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Effect of Integrated Nutrient Management on Nutrient Availability Dynamics in Laboratory-incubated Black Clay Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Nutrient release in different soils is a dynamic process influenced by a multitude of factors, including soil texture, structure, organic matter content, pH, microbial activity, and nutrient management practices. An incubation study was conducted to study the nutrient availability and

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their release at different days after incubation through nutrient management practices. The results of the study revealed that at 15 DAI, available nitrogen and its fraction, available sulphur were recorded higher in the treatment receiving soil test based NPK, at 30 DAI in the treatment with integrated application 100% RDF, FYM and biofertilizers, at 45 and 60 DAI treatment receiving 75% soil test based NPK, FYM and biofertilizers. Available phosphorus recorded content recorded higher in the treatment with integrated application 100% RDF, FYM and biofertilizers and it continued to increase upto 45 DAI and their after its content decreased slightly to 60 DAI. Similar to available phosphorus, available potassium content also recorded higher in the treatment with integrated application 100% RDF, FYM and biofertilizers and it continued to increase upto 60 DAI. Treatments receiving sole inorganic fertilizers exhibited early decline in nutrient content whereas integrated treatments maintained the nutrient availability more than the sole inorganic fertilizers applied treatments.

Keywords: Nitrogen; phosphorus; potassium; sulphur and biofertilizers.

1. INTRODUCTION

Integrated Nutrient Management (INM) has emerged as a crucial technique in contemporary agricultural methods, aiming to optimize the presence of vital nutrients essential for plant growth, enhance soil well-being, and ensure sustainable crop yield. Among these crucial nutrients, nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) take centre stage as primary contributors to plant growth and maturation. Understanding the intricate interplay between INM strategies and the release of these essential nutrients in diverse soil types is imperative for achieving efficient nutrient utilization, mitigating environmental repercussions, and maintaining agricultural productivity. Integrated nutrient management (INM) involves utilizing diverse nutrient sources, such as organic fertilizers, residues, and synthetic fertilizers, to enhance soil quality and crop output. INM holds particular significance for small-scale farmers who lack resources to solely rely on synthetic fertilizers. Organic fertilizers and residues can enhance soil structure and moisture retention, in addition to furnishing nutrients to crops. This can potentially decrease the dependence on synthetic fertilizers and enhance the sustainability of agricultural production. Integrated Nutrient Management entails skillfully integrating organic and inorganic fertilizers, alongside other enriching practices, to establish a harmonious and effective nutrient supply system. This approach influences the patterns of nutrient release and transformations within the soil matrix, consequently impacting nutrient accessibility for plants. Sustainable agriculture hinges on prudent organic matter management in soil. Augmenting soil organic matter content can aid in reversing soil degradation and augmenting soil fertility, culminating in amplified crop yield [1]. The interaction between organic materials and mineral particles in the soil is a fundamental process significantly influencing soil organic matter (SOM) dynamics and the formation as well as stabilization of soil aggregates [2].

Soil nutrient availability is a dynamic phenomenon influenced by an array of factors, including soil texture, structure, organic matter content, pH, and microbial activity. The impact of integrated nutrient management on the release of N, P, K, and S varies across diverse soil types, each possessing distinct physical and chemical attributes that shape nutrient dynamics. Sandy soils, characterized by low nutrient retention capacity, often experience swift leaching of N, P, K, and S. INM techniques can alleviate these losses by encouraging gradual and controlled nutrient release, thus refining nutrient efficiency. In contrast, clay-rich soils exhibit higher cation exchange capacity but may manifest nutrient immobilization and reduced accessibility.

INM interventions can stimulate microbial activity and foster nutrient mineralization, amplifying nutrient availability in such soils. Loam soils, with their balanced amalgamation of sand, silt, and clay, offer intermediate nutrient dynamics that can be further optimized through INM methodologies. By unraveling the complexities of nutrient interplay within the soil-plant continuum, we can optimize nutrient usage, heighten crop productivity, and endorse sustainable agricultural practices to accommodate a burgeoning global populace.

2. MATERIALS AND METHODS

A study was conducted at the Department of Soil Science and Agricultural Chemistry, Agricultural College, Jagtial, through an incubation experiment. The goal was to examine the impact of integrated nutrient management on the availability and release patterns of nitrogen, phosphorus, potassium, and sulphur, along with different nitrogen fractions. The experiment began with the collection of 30 soil samples from mustard fields in the Northern Telangana Zone. After analyzing their physico-chemical properties, three distinct soils were chosen based on nutrient content, color, and texture for further incubation.

These selected soils underwent a preparation process involving drying, grinding using a wooden pestle and mortar, and sieving through a 2mm sieve. Physical and chemical properties were then determined. Each soil sample (1 kg) was placed in pots and subjected to various treatments, including an absolute control, and incubated for 60 days under field capacity soil moisture conditions. Soil samples were collected at 15, 30, 45, and 60 days to assess physico-chemical properties and monitor nutrient status and release resulting from the integration of fertilizers with organic (FYM) and microbial (biofertilizers) sources.

The experiment employed a Completely Randomized Design (CRD) layout with three replications, consisting of the following treatments: T1: 100% Recommended dose of Fertilizer (RDF), T2: 100% RDF + FYM, T3: 100% RDF + FYM + Biofertilizer consortium, T4: 75% RDF, T5: 75% RDF + FYM, T6: 75% RDF + FYM + Biofertilizer consortium, T7: Soil Test Based NPK, T8: 75% STB NPK + FYM and T9: 75% STB NPK + FYM + Biofertilizer consortium. Biofertilizer consortium includes Azotobacter + Phosphate Solubilizing Bacteria + Potassium Solubilizing Bacteria + Zinc Solubilizing Bacteria. A recommended dose of 100% RDF (N:P:K - 26.8:17.9:17.9) mg kg^{-1}, 75 % RDF (N:P:K - 20.1:13.4:13.4) mg kg^{-1}, STB (N:P:K - 34.8:12.5:12.5) mg kg^{-1} and 75% STB NPK+FYM (N:P:K - 26.1:9.4:9.4) mg kg^{-1}. Analysis of initial soil samples showed that the texture of soil was clay soil and black in colour with available nitrogen, phosphorus, potassium, sulphur, ammonical nitrogen and nitrate nitrogen contents of 112.5, 12.1, 150.6, 18.4, 59.0 and 36.6 mg kg^{-1} respectively. Available nitrogen content in soil is estimated by alkaline permanganate method [3] available phosphorus by 0.5 M $NaHCO_3$ extractable [4], available potassium by neutral normal ammonium acetate method [5], available sulphur [6]. Nitrogen fractions were analysed by extraction with potassium chloride followed by distillation with kelplus apparatus [7].

3. RESULTS AND DISCUSSION

3.1 Available Nitrogen

In black clay soils, available nitrogen content at 15 DAI was recorded significantly higher under STB NPK (129 mg kg-1 soil) which was on par with 100% RDF+FYM+ Biofertilizer consortium (128 mg kg-1 soil), 75% STB NPK +FYM+ Biofertilizer consortium (127 mg kg-1 soil), 100% RDF+FYM (126 mg kg^{-1} soil), 75% STB NPK+ FYM (126 mg kg^{-1} soil) and 75% RDF+ FYM+ Biofertilizer consortium (124 mg kg^{-1} soil) (Table 1). STB NPK treatment received higher amount of inorganic fertilizer might have released higher N into soil. However, at 30 DAI, 100% RDF+FYM + Biofertilizer consortium treatment has recorded (135 mg kg^{-1} soil) higher available N followed by STB NPK (135 mg kg^{-1} soil), 75% STB NPK + FYM + Biofertilizer consortium (134 mg kg^{-1} soil), 100% RDF + FYM (132 mg kg^{-1} soil), 75% STB NPK + FYM (129 mg kg^{-1} soil), 75% RDF + FYM + Biofertilizer consortium (127 mg kg^{-1} soil), 100% RDF (125 mg kg^{-1} soil), 75 % RDF + FYM (124 mg kg^{-1} soil), 75% RDF (122 mg kg^{-1} soil) and control (110 mg kg^{-1} soil). Under 100% RDF+FYM + Biofertilizer consortium treatment, FYM and biofertilizer consortium used beside inorganics might have caused mineralization of organic N, biological N fixation and release of N from inorganic source might be the reason for high N in soil. At 45 DAI, higher available N of 86.6 mg kg^{-1} soil was recorded under 75% STB NPK + FYM + Biofertilizer consortium which was on par with 100% RDF + FYM + Biofertilizer consortium (137 mg kg^{-1} soil), 100% RDF+FYM (137 mg kg^{-1} soil), STB NPK (133 mg kg^{-1} soil), 75% STB NPK (132 mg kg^{-1}) and 75% RDF + FYM + Biofertilizer consortium (131 mg kg^{-1} soil). At 60 DAI available N content ranged from 117 to 136 mg kg^{-1}.

Further it was observed that, treatments receiving sole inorganic source of N, the available N content in soil increased up to 30 DAI, on the other hand, treatments receiving FYM, Biofertilizer consortium besides inorganic fertilizers the increase was observed up to 45 DAI. Then after all the treatments showed decline in soil N content. Under control treatment which has received no inputs available N content was more or less maintained as the same. Increase in available N up to 30 DAI in soils in different treatments is due to release of N from urea granules and then it continued to decline in treatments receiving inorganic source of nutrients might be due to loss of available nitrogen in the form of volatilization [8] and ammonia fixation in clay lattice at 45 and 60 DAI. Whereas available N increased up to 45 DAI in the treatments receiving inorganic nutrients along with FYM and Biofertilizers might be due to mineralization of organic N and biological nitrogen fixation by free living microorganism. The higher available N release in soils may be due to the fact that organic matter addition results in higher microbial activity leading to higher mineralization [9]. The decline in available N after 45 DAI under these treatments was observed a little. In black clay soils 75% STB NPK + FYM + Biofertilizer consortium showed higher cumulative nitrogen release (23.4 mg kg^{-1}), this soil could release on an average of 13.5 mg kg^{-1} N (Fig. 1).

Table 1. Effect of integrated nutrient management on soil available nitrogen content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	122	125	125	121
100% RDF+ FYM	126	132	137	133
100% RDF+ FYM+ BC	128	135	137	135
75 % RDF	118	122	122	117
75 % RDF + FYM	120	124	128	123
75 % RDF + FYM+ BC	124	127	131	124
STB NPK	129	135	133	130
75% STB NPK+FYM	126	129	132	128
75% STB NPK+FYM + BC	127	134	139	136
Control	109	110	112	114
Mean	123	127	129	125
Sem±	2.88	2.97	4.35	5.69
CD (P=0.05)	6.42	6.62	9.70	12.7
CV	2.35	2.33	3.38	4.55
Initial (112.5 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based NPK

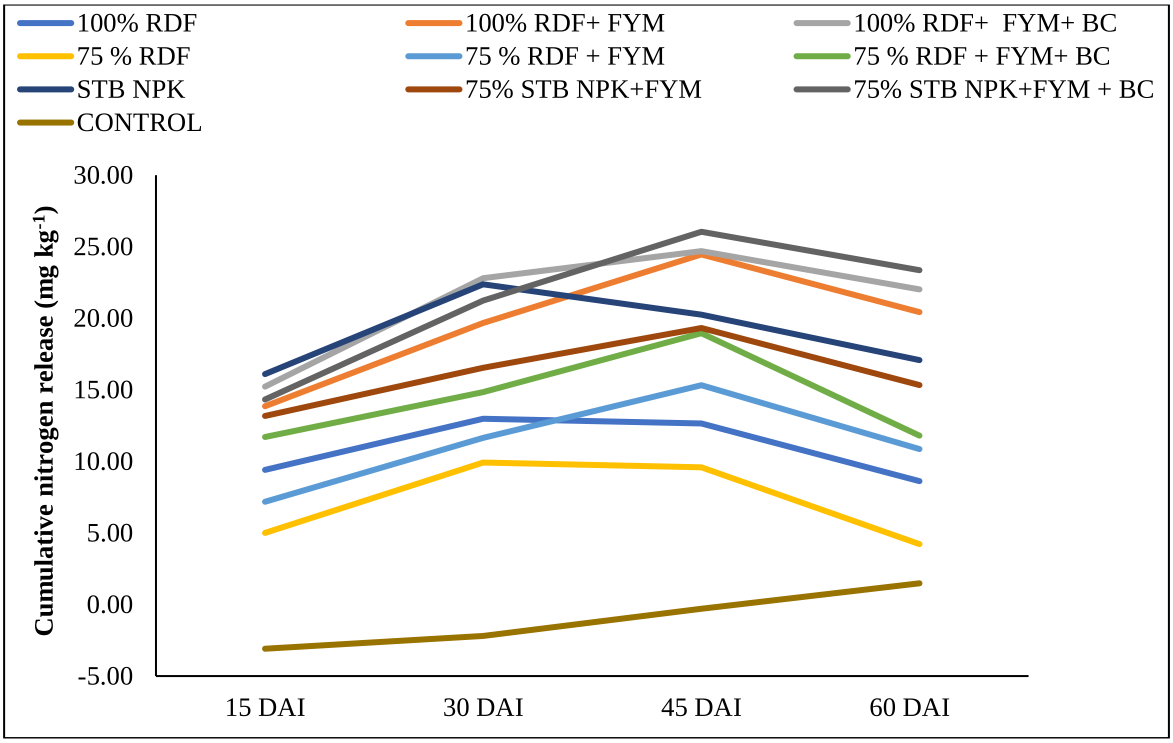

Fig. 1. Effect of integrated nutrient management on cumulative nitrogen release (mg kg^{-1}) in soil during incubation period in black clay soils

3.2 Available Phosphorus

In black clay soils, available phosphorus content at 15 DAI was recorded significantly higher under 100% RDF+ FYM+ Biofertilizer consortium (13.9 mg kg^{-1}) which was on par with 100% RDF+ FYM (13.7 mg kg^{-1}), 100% RDF (13.6 mg kg^{-1}), 75% RDF + FYM+ Biofertilizer consortium (13.5 mg kg^{-1}), 75% RDF + FYM (13.3 mg kg^{-1}), 75% RDF (13.2 mg kg^{-1}), STB NPK (13.1 mg kg^{-1}), 75% STB NPK+FYM + Biofertilizer consortium (12.9 mg kg^{-1}) and 75% STB NPK+FYM (12.8 mg kg^{-1}) (Table 2). Lower available phosphorus was recorded in the control treatment. Similar trend was observed at 30, 45 and 60 DAI. Available phosphorus was varied from 11.7 to 14.2 mg kg^{-1}, 11.7 to 14.6 mg kg^{-1} and 11.6 to 14.5 mg kg^{-1} at 30, 45 and 60 DAI, respectively. Up to 45 DAI, all the treatments except control showed increasing trend in available P and trend of P content was similar with previous days. However, at 60 DAI P content in soil was declined and significantly higher available phosphorus was recorded under 100% RDF+FYM+ Biofertilizer consortium (14.5 mg kg^{-1}). 75% STB NPK + FYM + Biofertilizer consortium showed higher cumulative phosphorus release after 60 DAI in these soils ranges from -0.45 to 2.42 mg kg^{-1} (Fig. 2).

Increase in available phosphorus content upto 45 DAI might be due to release of P from applied fertilizer (SSP), FYM and solubilisation of native P by PSB. SSP applied in the soil reacts with soil moisture results in release of orthophosphoric acid and dicalcium phosphate, the released orthophosphoric acid diffuses in to surrounding soil [10]. FYM might also contribute to phosphorus by mineralization, under Biofertilizer consortium used treatments PSB might dissolved native insoluble P [11]. Besides, continuous availability of moisture, which may cause solubilisation of P linked to colloidal complexes, releasing phosphorus into the labile pool and making it available [11]. Furthermore, with a gradual increase in added P, the H2PO4 - would have been adsorbed and satisfied the sorption sites, while the remaining H2PO4 - would have been transported to the labile pool, increasing P availability. Similar findings were reported by Nanthakumar and Pannerselvam [12]. Keen observation among the treatments revealed that, FYM + Biofertilizer consortium applied treatments releasing more amount of P followed by FYM applied treatment. Decline in available phosphorus at 60 DAI might be due to conversion of available phosphorus into unavailable inorganic forms with increasing time [13]. Decline at 60 DAI was marginal under FYM+BC used treatment and FYM applied treatment, which indicates fixation of P might be reduced by application of FYM as humate ions compete with phosphate ion for same site for fixation [14].

3.3 Available Potassium

In black clay soils, available potassium content at 15 DAI was recorded significantly higher under 100% RDF+ FYM+ Biofertilizer consortium (169 mg kg^{-1}) which was on par with 100% RDF+ FYM (168 mg kg^{-1}), 100% RDF (166 mg kg^{-1}), 75% STB NPK+FYM + Biofertilizer consortium (165 mg kg^{-1}), 75% STB NPK+FYM (164 mg kg^{-1}), STB NPK (162 mg kg^{-1}) and 75% RDF + FYM+ Biofertilizer consortium (161 mg kg^{-1}) (Table 3). Lower available potassium content of 152 mg kg^{-1} was recorded in the control treatment. This trend was continued to 60 DAI. Available potassium content varied from 153 to 173 mg kg^{-1}, 155 to 176 and 156 to 179 mg kg^{-1} at 30. 45 and 60 DAI, respectively. Further observation of data revealed that available potassium was continued to increase in the soil up to 60 DAI and the release of available potassium was more under treatments receiving integration of inorganic sources along with FYM and biofertilizers. Release of K from the fertilizer could be the reason for continuous increase in available K in soils, decomposition of FYM, Potassium solubilising microorganisms could be other sources for this. K solubilizers produce organic acids which acidifies soil environment and solubilise K from native minerals [15]. K fixation by clay lattice is a common phenomenon in soil, however, in red soil K fixation tendency is low as in these soils dominant minerals are kaolinite or iron aluminium oxides which has zero K fixation power [16]. In black clay soils 100 % RDF + FYM + Biofertilizer consortium showed higher cumulative potassium release (28.4 mg kg^{-1}), this soil could release on an average of 18.8 mg kg^{-1} potassium (Fig. 3).

3.4 Available Sulphur

In black clay soils, available sulphur at 15 DAI was recorded significantly higher under STB NPK (22.3 mg kg^{-1} soil) which was on par with 75% STB NPK +FYM+ Biofertilizer consortium (22.1 mg kg^{-1} soil), 100% RDF+FYM+ Biofertilizer consortium (21.8 mg kg^{-1} soil), 100% RDF+FYM (21.2 mg kg^{-1} soil) (Table 4). A STB NPK treatment received higher amount of inorganic fertilizer might have released higher sulphur into soil. However, at 30 DAI, 100% RDF+FYM + Biofertilizer consortium treatment has recorded higher available sulphur of (23.4 mg kg^{-1} soil) which was on par with STB NPK (23.1 mg kg^{-1} soil), 75% STB NPK + FYM + Biofertilizer consortium (22.9 mg kg^{-1} soil) and 100% RDF+FYM (22.8 mg kg^{-1} soil). Under 100% RDF+FYM + Biofertilizer consortium treatment FYM and biofertilizer consortium used beside inorganics might have caused mineralization of organic sulphur and release of sulphur from inorganic source might be the reason for high sulphur in soil. At 45 DAI, higher available sulphur of 23.8 mg kg^{-1} soil was recorded under 75% STB NPK + FYM + Biofertilizer consortium which was on par with 100% RDF + FYM + Biofertilizer consortium (23.7 mg kg^{-1} soil), 100% RDF+FYM (23.5 mg kg^{-1} soil) and STB NPK (23.4 mg kg^{-1} soil). Lower available sulphur was recorded in the control all the stages of incubation. Similar trend was observed at 60 DAI which varied from 17.5 to 23.1 mg kg^{-1}). In black clay soils 75 % STB NPK + FYM + Biofertilizer consortium showed higher cumulative sulphur release (13.9 mg kg^{-1}) this soil could release on an average of 2.9 mg kg^{-1} sulphur (Fig. 4).

3.5 Ammonical Nitrogen

In black clay soils, ammonical nitrogen content at 15 DAI was recorded significantly higher under STB NPK (69.7 mg kg^{-1} soil) which was on par with 100% RDF+FYM+ Biofertilizer consortium (68.3 mg kg^{-1} soil), 75% STB NPK +FYM+ Biofertilizer consortium (67.9 mg kg^{-1} soil), 100% RDF+FYM (66.5 mg kg^{-1} soil) and 75% STB NPK +FYM (65.7 mg kg^{-1}) (Table 5). STB NPK treatment received higher amount of inorganic fertilizer might have released higher ammonical nitrogen into soil. However, at 30 DAI, 100% RDF+FYM + Biofertilizer consortium treatment has recorded (75.0 mg kg^{-1} soil) higher ammonical nitrogen followed by STB NPK (74.1 mg kg^{-1} soil), 75% STB+ FYM + Biofertilizer consortium (73.3 mg kg^{-1} soil), and 100% RDF+FYM (71.9 mg kg^{-1} soil). At 45 DAI, higher ammonical nitrogen of 76.8 mg kg^{-1} soil was recorded under 75% STB NPK + FYM + Biofertilizer consortium which was on par with 100% RDF + FYM + Biofertilizer consortium (75.0 mg kg^{-1} soil), 100% RDF+FYM (74.2 mg kg^{-1} soil), STB NPK (72.4 mg kg^{-1} soil) and 75% RDF + FYM + Biofertilizer consortium (66.1 mg kg^{-1}). Similar pattern was observed at 60 DAI and the ammonical nitrogen content varied from 58.5 to 72.3 mg kg^{-1}.

Furthermore, it was observed that when only an inorganic supply of nutrients was used, the ammonical nitrogen level in the soil increased up to 30 DAI. Whereas treatments receiving FYM, Biofertilizer consortium, and inorganic fertilisers, on the other hand, results in an increase of ammonical nitrogen up to 45 DAI. At 60 DAI all the treatments showed decline in ammonical nitrogen content. The ammonical nitrogen content was more or less maintained in the control treatment, which received no inputs. Cumulative ammonical nitrogen released after 60 DAI by black clay soils ranges from -0.4 to 13.4 mg kg^{-1}, this soil could release on an average of 7.5 mg kg^{-1} of ammonical nitrogen (Fig. 5).

Table 2. Effect of integrated nutrient management on soil available phosphorus content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	13.6	13.7	14.0	13.8
100% RDF+ FYM	13.7	14.0	14.3	14.1
100% RDF+ FYM+ BC	13.9	14.2	14.6	14.5
75 % RDF	13.2	13.3	13.5	13.3
75 % RDF + FYM	13.3	13.5	13.7	13.6
75 % RDF + FYM+ BC	13.5	13.7	14.0	13.9
STB NPK	13.1	13.2	13.4	13.2
75% STB NPK+FYM	12.8	12.9	13.1	13.0
75% STB NPK+FYM + BC	12.9	13.1	13.3	13.2
Control	11.7	11.7	11.7	11.6
Mean	13.2	13.3	13.5	13.4
Sem±	0.62	0.62	0.64	0.65
CD (P=0.05)	1.38	1.39	1.42	1.44
CV	4.69	4.68	4.72	4.81
Initial (12.1 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based NPK

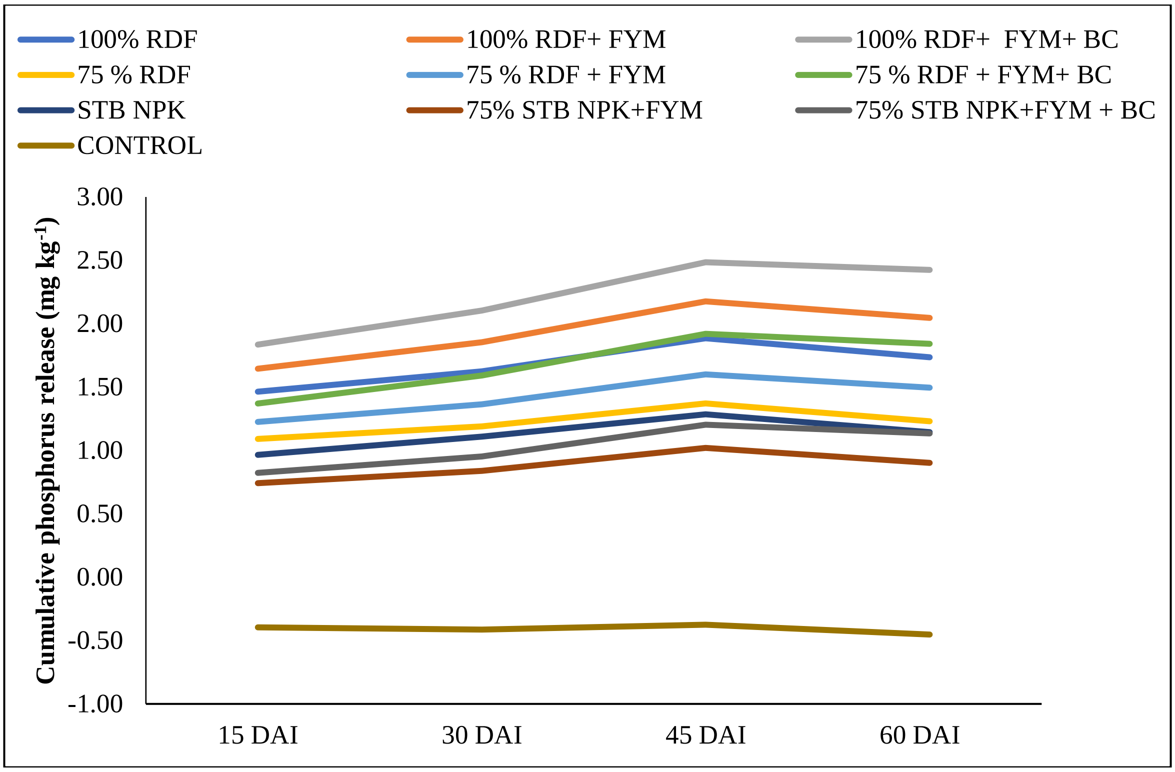

Fig. 2. Effect of integrated nutrient management on cumulative phosphorus release (mg kg^{-1}) in soil during incubation period in black clay soils

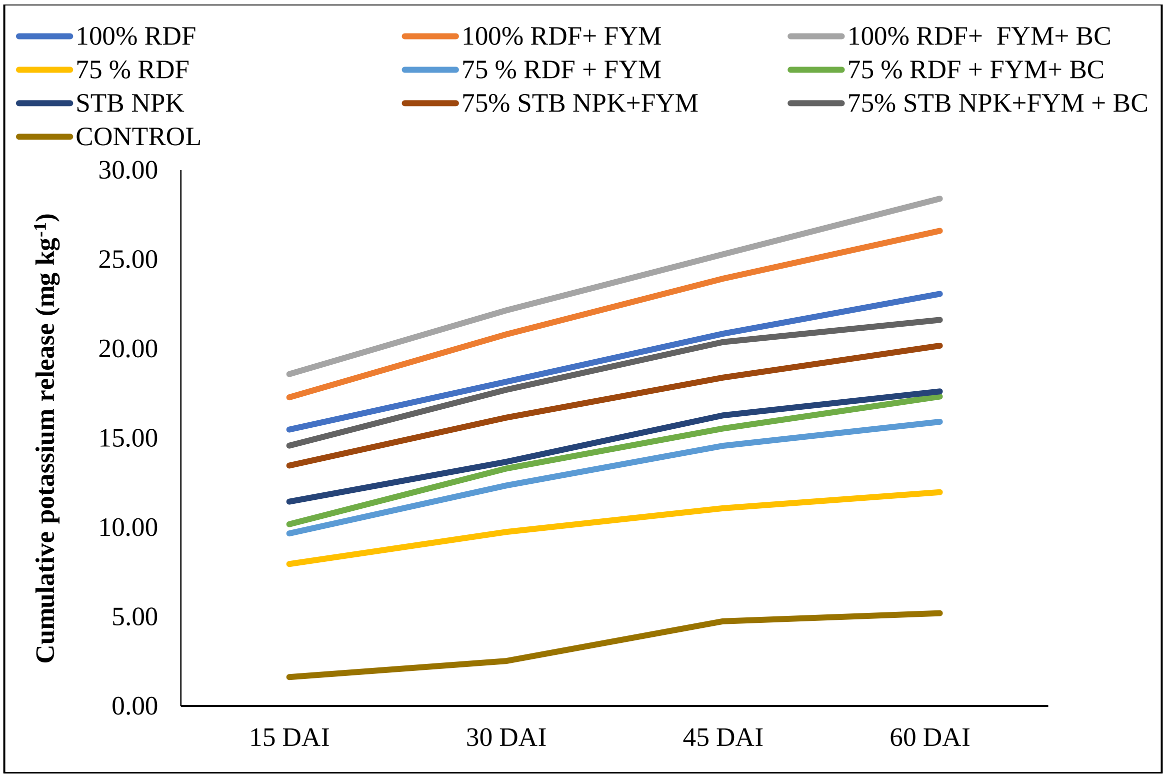

Fig. 3. Effect of integrated nutrient management on cumulative potassium release (mg kg^{-1}) during incubation period in black clay soils

Table 3. Effect of integrated nutrient management on soil available potassium content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	166	169	171	174
100% RDF+ FYM	168	171	175	177
100% RDF+ FYM+ BC	169	173	176	179
75 % RDF	159	160	162	163
75 % RDF + FYM	160	163	165	167
75 % RDF + FYM+ BC	161	164	166	168
STB NPK	162	164	167	168
75% STB NPK+FYM	164	167	169	171
75% STB NPK+FYM + BC	165	168	171	172
Control	152	153	155	156
Mean	163	165	168	169
Sem±	3.91	4.56	4.82	5.53
CD (P=0.05)	8.72	10.2	10.7	12.3
CV	2.41	2.76	2.87	3.27
Initial (150.6 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based

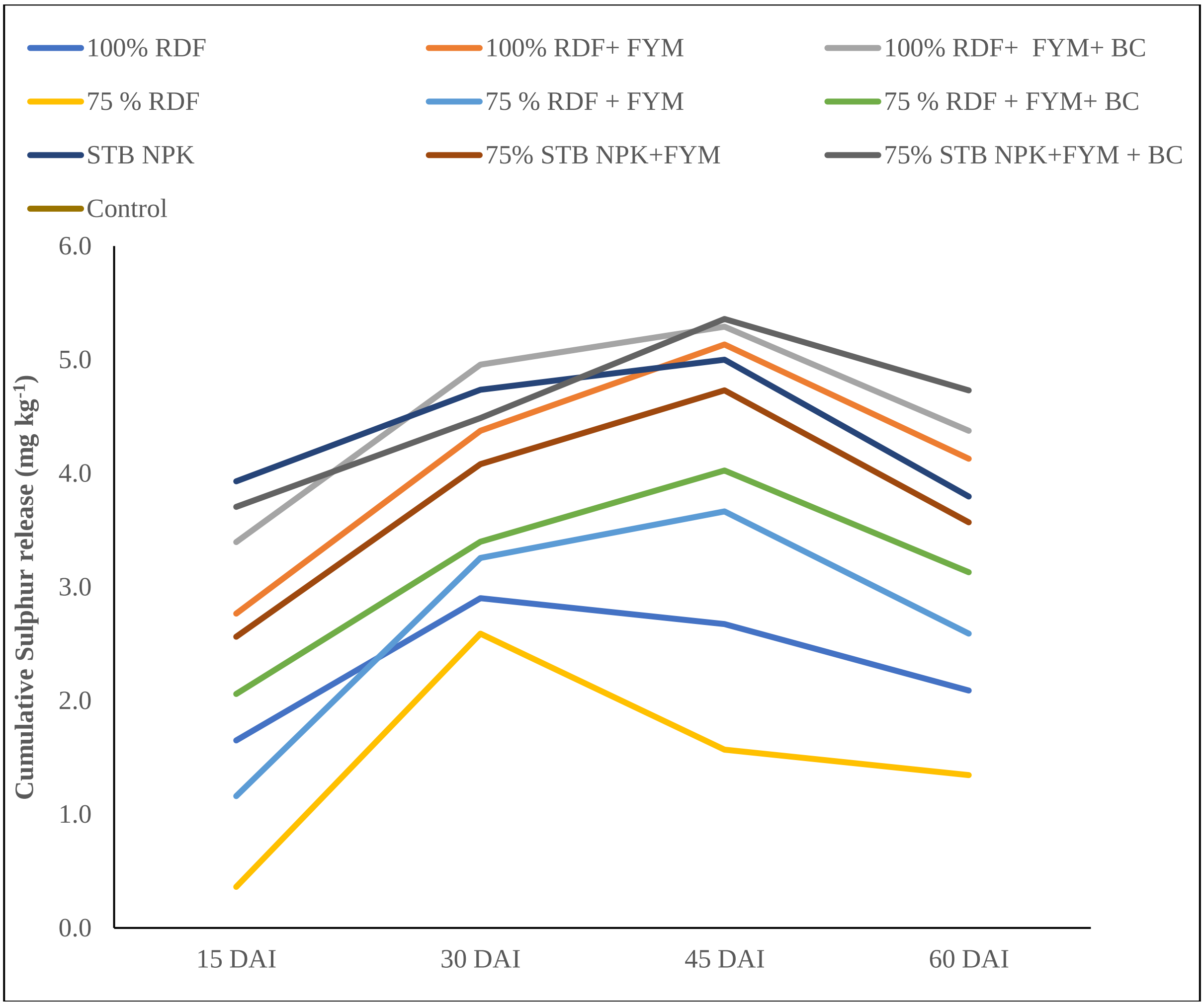

Fig. 4. Effect of integrated nutrient management on cumulative sulphur release (mg kg^{-1}) during incubation period in black clay soils

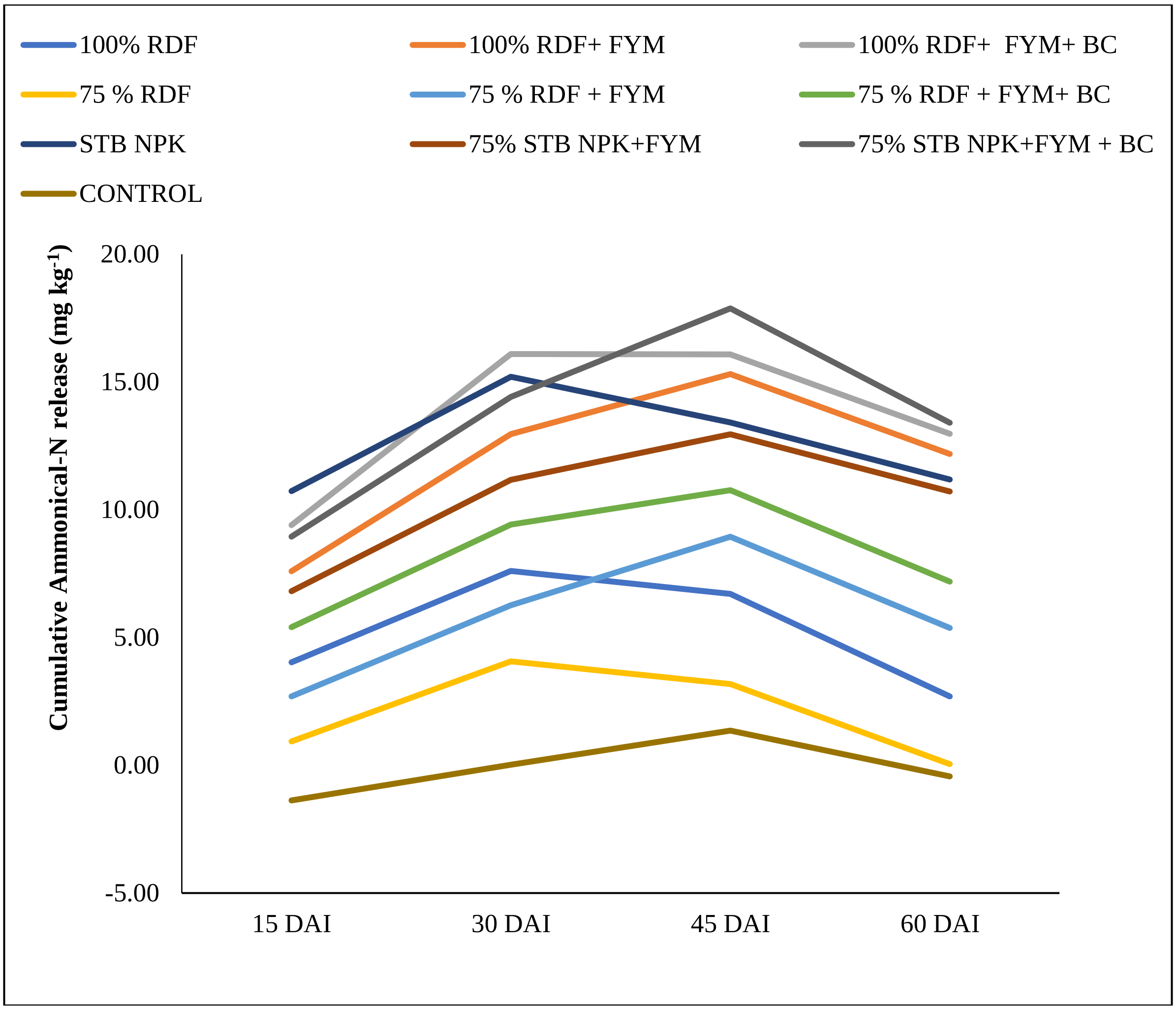

Fig. 5. Effect of integrated nutrient management on cumulative ammonical nitrogen release (mg kg^{-1}) during incubation period in black clay soils

Table 4. Effect of integrated nutrient management on soil available sulphur content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	20.1	21.3	21.1	20.5
100% RDF+ FYM	21.2	22.8	23.5	22.5
100% RDF+ FYM+ BC	21.8	23.4	23.7	22.8
75 % RDF	18.8	21.0	20.0	19.7
75 % RDF + FYM	19.6	21.7	22.1	21.0
75 % RDF + FYM+ BC	20.5	21.8	22.4	21.5
STB NPK	22.3	23.1	23.4	22.2
75% STB NPK+FYM	21.0	22.5	23.1	22.0
75% STB NPK+FYM + BC	22.1	22.9	23.8	23.1
Control	17.2	17.3	17.6	17.5
Mean	11.2	12.4	12.9	12.1
Sem±	0.53	0.51	0.51	0.54
CD (P=0.05)	1.18	1.13	1.14	1.20
CV	4.70	4.11	3.99	4.47
Initial (18.4 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based NPK

Table 5. Effect of integrated nutrient management on ammonical nitrogen content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	63.0	66.5	65.6	61.6
100% RDF+ FYM	66.5	71.9	74.2	71.1
100% RDF+ FYM+ BC	68.3	75.0	75.0	71.9
75 % RDF	59.9	63.0	62.1	59.0
75 % RDF + FYM	61.6	65.2	67.9	64.3
75 % RDF + FYM+ BC	64.3	68.4	69.7	66.1
STB NPK	69.7	74.1	72.4	70.1
75% STB NPK+FYM	65.7	70.1	71.9	69.7
75% STB NPK+FYM + BC	67.9	73.3	76.8	72.3
Control	57.6	58.9	60.3	58.5
Mean	64.4	68.7	69.6	66.5
Sem±	2.58	2.03	3.31	3.21
CD (P=0.05)	5.74	4.53	7.38	7.16
CV	4.00	2.96	4.76	4.83
Initial (59.0 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based NPK

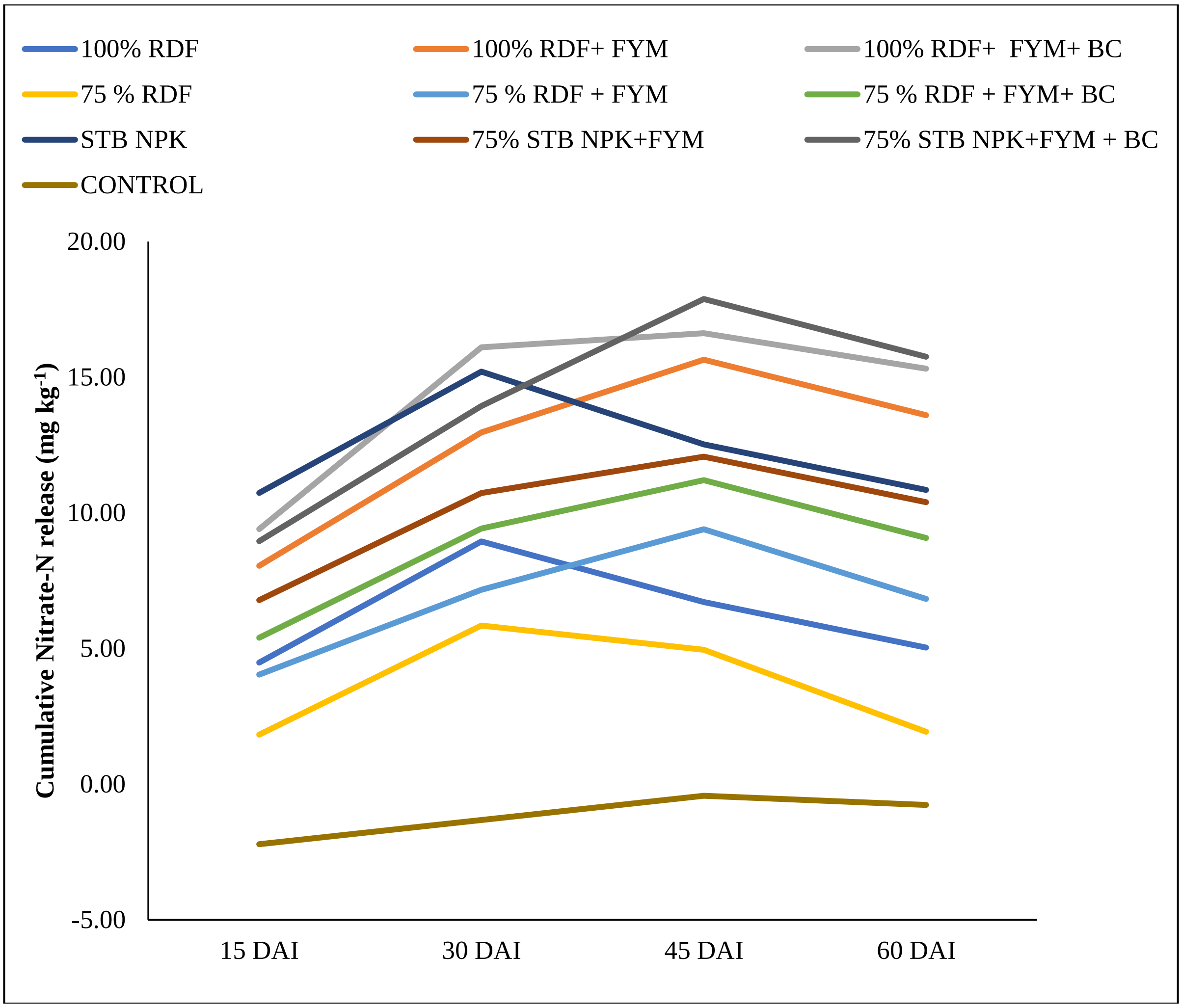

Fig. 6. Effect of integrated nutrient management on cumulative nitrate nitrogen release (mg kg^{-1}) during incubation period in black clay soils

Table 6. Effect of integrated nutrient management on nitrate nitrogen content (mg kg^{-1}) during incubation period in black clay soils

Treatment	15 DAI	30 DAI	45 DAI	60 DAI
100% RDF	41.1	45.5	43.3	41.6
100% RDF+ FYM	44.6	49.6	52.2	50.2
100% RDF+ FYM+ BC	46.0	52.7	53.2	51.9
75 % RDF	38.4	42.4	41.6	38.5
75 % RDF + FYM	40.6	43.8	46.0	43.4
75 % RDF + FYM+ BC	42.0	46.0	47.8	45.7
STB NPK	47.3	51.8	49.1	47.4
75% STB NPK+FYM	43.4	47.3	48.7	47.0
75% STB NPK+FYM + BC	45.6	50.5	54.5	52.4
Control	34.4	35.3	36.2	35.8
Mean	42.3	46.5	47.3	44.4
Sem±	2.10	2.23	2.28	2.21
CD (P=0.05)	4.68	4.96	5.08	4.93
CV	4.96	4.79	4.83	4.98
Initial (36.6 mg kg^{-1})				

BC= Biofertilizer consortium, RDF= Recommended dose of fertilizer, STB NPK= Soil test based NPK

3.6 Nitrate Nitrogen

In black clay soils, nitrate nitrogen content at 15 DAI was recorded significantly higher under STB NPK (47.3 mg kg^{-1} soil) which was on par with 100% RDF+FYM+ Biofertilizer consortium (46.0 mg kg^{-1} soil), 75% STB NPK +FYM+ Biofertilizer consortium (45.6 mg kg^{-1} soil), 100% RDF+FYM (44.6 mg kg^{-1} soil) (Table 6). STB NPK treatment received higher amount of inorganic fertilizer might have released higher nitrate nitrogen into soil. However, at 30 DAI, 100% RDF+FYM + Biofertilizer consortium treatment has recorded (52.7 mg kg^{-1} soil) higher nitrate nitrogen followed by STB NPK (51.8 mg kg^{-1} soil), 75% STB NPK + FYM + Biofertilizer consortium (50.5 mg kg^{-1} soil) and 100% RDF+FYM (49.6 mg kg^{-1} soil). At 45 DAI, higher nitrate nitrogen of 54.5 mg kg^{-1} soil was recorded under 75% STB NPK + FYM + Biofertilizer consortium which was on par with 100% RDF + FYM + Biofertilizer consortium (53.2 mg kg^{-1} soil), 100% RDF+FYM (52.2 mg kg^{-1} soil). At 60 DAI significantly highest nitrate nitrogen of 52.4 mg kg^{-1} soil was recorded under 75% STB NPK + FYM + Biofertilizer consortium which was on par with 100% RDF + FYM + Biofertilizer consortium (51.9 mg kg^{-1} soil) and 100% RDF + FYM (50.2 mg kg^{-1}). Lower nitrate nitrogen content at all the incubation stages was recorded in the control treatment. On further observation of data, when only an inorganic supply of nutrients was used, the nitrate nitrogen content in the soil increased by up to 30 DAI. Treatments with FYM, Biofertilizer Consortium, and inorganic fertilisers results in increase of nitrate nitrogen up to 45 DAI. This could be due to increased microbial population especially nitrifiers which led the formation of nitrates [17]. At 60 days after incubation, all treatments showed a decrease in nitrate nitrogen concentration. In the control treatment, which received no inputs, the nitrate nitrogen content was mostly maintained. In black clay soils 75 % STB NPK + FYM + Biofertilizer consortium showed higher cumulative nitrate nitrogen release (15.8 mg kg^{-1}), this soil could release on an average of 8.80 mg kg^{-1} nitrate nitrogen (Fig. 6).

4. CONCLUSIONS

In conclusion, this study underscores the paramount importance of Integrated Nutrient Management (INM) as a pivotal approach in modern agricultural practices. The research findings accentuate the potential of INM strategies to optimize nutrient release and availability over time. The judicious integration of organic sources, such as farmyard manure (FYM) and microbial biofertilizers, with conventional inorganic fertilizers showcases a dynamic synergy that leads to sustained and controlled nutrient liberation. This approach not only augments nutrient accessibility for plant uptake but also mitigates potential losses through leaching or fixation, thereby promoting efficient nutrient utilization. The study's outcomes have illuminated the temporal patterns of nutrient availability under different treatments. The gradual and prolonged release of essential nutrients observed in INM-treated soils demonstrates its capacity to sustain plant growth throughout critical stages of development. This effect, attributed to processes like mineralization of organic nutrients, microbial activity, and enhanced solubilization, highlights the potential of INM to provide a continuous and balanced nutrient supply to crops. Nitrogen availability, a pivotal driver of plant growth, is notably influenced by INM techniques, which encourage both organic and inorganic nitrogen sources to work synergistically. Phosphorus availability benefits from the solubilizing potential of phosphate-solubilizing bacteria and organic matter, enhancing the pool of accessible phosphorus for plants. Potassium, another crucial nutrient, experiences sustained release due to the combined effects of mineral dissolution and microbial action. Additionally, sulphur availability sees a marked improvement under INM, contributing to enhanced plant nutrition and productivity. These findings hold substantial implications for sustainable agriculture, particularly for resource-constrained small-scale farmers who can harness the benefits of organic amendments and biofertilizers to reduce dependency on costly synthetic fertilizers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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