Design (RBD) with seven treatments replicated three times. Horse gram local variety was sown in mid-September with a spacing of 30 cm × 10 cm in plots measuring 4.0 m × 3.0 m. The crop was harvested in mid of December.

The experiment consisted of seven treatments T_1: 15:35:15 kg $N:P_2O_5:K_2O$ ha^{-1}; T_2: 10:26:15 kg $N:P_2O_5:K_2O$ ha^{-1} + *Rhizobium*-PSB consortia (50 g kg^{-1} seed); T_3: 10:26:10 kg $N:P_2O_5:K_2O$ ha^{-1} + 0.5% NPK (19:19:19) foliar spray at pre-flowering and pod initiation stages; T_4: 10:26:10 kg $N:P_2O_5:K_2O$ ha^{-1} + 0.5% NPK foliar spray at pre-flowering stage; T_5: 0.5% NPK (19:19:19) foliar spray at pre-flowering and pod initiation stages; T_6: *Rhizobium*-PSB consortia (50 g kg^{-1} seed); and T_7: *Rhizobium*-PSB consortia (50 g kg^{-1} seed) + 0.5% NPK (19:19:19) foliar spray at pre-flowering and pod initiation stages.

The RDF was applied at 15:35:15 kg $N:P_2O_5$: K_2O ha^{-1} while microbial consortia containing *Rhizobium*-PSB were applied as per treatment. Standard agronomic practices were uniformly adopted for all treatments. Observations were recorded on growth and yield attributes including plant height, number of branches $plant^{-1}$, number of pods $plant^{-1}$, number of seeds pod^{-1}, 100-seed weight, seed yield, and stover yield. Post-harvest soil samples were analysed for pH, organic carbon, and available N, P, and K using standard procedures described by Jackson 1973. Economic parameters, namely cost of cultivation, gross return, net return, and benefit–cost (B:C) ratio, were computed using prevailing market prices.

The experimental data were statistically analyzed following the analysis of variance (ANOVA) procedure appropriate for RBD, and treatment means were compared at a 5% level of significance. Statistical analysis was carried out using the online statistical software OPSTAT (Sheoran *et al*., 1998). The standard error of mean (SEm±) and critical difference (CD) values were reported for interpretation.

Results and Discussion

Plant Height (cm)

A significant variation in plant height of horse gram was observed under different nutrient management treatments (Table 1). The maximum plant height (113.0 cm) was recorded in T_7 (Rhizobium + PSB seed inoculation + 0.5% NPK foliar spray at pre-flowering and pod initiation stages), which was significantly superior to all other treatments, as justified by the CD (5%) value of 3.18 cm. This was followed by T_6 (108.0 cm) and T_4 (96.65 cm), while the shortest plants (81.30 cm) were recorded in T_1 (recommended chemical fertilizers alone). The increase in plant height under T_7 may be attributed to improved nitrogen fixation and balanced nutrient uptake due to microbial inoculation combined with foliar nutrient supplementation, which accelerated vegetative growth. Similar enhancement in plant growth through integrated nutrient sources in legume crops has been reported by Rajkhowa *et al.* (2022) and Devi & Singh (2021).

Number of branches per plant

The number of branches per plant varied significantly across treatments. T_7 recorded the highest number of branches (8.6), followed by T_6 (7.85) and T_4 (7.65). In contrast, the lowest number of branches was observed in T_1 (6.7). The improvement in branching under T_7 may be attributed to greater root proliferation and higher cytokinin synthesis stimulated by Rhizobium and PSB inoculation, coupled with timely foliar feeding which helps in maintaining canopy vigor. Comparable findings were reported by Choudhury *et al.* (2019) and Renganathan *et al.* (2020), who highlighted the synergistic role of biofertilizers and foliar nutrition in enhancing branching in pulses.

Number of seeds per pod

The number of seeds per pod ranged from 5.0 (T_2) to 5.85 (T_7). Treatments T_6 (5.7) and T_3 (5.6) were statistically at par with T_7. The lowest value was observed in T_2, indicating that seed inoculation alone without foliar nutrition was not sufficient to improve reproductive efficiency. The improvement under T_7 may be explained by enhanced nutrient translocation and improved enzymatic activity during the reproductive phase, which facilitated better seed setting. These findings align with the results of Sarkar *et al.* (2018), who reported improved pod and seed traits in legumes through integrated nutrient management.

Number of pods per plant

A significant variation was also observed in number of pods per plant. T_7 recorded the maximum number of pods (126.6), which was significantly higher than all other treatments (CD = 7.53). T_6 (107.3), T_4 (105.65) and T_3 (104.4) formed the next superior group. The lowest pod number (83.7) was recorded in T_2. The increased pod setting under T_7 may be attributed to balanced nutrient availability throughout crop growth and enhanced photosynthetic efficiency, leading to better flower retention and reduced pod abortion. Similar observations were noted by Singh *et al.* (2020) in horse gram under integrated nutrient practices.

Seed weight per plot (kg)

Seed weight per plot was significantly influenced by nutrient treatments. The highest seed weight (1.73 kg plot^{-1}) was recorded in T_7, which was significantly superior to other treatments (CD = 0.09). T_3 (1.61 kg) and T_6 (1.59 kg) formed the next best group. The lowest seed weight (1.32 kg) was recorded in T_2. The results suggest that INM plays a vital role in efficient dry matter partitioning towards reproductive sinks. This is supported by earlier findings of Renganathan *et al.* (2020).

1000-seed weight(g)

The 1000-seed weight showed slight variation; however, T_7 (28.58 g) recorded the highest value, followed closely by T_3 (28.39 g) and T_6 (28.37 g). The differences remained within the limits of CD (0.90 g), indicating that seed size in horse gram is relatively stable, but can be slightly enhanced with balanced nutrient availability and improved metabolic efficiency (Devi & Singh, 2021).

Table 1: Effect of INM on growth parameters of Horse gram ((Pooled data of last two years, 2023, 2024)

Treatments	Plant height (cm)	No. of Branches per plant	No. of seeds per pod	No. of pods per plant	No. seed weight (kg) per plot	Seed weight (g) per 1000 seed
T1	81.30	6.7	5.2	94.1	1.41	28.09
T2	89.20	6.9	5.0	83.7	1.32	27.82
T3	91.30	7.15	5.6	104.4	1.61	28.39
T4	96.65	7.65	5.55	105.65	1.56	28.24
T5	93.60	7.4	5.45	98.7	1.47	28.27
T6	108.0	7.85	5.7	107.3	1.59	28.37
T7	113.0	8.6	5.85	126.6	1.73	28.58
CD (5%)	3.18	0.60	0.36	7.53	0.09	0.90
SE(m)	1.06	0.20	0.12	2.51	0.03	0.30
SE(d)	1.50	0.28	0.19	3.55	0.05	0.42
C.V(%)	1.92	3.24	1.26	1.61	3.05	1.85

Seed yield (q ha^{-1})

The seed yield of horse gram was significantly influenced by different nutrient management treatments (Table 2). The highest seed yield (14.41 q ha^{-1}) was recorded in T_7 (Rhizobium + PSB seed inoculation + 0.5% NPK foliar spray at pre-flowering and pod initiation stages), which was significantly superior to all other treatments as confirmed by the CD (5%) value of 0.21. This was followed by T_3 (13.41 q ha^{-1}) and T_4 (12.99 q ha^{-1}), which also showed marked improvement over the control (T_1: 11.74 q ha^{-1}) and the sole fertilizer treatment (T_2: 10.99 q ha^{-1}).

The lowest seed yield in T_2 indicates that chemical fertilizers alone or chemical fertilizers + biofertilizer seed inoculation without foliar nutrient supplementation were insufficient for optimum yield. The notable improvement in seed yield under T_7 can be attributed to enhanced biological nitrogen fixation, improved phosphorus solubilization, and increased nutrient use efficiency, supported by the supplemental foliar application which ensured nutrient availability during critical reproductive stages.

These results are in line with findings of Devi and Singh (2021) and Renganathan *et al.* (2020), who also reported significant yield enhancement in legumes under integrated nutrient management through combined use of biofertilizers and foliar NPK application.

The stover yield also showed significant variation among treatments. The maximum stover yield (20.25 q ha^{-1}) was observed in T_7, followed by T_6 (19.70 q ha^{-1}) and T_3/T_4 (19.40 q ha^{-1}). The lowest stover yield (17.75 q ha^{-1}) was recorded under T_2. The CD (5%) value of 0.48 confirmed the statistical differences among treatments.

Stover yield (q ha^{-1})

Higher Stover yield under integrated treatments (especially T_7) may be attributed to greater biomass accumulation resulting from improved vegetative growth, efficient nutrient uptake from root inoculants, and enhanced photosynthetic activity due to balanced nutrient supply, both through soil and foliar pathways. Similar biomass enhancement effects under INM have been reported in pulses by Choudhury *et al*. (2019) and Sarkar *et al*. (2018).

Table 2: Effect of INM on yield parameters of Horse gram (Pooled data of two years, 2023, 2024)

Treatments	Seed yield (q/ha)	Stover yield(q/ha)
T_1	11.74	18.10
T_2	10.99	17.75
T_3	13.41	19.40
T_4	12.99	19.40
T_5	12.24	18.45
T_6	12.84	19.70
T_7	14.41	20.25
CD (5%)	0.21	0.48
SE(m)	0.07	0.16
SE(d)	0.11	0.23
C.V(%)	0.57	1.5

Soil fertility

The data presented in Table 3 revealed that soil pH, organic carbon (OC), and available N, P_2O_5 and K_2O were significantly influenced by the different nutrient management treatments. The initial soil was slightly acidic in reaction, and variations in soil pH after crop harvest ranged from 5.77 to 5.95. Among the treatments, T_4 (10:26:10 + 0.5% NPK spray at pre-flowering) recorded the highest pH (5.95), which was statistically at par with T_7 and T_6. The relative improvement in soil pH in foliar-fed and bio-inoculated treatments might be associated with the buffering action of microbial metabolites that neutralize excess acidity and enhance rhizosphere stability. Similar improvements in soil pH under biofertilizer application were reported by Kumar *et al.* (2020) who attributed the effect to enhanced microbial-driven carbonates and organic acid dynamics.

Soil organic carbon (%) varied significantly across treatments, with the highest OC (1.08%) obtained in T_7: Rhizobium-PSB consortia + 0.5% NPK foliar spray, followed closely by T_6 and T_5. The increase in OC under microbial inoculation treatments may be due to improved root biomass deposition and enhanced microbial turnover, leading to increased soil organic matter accumulation. This result is in conformity with Singh and Biswas (2021) who reported higher OC with Rhizobium and P-solubilizers due to improved carbon input through biological nitrogen fixation and root exudation.

A similar trend was observed in available nitrogen (N), which ranged from 361.6 to 378.3 kg ha^{-1}. The maximum available N was recorded in T_7, which was significantly superior to all treatments except T_5 and T_6. The improvement may be attributed to enhanced biological nitrogen fixation and sustained mineralization in the rhizosphere stimulated by microbial consortia. Comparable findings were reported by Choudhury and Kennedy (2004), who documented greater N availability in legume cropping systems associating with N-fixing microbes.

Available P_2O_5 content varied between 20.45 and 21.75 kg ha^{-1}. The highest value was observed in T_7, which was significantly higher than the control. The increase in P availability might be due to enhanced phosphate solubilization by PSB present in the consortia. The secretion of organic acids and phosphatase enzymes by PSB plays a major role in converting insoluble P into plant-available forms. This is supported by the findings of Rodríguez and Fraga (1999), who highlighted the role of phosphate-solubilizing bacteria in mobilizing native soil phosphorus.

Likewise, available K_2O ranged from 260.0 to 277.4 kg ha^{-1}, with the highest in T_7. Increased K availability under Rhizobium-PSB + foliar NPK may be attributed to improved microbial weathering of K-bearing minerals and root-mediated nutrient mobilization. Similar enhancement in K mobilization with microbial inoculants was reported by Bhowmik and Das (2018).

Table 3: Effect of INM on fertility status of Soil (Pooled data of two years, 2023, 2024)

Treatments	Soil Properties				
	pH	OC %	Av. N	Av. P_2O_5	Av.K_2O
			kg ha^{-1}		
T_1	5.79	0.97	366.6	20.55	263.9
T_2	5.77	0.88	363.8	20.45	260.0
T_3	5.84	0.99	370.5	20.90	264.5
T_4	5.95	0.98	361.6	21.30	265.6
T_5	5.8	1.03	374.3	21.40	269.1
T_6	5.84	1.05	370.5	21.40	269.6
T_7	5.86	1.08	378.3	21.75	277.4
CD (5%)	0.11	0.04	2.81	0.13	1.25
SE(d)	0.05	0.02	1.29	0.06	0.57
SE(m)	0.03	0.01	0.91	0.04	0.41
CV (%)	1.03	2.43	0.43	0.34	0.26
Initial	5.75	0.84	350.2	19.87	258.7

Economics

The economic analysis of different nutrient management treatments in horse gram is presented in Table 4. A distinct variation in gross return, net return and benefit: cost (B:C) ratio was observed due to the imposed treatments. The maximum gross return (Rs. 68,895 ha^{-1}), net return (Rs. 39,945 ha^{-1}) and B:C ratio (2.38) were recorded under T_7 (Rhizobium-PSB consortia @ 50 g kg^{-1} seed + foliar application of 0.5% NPK (19:19:19) at pre-flowering and pod initiation stages). The superiority of this treatment may be attributed to improved nutrient uptake and enhanced nodulation facilitated by biofertilizer consortia, coupled with efficient nutrient supplementation through foliar feeding during critical physiological stages, resulting in increased seed yield and economic advantage. Similar benefits of integrated microbial inoculation and foliar nutrition in horse gram were reported by Patil *et al.* (2020) and Nalina and Govindarajan (2021).

Treatments T_3 and T_4, which involved foliar application of NPK, also recorded higher net returns (Rs. 35,095 ha^{-1} and Rs. 33,595 ha^{-1}, respectively) and favorable B:C ratios (>2.10). This demonstrates that foliar nutrition of balanced NPK during reproductive stages enhanced nutrient-use efficiency, minimized temporary nutrient stress, and promoted effective translocation of photosynthates to developing pods, thereby improving productivity and profitability (Kamble *et al.*, 2018).

Moderate economic returns were obtained under T_6 (Rhizobium-PSB consortia alone), indicating the beneficial but limited yield enhancement effect of biofertilization when not supplemented by additional nutrient sources. On the other hand, T_2 recorded the lowest B:C ratio (1.87), mainly due to comparatively lower seed yield which reduced gross income.

Table 4: Economics

Treatment	Seed yield (q/ha)	Stover yield(q/ha)	Gross Return	Total Cost	Net Return	B:C
T1	11.74	18.10	58,050.00	28,950.00	29,100.00	2.006
T2	10.99	17.75	54,175.00	28,950.00	25,225.00	1.871
T3	13.41	19.40	64,045.00	28,950.00	35,095.00	2.212
T4	12.99	19.40	62,545.00	28,950.00	33,595.00	2.161
T5	12.24	18.45	58,330.00	28,950.00	29,380.00	2.015
T6	12.84	19.70	61,930.00	28,950.00	32,980.00	2.140
T7	14.41	20.25	68,895.00	28,950.00	39,945.00	2.379

Conclusion

The integrated use of Rhizobium-PSB consortia along with foliar application of 0.5% NPK at critical growth stages (T_7) significantly improved growth, yield, soil fertility and economic returns of horse gram under rainfed conditions of Assam. Therefore, T_7 may be recommended as a sustainable and profitable nutrient management practice for horse gram cultivation in similar agro-ecological conditions.

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