**PROMOTING SUSTAINABLE AGRICULTURE IN SEMI-ARID VERTISOLS: SYNERGISTIC INTEGRATION OF MANURE AND FERTILIZER PRACTICES FOR ENHANCING SOIL FERTILITY AND CROP PRODUCTION**

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**Abstract**

Improving soil nutrients are essential for the sustainable agriculture. Manure is an excellent source of supplying nutrients such as organic matter that can help in enhanced production. Manure provides higher organic matter to the soil and hence impact on soil quality. The addition of organic manures in soil has been evidenced to improve soil characteristics, in addition to improving nutrient availability.Fertilization is an important management strategy for crop yields by mediating soil fertility. Fertilization showed profound impacts on soil health by altering soil chemical, physical, and biological processes. Balanced and integrated use of organic and inorganic fertilizers may enhance the accumulation of soil organic matter and improves soil physical properties.

**Keywords:** Manuring, fertilization, INM, soil physico-chemical properties, crop productivity.

**I. INTRODUCTION**

Over the past six decades, India has witnessed a remarkable surge in food production, primarily attributed to the adoption of modern agricultural technologies. Among these advancements, fertilizers stand out as a pivotal component contributing to this transformative progress. Nutrient inputs, particularly Nitrogen (N) and Phosphorus (P), have emerged as critical determinants in unlocking the productivity potential of high-yielding crop varieties [1].

Modern agricultural practices have witnessed widespread utilization of chemical fertilizers, which, unfortunately, has brought about adverse consequences for the environment and land quality. In order to mitigate these repercussions and ensure a more harmonious coexistence between agricultural productivity and environmental well-being, a paradigm shift towards balanced fertilization strategies is imperative. This entails the application of carefully calibrated fertilizers that not only foster enhanced crop yields but also uphold the integrity of the soil ecosystem.

The paramount significance of balanced fertilization becomes evident in its twofold impact: augmenting agricultural output and safeguarding soil health. The intricate interplay between nutrient availability and crop productivity is mediated by the judicious use of fertilizers. Achieving an optimal equilibrium in nutrient supply not only leads to increased crop productivity but also acts as a safeguard against soil degradation. Sustainable agriculture hinges upon the preservation and enhancement of soil quality, a feat that hinges on the integration of various nutrient sources**.**

Organic manure emerges as a cornerstone of this integrated approach. Laden with organic matter and essential nutrients, manure contributes significantly to soil fertility enhancement and crop yield amplification. The enrichment of soil with organic matter through manure application has a profound impact on soil structure and quality. Moreover, the incorporation of organic manures augments nutrient availability, nurturing a soil environment conducive to robust plant growth.

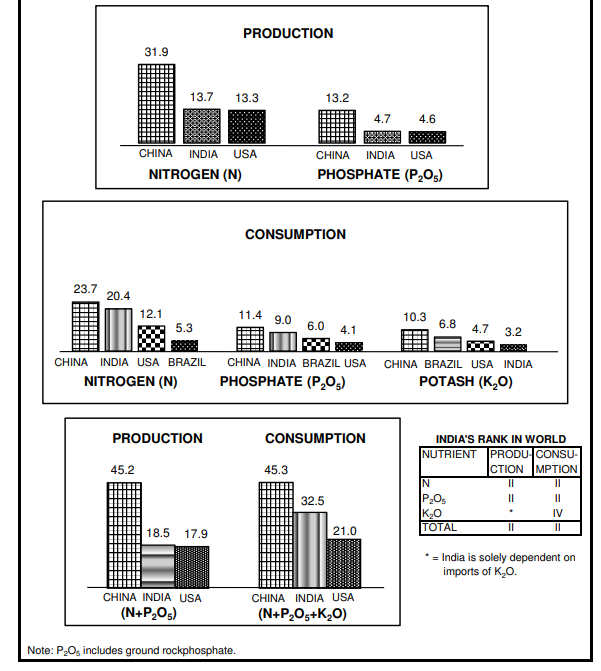
However, the continuous application of imbalanced fertilizers, especially within the intensive rice-wheat cropping system of the Indo-Gangetic Plains, has exerted deleterious effects on soil health. To counteract this, the practice of integrated nutrient management emerges as a viable solution, demonstrating the potential to rejuvenate soil's physical structure and chemical fertility. This, in turn, contributes to the enhancement of soil organic carbon content, ultimately fostering sustainable productivity within the agricultural system. While existing literature extensively examines the influence of organic matter on soil structure and other properties, the focus often centers on the bulk soil level. Regrettably, less attention has been directed towards comprehending soil mechanical properties at the scale of aggregates, which presents distinct manifestations that can substantially impact bulk soil characteristics [3].

The application of organic manures engenders improvements in soil structure, manifesting in enhanced air capacity, potential root extension, and exploitation of a larger soil volume. Additionally, it bolsters water retention within the soil profile [4], [5]. This augmentation in water retention subsequently translates to increased moisture availability for crops [6]; [7]; [8]. solidifying the acknowledged significance of organic matter in relation to soil's physical fertility [9]; [10]. Remarkably, the incorporation of organic matter into soil induces positive effects on aggregation [11].

Concurrently, the judicious incorporation of inorganic fertilizers complements the organic facet of nutrient management. Fertilization regimes, when properly tailored, exert transformative effects on soil health by influencing its chemical, physical, and biological attributes. The strategic integration of organic and inorganic fertilizers holds the promise of fostering enriched soil organic matter accumulation and refining key soil physical properties.

Conversely, inorganic fertilizers have been documented to stimulate root proliferation and depth in cereal crops [12]; [13]. with their impact on soil aggregation also observed [14]. Furthermore, the application of composted manure has been linked to the improvement of water-stable aggregates in soil [15].

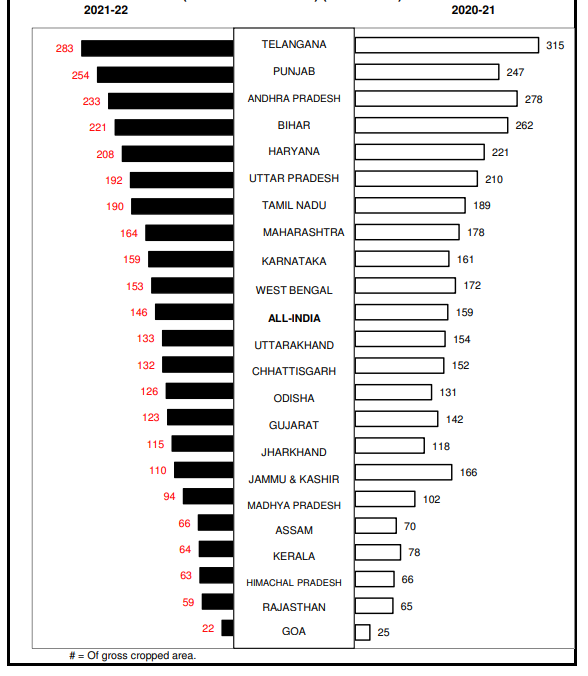
The integration of organic manures and fertilizers presents a promising avenue, not only for sustaining heightened productivity but also for enhancing yield stability [2].



**Fig. 1: Rank of India in world production and consumption of fertilizer nutrients**

**2020 (million tonnes)**

**(Source: Fertiliser-Stat-Book-2021-22)**

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**Fig.2: Consumption of plant nutrients in major states (N+P2O5+K2O kg ha-1)** (Source: Fertiliser-Stat-Book-2021-22).

**Consumption of plant nutrients (N+P2O5+K2O kg ha-1) in major states of India 2021-22:**

In India Telangana states recorded highest consumption of plant nutrient i.e., 283 kg ha-1 followed by Punjab (254 kg ha-1), Andhra Pradesh (233 kg ha-1), Bihar (221 kg ha-1), Haryana(208 kg ha-1), Uttar Pradesh(192 kg ha-1), Tamil Nadu (190 kg ha-1), Maharashtra (164 kg ha-1), Karnataka (159 kg ha-1), West Bengal (153 kg ha-1), Uttarakhand (133 kg ha-1), Chhattisgarh (132 kg ha-1), Odisha (126 kg ha-1), Gujrat (123 kg ha-1), Jharkhand (115 kg ha-1), Jammu And Kashmir (110 kg ha-1), Madhya Pradesh (94 kg ha-1), Assam (66 kg ha-1), Kerala (64 kg ha-1), Himachal Pradesh (63 kg ha-1), Rajasthan (59 kg ha-1), and the state which is the least number for consumption of plant nutrients is Goa (22 kg ha-1) (Source: Fertiliser-Stat-Book-2021-22).

Total fertilizer nutrient consumption (N+P2O5+K2O) was estimated at 29.80 million metric tonnes (million MT) as against 32.54 million MT in the previous year registering a negative growth of 8.4%. The consumption of N, P2O5 and K2O at 19.44 million MT, 7.83 million MT and 2.53 million MT during 2021-22 declined by 4.7%, 12.8% and 19.8%, respectively, over 2020-21. In terms of products, consumption of urea at 34.18 million MT, DAP at 9.27 million MT, MOP at 2.46 million MT and NP/NPK complex fertilizers at 11.48 million MT during 2021-22 witnessed decline of 2.5%, 22.2%, 28.3% and 2.8%, respectively, over 2020-21. However, consumption of SSP at 5.68 million MT recorded a sharp increase of 26.6% during the period. Total consumption of fertilizer products 63.94 million MT during 2021-22 showed a decline of 5.4% over 2020- 21. All-India NPK use ratio widened from 6.5:2.8:1 during 2020-21 to 7.7:3.1:1 during 2021-22. Per hectare use of total nutrients (N+P2O5+K2O) reduced from 160.1 kg in 2020-21 to 146.7 kg in 2021- 22 (Annual review of fertilizer production and consumption 2021-22).

**Effect of different treatments on soil properties:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Location and soil texture | Cropping system | Impact on soil fertility | | | | | | |
| Soil properties | | control | | Only fertilization | Only manuring | INM |
| Gabhane et al., 2022 | Central India Clayey | Cotton + greengram intercropping | pH | | 8.10 | | 8.05-8.02 | 7.98-8.0 | 7.98-7.99 |
|  |  |  | OC (g kg-1) | | 4.50 | | 6-5.10 | 6.10-5.90 | 6.90-6.90 |
| Kharche et al., 2013 | Central India Clayey | Sorghum+  wheat | Available nutrients (kg ha-1) | N: | | 117 | 153-271 | 152-235 | 246-283 |
| P: | | 6.4 | 15.2-20.5 | 15-17.7 | 16.5-24.6 |
| K: | | 484 | 513-579 | 515-575 | 586-606 |
| KATKAR et al., 2011 | Central India Clayey | Sorghum+  wheat | Available S (mg kg-1) | | 28.67 | | 34.05-58.08 | 31.58 | 63.39 |
|  |  |  | Total N (%) | | 0.0331 | | 0.0428- 0.0516 | 0.0512 | 0.0594 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Location and soil texture | Cropping system | Impact on soil physical properties | | | | |
| Soil properties | control | Only fertilization | Only manuring | INM |
| Nandapure et al., 2011 | Central India Clayey | Sorghum+  wheat | BD (Mg m-3) | 1.38 | 1.24- 1.36 | 1.24 | 1.22 |
|  |  |  | HC (cm hr-1) | 0.23 | 0.28-0.60 | 0.60 | 0.71 |
| Ramteke et al., 2022 | Central India Clayey | Cotton + greengram intercropping | WSA (%) | 78.76 | 81.00-85.37 | 80.80-83.37 | 90.88- 91.10` |
| Katkar et at.,2012 | Central India Clayey | Sorghum+  wheat | AWC (cm m-1) | 15.86 | 17.48-21.31 | 21.59 | 21.95 |
|  |  |  | MWD (mm) | 0.737 | 0.772- 1.169 | 1.254 | 1.412 |
| Dhamak et al., 2020 | Central India Clayey | Sorghum+  wheat | Porosity (%) | 56.32 | 56.51- 56.89 | 58.32- 58.35 | 58.12 -58.48 |
|  |  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Location and soil texture | Cropping system | Impact on biological properties | | | | |
| properties | control | Only fertilization | Only manuring | INM |
| Meshram et al., 2016 | Central India Clayey | soybean-safflower | Bacteria (CFU X 107 g -1 soil) | 95.26 | 124.62- 175.20 | 198.69 | 211.06 |
|  |  |  | Fungi i (CFU X 104 g -1 soil) | 5.06 | 5.33-8.19 | 11.17 | 8.22 |
|  |  |  | Actinomycetes (CFU X 106 g -1 soil); | 30.05 | 32.53-  45.87 | 51.36 | 53.16 |
| KATKAR et al., 2012 | Central India Clayey | Sorghum+  wheat | SMBC (mg kg-1) | 139 | 179- 227 | 222 | 247 |
|  |  |  | SMBN (mg kg-1) | 8.86 | 11.98-16.03 | 15.18 | 17.53 |
|  |  |  | DHA ug gm-1 24hr-1 | 32.51 | 36.97-45.69 | 45.08 | 49.78 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Location and soil texture | Cropping system | Impact on crop productivity | | | | |
|  | control | Only fertilization | Only manuring | INM |
| Jadhao et al., 2020 | Central India Clayey | Sorghum+  wheat | Wheat Grain yield (q ha-1) | 5.6 | 8.2-32.4 | 10.9 | 34.0 |
|  |  |  |  |  |  |  |  |
| Jadhao et al., 2019 | Central India Clayey | Sorghum+  wheat | Sorghum grain yield (t ha-1) | 0.38 | 1.76-4.22 | 3.61 | 4.60 |
|  |  |  | Sorghum fodder yield (t ha-1) | 0.83 | 4.18-10.14 | 5.82 | 8.48-11.05 |
| CHAUHAN et al., 2014 | Central India Clayey | Soybeans-wheat | Sustainability yield index of soybean | 0.131 | 0.145- 0.369 | 0.326 | 0.394 |
| Meshram et al., 2017 | Central India Clayey | soybean-safflower | Soybean grain yield (q ha-1) | 11.62 | 14.20-26.30 | 19.62 | 26.58 |
|  |  |  | Safflower grain yield (q ha-1) | 10.78 | 11.81-18.36 | 13.15 | 18.52 |

**II. IMPACT OF MANURES AND FERTILIZATION MANAGEMENT ON SOIL HEALTH AND CROP PRODUCTIVITY**

1. **EFFECT ON SOIL PHYSICAL PROPERTIES:**

The physical properties of soil viz., bulk density, aggregate stability, hydraulic conductivity, and mean weight diameter and water retention were significantly improved due to integration of chemical fertilizers with organics as compared to only chemical fertilizer [16].

1. **Effect on soil structure and water stable aggregate distribution**

Fertilizer N management significantly affected soil bulk density (BD) as did the depth by rotation interaction. 75 kg N/ha had a significantly lower BD than the other N fertilizer managements (p < 0.05). In the depth by rotation interaction, BD was not significantly different between 0 and 10 cm and 10–20 cm depths in mono-cropping, while 10–20 cm had significantly lower BD than 0–10 cm in rotation (p < 0.05). Fertilizer N management and the depth by rotation interaction significantly affected the MWD and GMD. Aggregate size fractions were affected, significantly, by N fertilizer management, rotation, depth and their interactions, but to different extents. Generally, the proportion of large and small macroaggregates increased within 10–20 cm soil depth, while that of microaggregates and silt-clay size fractions decreased. Manure application had the highest large macroaggregate proportion, with other aggregates being a lower proportion than in the chemical fertilizer treatments [19].

Fertilization significantly improved soil aggregation and aggregate stability in both surface and subsurface soil over control [26]. Fertilization enhanced aggregation by its effect on plant growth and ultimately, biomass returned to soil [14].

**2. Effect on Aggregate associated Carbon and Nitrogen.**

Organic material incorporation improves the relative abundance of macroaggregates at the expense of other fractions and also results in higher C in macroaggregate fractions. While fertilizer treatment effect in promoting soil aggregation is less pronounced, C content is similar across aggregate fractions [17]. Long-term application of a fertilizer in conjunction with organic manures induced a significant increase in the organic carbon status of the soil. This was clearly reflected by aggregate properties and stability. Manure amendment increased SOC concentration signiﬁcantly more than the three chemical N fertilization treatments (p < 0.05). At the 10–20 cm depth, tobacco-rice rotation still had higher SOC concentration than monocropping, except for the 0 kg N/ha treatment. Soil depth signiﬁcantly aﬀected all aggregate-associated TSN concentrations (p < 0.05), except for the whole soil. Both large and small macroaggregate and microaggregate associated TSN concentrations were numerically higher at 0–10 cm than 10–20 cm depth. Nitrogen fertilizer management signiﬁcantly aﬀected whole-soil and small macroaggregates and microaggregates and silt-clay fraction associated SOC (p < 0.05), except for large macroaggregates [19].

Manure provides soil organic addition [20]. This SOM can serve as a core for soil aggregation based on the aggregate-SOM models proposed by [21]. In addition, prior studies show manure promotes soil microbial community diversity and enzyme activity [22]; [23], which would also produce fungal hyphae to further cause coarse aggregate formation [24]; [25]. Manure amendment practices and tobacco-rice rotation could synergistically increase SOC and TSN, benefit soil structure and soil quality [19].

Greater aggregate-N concentration due to fertilizer application was also reported by [27]. Continuous cropping without nutrient management led to decreased N in all aggregate fractions in paddy soil [28].

**3. Effect on soil bulk density and hydraulic conductivity:**

The OM treatment significantly decreased soil BD and increased SOC compared with control treatment. The OM treatment generally increased soil organic concentration, leading to a decrease in soil BD and increased organic carbon content, because application of OM to the soil increases soil organic matter [31]. The reduction in bulk density of soil under integrated nutrient management is due to better aggregation, increased porosity and improvement in soil structure caused due to increase in soil organic matter [16]. [29] also observed that application of FYM along with fertilizers decreases the BD of soil.

Balanced fertilization with FYM markedly improved the hydraulic conductivity due to more organic matter content which increased biological activity, improved soil aggregation, and optimum pore volume as well as the effective connectivity of the pores [30].

**4. Effect on Soil water content:**

Fertilization systems had significant (p < 0.05) effects on SWC, in addition to factors of local climates and soil types. OM treatment had a greater impact on SWC than NPK and NPK + S at all soil depths (p < 0.05) [31]. [32] found that OM plots recorded higher SWC than the inorganic fertilizer, irrespective of soil depths. SWC further confirmed the soil water retention trends, i.e., at most sampling dates the OM treatment soil had significantly higher water contents than CK at 0–10 cm depth, but not at 10–20 cm.

**B) EFFECT ON SOIL FERTILITY:**

**1. Soil pH and EC:**

Soil pH values did not change significantly even after 46 years of soybean and wheat cultivation and continuous use of chemical fertilizers and/or organic manure Use of chemical fertilizer like urea, though it possesses net residual acidity could not create significant alteration in the soil pH values. This effect appears to have been controlled by the presence of calcium carbonate. However, the electrical conductivity has been observed that no significant changes have occurred due to imposed treatments with values ranging from 0.16 to 0.19 dSm-1 [33]. Similar, results on soil pH and EC has been earlier reported by [34], and [35].

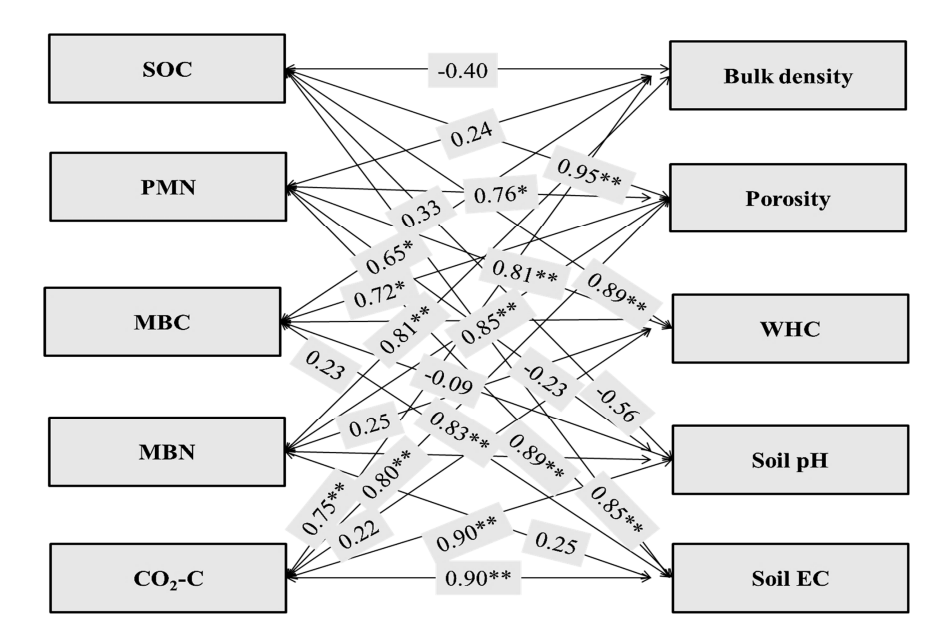
**2. Effect on soil organic carbon (SOC):**

Application of manure or straw on the farmyard increased the concentration of SOC significantly in depths of 0-20, 20-40 and 40-60 cm. At soil depths of 0-20 and 20-40 cm, SOC was the highest in NP+FKM followed by treatments with NP+S and FYM and the least in treatment with CK [36]. The application of fertilizers and/or FYM resulted in greater C sequestration and also increase the accumulation of SOC was higher in the surface layer of the soil as compared to subsurface layer due to the greater accumulation of the organic residues and external additions of organic matter at the surface layer [37]. [38] showed that addition of farmyard manure (FYM) with Nitrogen (N) or NPK fertilizers increased SOC contents. [39] observed that the plots with 50% NPK fertilizers + 50% farmyard manure (FYM) had significantly higher SOC content followed by 50% NPK fertilizers + 50% Green manure (GM) in topsoil.

[40] Revealed that treatments which received organic manure had significantly higher SOC concentrations compared to the mineral and control treatments as much as 35.39 Mg ha−1 more C in the top 20cm than the CK treatment. Furthermore, SOC concentrations significantly increased with increasing manure input rates. Increasing levels of fertilizer application has helped in increasing the organic carbon content, which is due to increased contribution from the biomass, as it is also observed that with increasing levels of fertilizer application, the crop yields had increased [33]. applying organic manure along with NPK fertilizer was beneficial because it supplemented NPK and added some secondary and micronutrients and also improved the physical and biological characteristics of the soil. These findings indicate that organic carbon plays an important role in maintaining and improving soil health [41].

**3.Correlations between soil organic carbon and physical properties:**

The soil BD showed a negative correlation with SOC, which indicated that the organic matter addition produced a decrease in BD. Also, there was a negative correlation between the soil Penetration Resistance (PR) and SOC, indicating that the soil PR decreased with addition of organic matter. The BD also showed a negative correlation with the SWC and a positive correlation with PR and indicating that a decrease in BD improved the soil structure [31]. The high negative correlation observed between the SOC and the BD and the PR (p < 0.01) is due to different factors such as the reduced or no tillage in organic treatments, and the increase in the labile fraction of the organic carbon that is released through the microbial decomposition of organic matter deposited on the soil mineral fraction as a surface coating, yielding soil aggregation as reported by [42].



**Fig. 3**: The correlation coefficient of soil OC and microbiological community with soil properties (\*\*-correlation is significant at the 0.01 level; \*-correlation is significant at the 0.05 level), (Source: Dhaliwal et. al., 2021).

**4. Effect on nutrient status of soil:**

1. **Soil available Nitrogen:**

Continuous use of nitrogenous fertilizers for forty-six years tended to increase the available nitrogen status of soil [33 Nilesh Patidar 2021]. [43] who observed that available N content in soil increased significantly with the use of recommended fertilizer dose in combination with manure. [44] also reported an increase in available nitrogen contents due to graded application of NPK fertilizers.

1. **Soil available Phosphorous:**

The concentration of P in available pool further increased due to the P addition from FYM. The FYM besides being a direct source of nutrients, might have also solubilized the insoluble phosphate in the soil through release of various organic acids [34].

1. **Soil available Potassium:**

The highest available K status of soil was found associated with 100% NPK + FYM followed by 150% NPK treatments [33 Nilesh Patidar2021]. The application of organic manure may have caused reduction in K fixation and consequentially increased K content due to interaction of organic matter with clay besides the direct addition of K to the soil [45].

1. **Available Sulphur:**

The application of NPK with FYM resulted in significantly higher available S content (38.6 kg ha-1) than initial value (15.6 kg ha-1) after 46 years of experimentation due to the application of single super phosphate and FYM, which contained sulphur [33]. The continuous use of diammonium phosphate as P source has resulted in S deficiency in 100% NPK-S; causing reduction in crop yields [34].

1. **SUSTAINABLE CROP PRODUCTIVITY**

The continuous use of only chemical fertilizers was observed to be responsible for decline in yields which is also reflected in terms of deterioration in soil quality attributes while enhanced soil quality attributes observed under INM practices encouraged increase in crop yields [16]. Integrated use of inorganic fertilizers and organic manure found better under the long term which sustained crop productivity and enhanced soil quality in sorghum- wheat cropping sequence grown on Vertisol [46]. Increasing levels of fertilizer application has helped in increasing OC content, which is due to increased contribution from the biomass, as it is observed with increasing levels of fertilizers application also increased the crop yield [48]. [49] reported that an optimal level of SOC stock is an essential determinant of soil quality to support relatively high crop yield and a strong relationship between agronomic production and the SOC stock, especially in low-input agriculture (none or low rate of fertilizer input).

**CONCLUSION**

Applications of organic and mineral fertilizers to a soil improved soil physical property. Generally, the organic fertilizers yielded significant increase in SWRC at most potential and plant-available water content. In particular, SWC was increased at all soil depths with organic fertilizers under dry and wet periods. Furthermore, hydraulic conductivity (saturated and unsaturated), soil BD, and PR showed significant decrease with organic fertilizers than other treatments.

Balanced use of fertilizers alone or in combinations with organic manure resulted significant builds up of organic carbon content and in the available N, P, and K. Further, imbalance use of inorganic fertilizers reduced crop yields and deteriorated soil fertility. Hence, it is recommended that balance application of fertilizers integrating with FYM is necessary to maintain soil fertility, productivity.

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