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In situ green manuring for nutrient content optimization in *Rabi* maize (*Zea mays* L.)

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Abstract
An investigation was conducted during the 2022-23 *Rabi* season at the College of Agriculture, Rajendranagar, to study the effect of *in situ* green manuring at 45 DAS (days after sowing) and variable nitrogen application at the tasseling stage on nutrient content of maize. The experiment, arranged in a randomized block design, included treatments with green manuring (T_1-T_7) and control (T_8-farmer's practice without green manuring). The nitrogen (N), phosphorus (P) and potassium (K) contents in maize at knee-high (1.85-2.06, 0.375-0.434, 1.96-2.04%), pre-tasselling (1.32-1.46, 0.231-0.264, 1.33-1.41%) and tasselling (1.15-1.24, 0.209-0.223, 1.14-1.17%) stages were significantly higher in maize + green manure treatments (T_1 to T_7) as compared to T_8 (1.76, 0.375, 1.90; 1.26, 0.231, 1.27; and 1.13, 0.209, 1.11%, respectively) at the corresponding stages. However, at the grain-filling stage (T_4-0.96, 0.185, 1.14; and T_7-0.92, 0.178, 1.69%) and harvest (T_4-0.75, 0.126, 1.12; and T_7-0.72, 0.121, 1.64%, respectively), T_4 and T_7 conspicuously reported higher plant N, P and K contents than the other treatments. The grain N, P and K contents were also higher with T_4 (1.86, 0.338 and 0.48%) and T_7 (1.81, 0.334 and 0.47%) at knee height, grain filling stages and harvest, respectively.

Keywords: Green manuring, *in situ*, maize, nutrient content

1. Introduction

Maize, scientifically known as *Zea mays* L., is an extensively cultivated crop in the world. It is considered as 'Queen of Cereals' and it is the third most important cereal crop after wheat and rice in the world (Pal *et al*., 2015) [1]. Across the globe area under maize during 2023-2024 was 203.22 m ha with a production and productivity potential of 1,223.81 MMT and 3540 kg ha^{-1}, respectively (USDA, 2024). Maize is one of the important crops in Indian agriculture occupying a prominent position. During 2023-24, the area under maize in India was 11 M ha producing 37.5 MMT of grain with a productivity of 3410 kg ha^{-1} (USDA, 2024] [2]. The area under *Rabi* maize in India is gradually increasing as reported by the Ministry of Agriculture and Farmers Welfare, showing the increase in the area under *Rabi* maize from 1.79 M ha in 2021-22 to 2.14 M ha in 2022-23 (MoAFW, 2023) [3]. In Telangana state, maize is the 4th major agricultural crop. Maize's adaptability to wider agroecologies along with its high-yielding potential is unmatched by any other crop (Das *et al*., 2008 [4]; Sharma *et al*., 2011 [5]). The productivity of maize depends on the successful completion of its growth cycle to fully harness its potential, while also effectively adapting to the environmental conditions in which it is cultivated. Maize, a nutrient-demanding crop, significantly depletes soil nutrient reserves due to its high biomass production requirements, and under India's intensive cereal-cropping systems, nutrient extraction often surpasses replenishment. This imbalance has led to widespread multi-nutrient deficiencies. Organic manures play a critical role in soil fertility enhancement and productivity, directly benefiting nutrient uptake and crop performance (Datta *et al*., 2017) [6]. Green manures, rich in organic matter, substantially contribute to root and shoot growth, grain yield, and overall crop quality by adding organic material to the soil that, upon mineralization by soil microbes, enhances soil fertility and nutrient availability (Mancinelli *et al*., 2013) [7]. Leguminous green manure crops, such as sunhemp, fix atmospheric nitrogen through symbiosis with rhizobia in root nodules (Coombs *et al*., 2017; Vincent-Caboud *et al*., 2019) [8, 9].

Within legume-cereal cropping systems, legume-associated nitrogen can contribute up to 34% of nitrogen available in the rhizosphere to cereal crops (Laberge *et al*., 2011) [10]. Following green manure incorporation, organic nutrients undergo mineralization, converting to inorganic forms that are readily assimilated by crops (Mccauley *et al*., 2012) [11]. *In situ* intercropping with sunhemp, specifically, has shown promise for generating organic matter, significantly enhancing the soil's physical, chemical, and biological properties, which are often compromised in high-intensity cropping (Channagouda *et al*., 2015) [12]. Sunhemp intercropping can supplement up to 30 kg N ha^{-1}, meeting a substantial portion of maize's nitrogen requirements (Kumar *et al*., 2023) [13]. This study aims to evaluate the impact of *in situ* sunhemp green manuring, combined with variable nitrogen application, on the plant nutrient content of *Rabi* maize.

2. Materials and Methods

The study was conducted during the *Rabi* season of 2022 at the College Farm, College of Agriculture, Rajendranagar, Hyderabad, situated within the Southern Telangana Agro Climatic Zone of Telangana. According to Troll's classification, this area falls under the semi-arid tropics (SAT). During the experiment, the average weekly maximum and minimum temperatures recorded were 31.3 ℃ and 14.5 ℃, respectively. The average weekly relative humidity ranged from 83.5% at 0730 hrs to 39% at 1400 hrs. There were no rainy days observed, with only a total of 8.2 mm rainfall. The average daily sunshine duration varied from 4.4 to 10.1 hours. Wind speed ranged from 2.0 to 4.1 km hr^{-1}, and pan evaporation (measured by USWB Class A pan evaporimeter) ranged from 2.4 to 5.4 mm day^{-1}. The experiment was structured as a randomized block design with eight treatments: T_1: *In situ* green manuring of sunhemp at 45 DAS (GM) + 0 kg N ha^{-1} at tasselling (T), T_2: GM + 10 kg N ha^{-1} at T, T_3: GM + 20 kg N ha^{-1} at T, T_4: GM + 30 kg N ha^{-1} at T, T_5: GM + 40 kg N ha^{-1} at T, T_6: GM + 50 kg N ha^{-1} at T, T_7: GM + 60 kg N ha^{-1} at T, and T_8: Farmer's Practice (RDF application without green manuring). Each treatment was replicated three times on clay loam soil. Maize received a recommended nitrogen rate of 240 kg ha^{-1} in four splits: at sowing (basal), knee height, pre-tasselling, and tasselling. The first three splits of 60 kg N ha^{-1} were applied uniformly, while the fourth split was adjusted per treatment. Additionally, 80 kg P_2O_5 and K_2O ha^{-1} were uniformly applied at sowing. Both maize and sunhemp were sown on November 15, 2022, with paired rows of maize and two rows of sunhemp interspaced. For nutrient analysis, five healthy plants were randomly selected from each plot, dried, and ground. These samples were digested using a diacid mixture of HNO_3: $HClO_4$ (9:4) as per Jackson (1973) [14] for determining P and K contents, while N content was analyzed using a Kelplus N auto analyzer. Statistical analysis was conducted using the randomized block design methodology by Panse and Sukhatme (1967) [15]. Significance was evaluated with the "F" test at a 5% probability level (Snedecor and Cochron, 1967) [16], and critical differences were calculated for significant effects.

3. Results and Discussion

3.1 Plant nutrient contents

3.1.1 Nitrogen content

Significant variations in plant nitrogen content have been observed among the treatments throughout the crop growing season. The variation in plant nitrogen contents was broader up to the tasselling stage which was narrowed down by the grain filling stage and continued up to harvest. It further decreased gradually from knee high to harvest.

The data presented in Table 1 indicated that nitrogen content in maize ranged from 1.76 to 2.06, 1.26 to 1.46, 1.13 to 1.24, 0.71 to 0.96, and 0.60 to 0.75 percent at knee-high, pre-tasselling, tasselling, grain filling stages and harvest, respectively. An overview of plant nitrogen contents indicated broader variations among the treatments at knee high, pre-tasselling and tasselling stages with treatments, T_1 to T_7 bearing comparable and higher plant nitrogen contents ranging from 1.85-2.06, 1.32-1.46, and 1.15-1.24 percent, respectively. On the other hand, T_8 received lower plant N contents of 1.76, 1.26, and 1.13 percent at knee high, pre-tasselling, and tasselling stages, respectively. Sunhemp and maize both received recommended nutrients up to 60 DAS. Therefore, the nitrogen fixed by sunhemp would be an extra advantage to the associated crop, which ultimately resulted in the absorption and accumulation of nitrogen in higher proportions by T_1-T_7 treatments.

As a result of the incorporation of green manure at 45 DAS, its subsequent decomposition, and the addition of nitrogen in varying amounts during the tasselling stage, emerged notable differences between the treatments in the growth stages that followed. At the grain-filling stage and harvest, it became apparent that T_4 and T_7 had significantly higher plant nitrogen contents (T_4-0.96, 0.75 and T_7-0.92, 0.72 percent, respectively) than the other treatments. Differential performance of T_5 and T_6 and parity of T_7 with T_4 treatments infer that there was a considerable loss in nitrogen applied at the tasselling stage. Probably the more the application of nitrogen the greater the loss. Further, the increased population of microorganisms in the soil might had an engulfing effect resulting in lesser availability of nitrogen for the plants to build in T_5, T_6, and T_7 treatments. However, T_7 could made up to the level of T_4 with regards to plant N content due to the application of recommended N at the tasselling stage. The advantage of green manuring in addition to optimal microbial population might have resulted in increased plant N contents at the grain filling stage and harvest in T_4 treatment. On the other hand, T_1, T_2 and T_3 comparably registered the lowest nitrogen contents in the tune of 0.71, 0.74 and 0.77 percent at the grain filling stage and 0.60, 0.62 and 0.64 at harvest, respectively. The above treatments with 0, 10, and 20 kg ha^{-1} of N application at the tasselling stage might not have met the crop nitrogen requirement adequately at the grain filling stage and harvest.

At harvest, the maize grain's nitrogen content varied considerably as well. The amount of nitrogen in maize grain was larger than in stover, which was clear evidence of the transfer of nutrients from the plant to the growing sinks and their subsequent accumulation to change into matured grains. The percentage of nitrogen in the maize grains varied from 1.65 to 1.86 percent. The T_4 and T_7 treatments, which received 30 and 60 kg N ha^{-1}, respectively, at the tasselling stage in addition to green manuring, had the greatest nitrogen concentrations of 1.86 and 1.81 percent, respectively in the grains. The T_6 treatment, which combined green manuring with the application of 50 kg N ha^{-1} at the tasselling stage and had a 1.73 percent N content, alone was comparable to the T_7 treatment. It could not reach the level of parity with T_4 treatment. On the other hand, T_1, T_2, T_3 and T_8 were observed as equivalent as and lower than the other treatments, with respective N contents of 1.65, 1.68, 1.70 and 1.72 percent. At the tasselling stage, T_1 to T_3 included green manuring and application of N @ 0, 10, and 20 kg ha^{-1}, respectively, while T_8 involved the application of the recommended dose of fertilizers without any green manuring. Crop nutrient needs are calculated considering the type of soil, its physical and chemical characteristics, and estimating the likely soil nutrient loss in addition to the crop root's ability to absorb the soil's available nutrients. Green manure is an organic alternative to fertilizers for crops and has demonstrated a binding effect on nutrients, minimizing loss. Furthermore, 30 kg ha^{-1} of nitrogen supplied might be sufficient to meet the crop's nitrogen needs at the tasselling stage since the remaining nitrogen may be substituted by the green manuring effect in the T_4 treatment. Maize fertilized with nitrogen more than 30 kg ha^{-1} may be susceptible to likely losses, while T_7 treatment alone with the highest and recommended N at the tasselling stage could produce seeds with N contents comparable to T_4 treatment.

3.1.2 Phosphorus content

The information on plant phosphorus content was in line with plant nitrogen content. Table 2 shows the information on the phosphorus level in maize in response to *in situ* green manuring at 45 DAS and the variable nitrogen application rate at the tasselling stage. The data reported a gradual decline in plant phosphorus content from knee-high stage to harvest.

Table 1: Nitrogen content at different stages of maize in response to *in situ* green manuring at 45 DAS and variable nitrogen split application at the tasselling stage

Treatments	Plant nitrogen content (%) at different stages of maize					Grain nitrogen content (%)
	Knee-high	Pre-tasselling	Tasselling	Grain filling	Harvest (Stover)	
T_1: *In situ* green manuring of sunhemp at 45 DAS (GM) + 0 kg N ha^{-1} at tasselling (T) stage	1.85	1.32	1.18	0.71	0.60	1.65
T_2: GM + 10 kg N ha^{-1} at T	1.87	1.34	1.15	0.74	0.62	1.68
T_3: GM + 20 kg N ha^{-1} at T	1.89	1.37	1.17	0.77	0.64	1.70
T_4: GM + 30 kg N ha^{-1} at T	2.06	1.46	1.24	0.96	0.75	1.86
T_5: GM + 40 kg N ha^{-1} at T	1.93	1.38	1.19	0.81	0.66	1.73
T_6: GM + 50 kg N ha^{-1} at T	1.97	1.41	1.21	0.84	0.68	1.76
T_7: GM + 60 kg N ha^{-1} at T	2.01	1.44	1.22	0.92	0.72	1.81
T_8: Farmer's Practice (Application of RDF without green manuring)	1.76	1.26	1.13	0.80	0.65	1.72
S.E.M ±	0.07	0.05	0.02	0.02	0.01	0.03
CD (P=0.05%)	0.21	0.14	0.07	0.05	0.04	0.09

3.1.3 Phosphorus content

The information on plant phosphorus content was in line with plant nitrogen content. Table 2 shows the information on the phosphorus level in maize in response to *in situ* green manuring at 45 DAS and the variable nitrogen application rate at the tasselling stage. The data reported a gradual decline in plant phosphorus content from the knee-high stage to harvest.

The observations up to the tasselling stage indicated that the plant phosphorus levels were comparable across all maize + sunhemp treatments (T_1-T_7) and higher than the T_8 treatment. The maize grown solely without intercropping (T_8) had the lowest phosphorus concentration up to the tasselling stage. At knee-high, pre-tasselling and tasselling stages, the phosphorous concentration in maize varied between 0.375-0.434, 0.231-0.264, and 0.209-0.223 percent, respectively in the green manure intercropped maize treatments (T_1-T_7). Correspondingly, the phosphorus concentration in the lowest treatment (T_8) was 0.375, 0.231 and 0.209 per cent at knee high, pre-tasselling, and tasselling stages, respectively. As discussed earlier, the treatments T_1 through T_7 received an equivalent amount of nutrients and cropping conditions up to the tasselling stage, hence their performance was comparable. The higher phosphorus contents of these treatments can be attributed to the rooting activity and secretion of exudates by the associated crop (sunhemp) which might have increased the availability of phosphorus in the soil nutrient pool of maize. After the incorporation of green manure its decomposition enhanced the microbial colonies in the soil moderating the availability of nutrients, hence reflected in the higher nitrogen and phosphorus contents of maize up to the tasselling stage.

The application of nitrogen split in variable rates at the tasselling stage has brought about significant changes among the green-manured maize treatments later to the tasselling stage. Similar to nitrogen contents, the phosphorus contents of maize exhibited conspicuous differences at the grain-filling stage and harvest. Analysis for plant phosphorus content at the grain filling stage signified that the phosphorus concentration in maize was comparable and higher (0.185 and 0.178 percent, respectively) in T_4 and T_7 treatments receiving 30 and 60 kg N ha^{-1} at the tasselling stage. The rest of the treatments (T_1, T_2, T_3, T_5, T_6 and T_8) remained comparably lower with plant phosphorus contents ranging from 0.163 to 0.172 percent, respectively. According to Grunes (1959) [17], nitrogen frequently increases root growth and foraging capacity for phosphorus. Some of the effects of nitrogen are related to the effect of increasing the growth of plant tops and concurrently increasing the absorption of phosphorus. The ammonium form of nitrogen frequently increases phosphorus absorption more than the nitrate form. Nitrogen addition affects plant metabolism and may change the ability of unit areas of the root surface to absorb phosphorus. In the present study, though the rooting area of maize in response to various treatments was not measured, higher phosphorus absorption as reflected by increased phosphorus content in maize can be explained by the release of ammonical nitrogen in greater quantities than nitrate nitrogen and nitrogen addition to the tune of 210 kg ha^{-1} (60+60+60+30 kg N ha^{-1} at sowing, knee high, pre-tasselling and tasselling stages, respectively) in maize during *Rabi*.

The same is deciphered for the phosphorus contents in maize at harvest. The stover of maize accreted comparable and higher concentrations of phosphorus in T_4 (0.126%) and T_7 (0.121%) treatments. The next best treatments were T_5 (0.116%), T_6 (0.118%) and T_8 (0.115%). While T_1 (0.109%), T_2 (0.112%), and T_3 (0.113%) remained equivalent and low.

The concentration of phosphorus at harvest was higher in grain than stover reflecting the plants' metabolic ability to assimilate and transport the absorbed phosphorus to the developing sinks past the reproductive stage. The grain phosphorus contents also followed the same trend observed with stover. Comparable and higher phosphorus contents in the maize grain were noted in T_4

(0.338%) and T_7 (0.334%) treatments. However, T_7 was in turn found equivalent to T_5 and T_6 with grain phosphorus contents of 0.324 and 0.326 percent, respectively. The rest of the treatments (T_1, T_2, T_3, and T_8) remained equivalent with lower (0.314, 0.317, 0.319, and 0.321 percent, respectively) phosphorus concentrations in the maize grain.

Table 2: Phosphorus content at different stages of maize in response to *in-situ* green manuring at 45 DAS and variable nitrogen split application at the tasselling stage

Treatments	Plant phosphorus content (%) at different stages of maize					Grain phosphorus content (%)
	Knee-High	Pre-Tasselling	Tasselling	Grain filling	Harvest (Stover)	
T_1: *In situ* green manuring of sunhemp at 45 DAS (GM) + 0 kg N ha^{-1} at tasselling (T) stage	0.406	0.243	0.212	0.163	0.109	0.314
T_2: GM + 10 kg N ha^{-1} at T	0.409	0.247	0.214	0.165	0.112	0.317
T_3: GM + 20 kg N ha^{-1} at T	0.413	0.251	0.215	0.166	0.113	0.319
T_4: GM + 30 kg N ha^{-1} at T	0.434	0.264	0.223	0.185	0.126	0.338
T_5: GM + 40 kg N ha^{-1} at T	0.416	0.255	0.217	0.170	0.116	0.324
T_6: GM + 50 kg N ha^{-1} at T	0.426	0.258	0.219	0.172	0.118	0.326
T_7: GM + 60 kg N ha^{-1} at T	0.421	0.261	0.221	0.178	0.121	0.334
T_8: Farmer's Practice (Application of RDF without green manuring)	0.375	0.231	0.209	0.167	0.115	0.321
S.E.M ±	0.011	0.008	0.004	0.004	0.002	0.003
CD (P=0.05%)	0.032	0.023	0.012	0.011	0.005	0.010

3.1.4 Potassium content

The trend of the potassium and phosphorus contents in maize was comparable. The information on potassium concentration in response to *in situ* green manuring and variable nitrogen administration at the tasselling stage of maize is shown in Table 3. Up to the tasselling stage, the variations between the treatments seemed marginal, but beginning with the grain filling stage and continuing through harvest, they became more obvious. The plant potassium content in T_1 through T_7, which were green-manured at 45 DAS and then given nitrogen at variable rates, did not differ from one another at knee high, pre-tasselling and tasselling stages. The plant potassium content ranged from 1.96 to 2.04, 1.33 to 1.41 and 1.14 to 1.17 percent at knee high, pre-tasselling and tasselling stages, respectively for T_1 to T_7 treatments. T_8 accumulated the lowest (1.90, 1.27 and 1.11 percent, respectively) potassium concentrations than the other treatments at knee high, pre-tasselling and tasselling stages when the recommended nitrogen dose was administered in four equal splits without green manuring. The aforementioned finding signifies no competition between maize and sunhemp for nutrient absorption and utilization for apex and basal metabolism, respectively. Additionally, it may be inferred that the initial low availability of phosphorus and potassium in the soil led to more absorption and storage of nutrients to suit the different physiological needs of the crop.

As the crop growth progressed past the tasselling stage and continued into harvest, the disparity between the treatments for plant potassium content grew. From the grain filling stage to harvest, the plant potassium contents were comparable and higher with T_4 and T_7 treatments green manured at 45 DAS and administered with 30 and 60 kg N ha^{-1}, respectively at the tasselling stage. At the grain-filling stage and harvest, the plant potassium content in these treatments accounted for 1.14, 1.69 and 1.12, 1.64 percent, respectively. The rest of all treatments (T_1, T_2, T_3, T_5, T_6 and T_8) remained lower and on par with plant potassium contents ranging from 1.05 to 1.09 percent at the grain-filling stage and 1.51 to 1.57 percent at harvest. From the above result, it can be inferred that green manuring had compensated up to 30 kg N ha^{-1} resulting in better absorption and buildup of potassium content with lesser nutrient losses. On the other hand, nutrient addition from the decomposing green manure and the application of more nitrogen in T_7 may have made up for the nutrient losses achieving parity with T_4 concerning plant potassium contents.

Table 3: Potassium content at different stages of maize in response to *in-situ* green manuring at 45 DAS and variable nitrogen split application at the tasselling stage

Treatments	Plant potassium content (%) at different stages of maize					Grain potassium content (%)
	Knee-High	Pre-Tasselling	Tasselling	Grain filling	Harvest (Stover)	
T_1: *In situ* green manuring of sunhemp at 45 DAS (GM) + 0 kg N ha^{-1} at tasselling (T) stage	1.96	1.33	1.14	1.05	1.51	0.40
T_2: GM + 10 kg N ha^{-1} at T	1.98	1.34	1.15	1.06	1.53	0.41
T_3: GM + 20 kg N ha^{-1} at T	2.00	1.36	1.13	1.07	1.54	0.41
T_4: GM + 30 kg N ha^{-1} at T	2.04	1.41	1.17	1.14	1.69	0.48
T_5: GM + 40 kg N ha^{-1} at T	2.01	1.37	1.14	1.09	1.56	0.43
T_6: GM + 50 kg N ha^{-1} at T	2.02	1.39	1.15	1.09	1.57	0.44
T_7: GM + 60 kg N ha^{-1} at T	2.03	1.40	1.16	1.12	1.64	0.46
T_8: Farmer's Practice (Application of RDF without green manuring)	1.90	1.27	1.11	1.08	1.55	0.42
S.E.M ±	0.04	0.04	0.01	0.01	0.03	0.01
CD (P=0.05%)	0.11	0.12	0.04	0.04	0.10	0.02

The maize grain's potassium concentration was lower than the Stover, in contrast to the nitrogen and phosphorus contents of the seed. It varied between 0.40 and 0.48 percent. Lower potassium level in maize grain than in Stover emphasizes potassium's function in enhancing plant stature, which is supported by larger plant heights and the generation of dry matter, as well as nutrient translocation during the reproductive stage, highlighted by higher seed nitrogen and phosphorus contents. At harvest, the grain potassium contents were equivalent and higher (0.48 and 0.46 percent, respectively) for

T_4 and T_7 treatments. The T_7 treatment, however, was found on par with T_6 having a potassium content of 0.44 percent in the grain. On the other side, with grain potassium contents of 0.40 to 0.42 per cent the treatments, T_1, T_2, T_3 and T_8 were found comparable and lower than the other treatments. The fact that treatments T_4 and T_7 reached harvest equivalence indicates that maize may be adequately compensated for nitrogen split with *in situ* green manuring up to 30 kg ha^{-1} at the tasselling stage to absorb and build up greater nutrient levels. To reduce potential nitrogen loss and an increase in cultivation costs, greater dosages of nitrogen augmenting green manuring such as in T_5, T_6, and T_7 treatments can be avoided.

4. Conclusion
The results from this study highlights the efficacy of *in situ* green manuring with sunhemp at 45 DAS and the variable application of nitrogen at the tasselling stage for improving nutrient content in maize. Treatments incorporating green manuring (T_1 to T_7) consistently demonstrated significantly higher nitrogen, phosphorus, and potassium contents at key growth stages (knee-high, pre-tasselling, and tasselling) compared to the treatment without green manuring (T_8). Specifically, treatments T_4 and T_7 maintained superior nutrient levels in maize at the grain-filling stage and harvest, contributing to improved grain nutrient concentrations as well. The findings indicate that *in situ* green manuring can effectively meet the nutrient requirements of maize, optimizing nutrient content throughout the crop's growth stages.

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