Continuous application of fertilizer over four decades on yield, physical and chemical properties of swell-shrink soil under finger millet – maize cropping sequence

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ABSTRACT
Long term fertilizer applications and continuous cropping system of Maize - Finger millet (44 years of cropping sequence) has a significant impact on yield and nutrient balance on a soil system. The investigation assessed the effect of long term fertilizer usage on yield and nutrient balance through different treatments such as different doses of NPK (50%, 100% and 150%), NPK along with organic manure, omission of K, PK, addition of Zn along with NPK and omission of S from major nutrients. Application of inorganic NPK fertilizers at graded levels from 50 to 150% NPK increased the grain and straw yield of finger millet and maize. Under the integrated nutrient management practice (100% NPK+FYM), the percent increased grain yield was 17.08 in finger millet and 12.62 in maize over 100 % NPK indicating that INM is the best way of maximize the yield continuously in intensive cropping systems. Under this treatment, the soil available nutrient status was observed high. In INM treatment, possibly the added FYM, might have contributed directly in appreciable amounts of major and micronutrients to the soil and enhanced yields. The status of available N was highest under 100% NPK + FYM, followed by 100% NPK. Continuous addition of N alone did not influence available N, instead reduced available N when compared to NPK treatments. Addition of fertilizer P in progressive levels such as 50, 100 and 150% NPK levels has increased the soil available P (22.62 % in finger millet and 26.35 % in maize) over 100 per cent NPK. Also, addition of different levels of K has improved the soil available K (18.32 % in finger millet and 14.41 % in maize) when compared to 100 % NPK.

Key words: Long term fertilization, Maize – finger millet cropping system, Nutrient fractions, Swell shrink soil.

INTRODUCTION
Continuous cropping system, high yielding varieties, irrigation and high analysis fertilizer accelerated the mining of nutrient other than supplied even more from soil. Since large amount of nutrient has to be applied to soil in chemical form which may have impact on soil properties and soil productivity in long term. Interest in long-term field experiments as the suitable indicators of sustainability of agriculture has increased during last few decades the world over. These experiments indicate the extent to which yield and related parameters and the quality of ecosystem can be predicted. These are also capable of serving as an early warning system to detect problems that threaten future productivity (Berzenyi et al., 2000).

Primary (macro) nutrients viz., nitrogen, phosphorus, and potassium are the most frequently required in a crop fertilization schedule. Also, they are need in the greatest total quantity by plants as fertilizer. Nitrogen has a profound effect on soil fertility, crop yield and contributes to an increase in post harvest residue thus preventing the loss of soil organic matter (Wiatier and Chwil 2005). The results of the long term fertilization reviewed by Nambiar (1985) reported that there was a decline in available N status of soil in plots where N had not been applied since many years. Similarly continuous addition of K fertilizers decreased available N status due to blocking of adsorbed NH$_4^+$ by added K preventing its release into soil solution (Govindarajan and Gopala Rao, 1978).

Soil P exists in various chemical forms including inorganic P (Pi) and organic P (Po). These P forms differ in their behavior and fate in soil (Turner et al., 2007). In the soil, applied P is partitioned into readily available (labile) and less readily available (stable) inorganic and organic forms with different desorption, dissolution and mineralization rates that may contribute to plant P nutrition. Continuous long term application of fertilizers can lead to P accumulation in surface horizons greater than that required for optimum plant growth thus increasing the potential for P loss to surface water and cause eutrophication (McDowell et al., 2001).

The forms of soil K in the order of their availability to plants and microbes are solution > exchangeable > fixed (non exchangeable) > mineral (Sparks, 2000). The effects of the long term intensive cropping and fertilizers on available
K status in a *Haplustert* soil was that the available soil K declined over the 29 years of intensive cropping and fertilizer application even at 150 per cent NPKS (Temphare, 2002).

With this background, a study has been undertaken to evaluate the continuous application of mineral fertilizers along with the organics on yield, soil physical and chemical properties in finger millet – maize cropping sequence on black soils of *Vertic Ustropept* in Coimbatore, Tamil Nadu.

**MATERIALS AND METHODS**

**Site description:** Long Term Fertilizer Experiment (LTFE) of Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore was started during 1972 and it has crossed 42 years of continuous experimentation with three and two cropping sequence. The finger millet – maize cropping sequence was followed from 2008. The experimental soil (Periyanaiakenpalayam soil series) is sandy clay loam in texture and taxonomically grouped under *Vertic Ustropept*. Available nutrient status of experimental soil analyzed at 2008 showed that, low in available nitrogen (178 kg ha\(^{-1}\)), low in available phosphorus (11 kg ha\(^{-1}\)) and high in available potassium (810 kg ha\(^{-1}\)). Ten treatments are being studied in this LTFE trial, which comprises of T\(_{1}\), 50 % NPK, T\(_{2}\), 100 % NPK, T\(_{3}\), 150 % NPK, T\(_{4}\), 100 % NPK + Zn, T\(_{5}\), 100 % NPK + Zn, T\(_{6}\), 100 % NP, T\(_{7}\), 100 % N, T\(_{8}\), 100 % NP + FYM, T\(_{9}\), 100 % NPK + S (Single Super Phosphate as Phosphorus source) and T\(_{10}\) - control under randomized block design.

**Experimental design and treatments:** The finger millet (CO 13) was sown in raised bed and transplanted in main field with 30 cm X 10 cm spacing. As per the treatment structure, twenty days before the transplanting of crop farm yard manure @ 10 t ha\(^{-1}\) was applied uniformly over the main field. Hundred per cent recommended doses of P\(_{2}O_{5}\) and K\(_{2}O\) and 25 per cent of N (Urea) @ 90:45:17.5 kg ha\(^{-1}\) respectively was applied basally in the main field. The remaining 50 and 25 per cent of N was top dressed on 25\(^{th}\) and 50\(^{th}\) DAS. Fertilizers like urea for N, single super phosphate (SSP) for P and Muriate of Potash (MOP) for K was selected as source of fertilizer nutrient. Instead of Single Super Phosphate, Di Ammonium Phosphate was used as source of P to eliminate supply of sulphur in T\(_{3}\). Except T\(_{3}\), other treatments received soil application of pre emergence herbicide. routine cultural operations and needed plant protection measures were carried out at regular intervals as per the Crop Production Guide.

Grain and straw yield was recorded plot wise at the time of harvest and yield per hectare was arrived in 2014-2015. Available N in soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956), available P by Colorimetry method (Olsen *et al.*, 1954), available K by Neutral Normal Ammonium Acetate method (Stanford and English, 1949) and available micronutrients (Fe, Mn, Zn and Cu) were estimated by DTPA extraction followed by absorption spectrometry (Lindsay and Norvell, 1978) and all the values were subjected to analysis of variance as mentioned by Panse and Sukhatme (1985).

**RESULTS AND DISCUSSION**

**Grain and straw yield of Finger millet - Maize cropping system (kg ha\(^{-1}\)):** Long term fertilization on finger millet – maize cropping sequences resulted in significant higher grain and straw yield of both the crops. As the dosage of NPK increased, the crop yield also enhanced. Increase in grain yield from 2084 kg/ha to 2917 kg/ha was observed in finger millet and from 5132 to 5492 kg/ha in maize. The highest grain yield of finger millet 3071 kg ha\(^{-1}\) for 100 % NPK + FYM (T\(_{4}\)) was observed which was comparable with 150 % NPK (T\(_{8}\)) and 100 % NPK plus Zn (T\(_{9}\)) treatments. Furthermore, the straw yield of finger millet was significantly higher with 100 % NPK + FYM (T\(_{4}\)) followed by 150 % NPK (T\(_{8}\)) Similarly, the highest mean yield 6054 kg ha\(^{-1}\) of maize (Table 1) was achieved by 100 % NPK + FYM (T\(_{4}\)) and straw yield of 9379 kg ha\(^{-1}\) by recommended 150 % NPK and 100 % NPK + Zn. The increased yield of both the crops under the treatment T\(_{4}\) (100 % NPK + FYM) might be due to application of inorganic fertilizers along with farmyard manure could have encouraged the better rhizosphere environment, which would have made better nutrient availability in root zone and increased the nutrient absorption and translocation from source to sink exert a important regulatory function on complex process of yield formation. This was supported by the findings of Kumar *et al.* (2008) who revealed that addition of recommended dose of plant nutrients along with farm yard manure might be the great cause for yield increase over control. The grain yield of finger millet and maize obtained by application of NP alone was found comparable with T\(_{3}\) [100 % NPK (-S)] and T\(_{8}\) (100 % NPK) which may be attributed to higher soil available potassium that would have met plants K requirement during crop growth.

**Physical properties of the soil (Bulk density, hydraulic conductivity and infiltration rate):** Long term fertilization with varied levels of NPK had significant effect on soil physical properties. Bulk density of soil recorded was found to be from 1.25 to 1.37 Mg m\(^{-3}\) for various treatments. Application of 100 % NPK with FYM recorded lowest bulk density of 1.25 Mg m\(^{-3}\) while treatments (T\(_{5}\), T\(_{8}\), T\(_{9}\) and T\(_{10}\)) that received either 100 % NPK alone or with Zn recorded BD ranging from 1.30 to 1.33 Mg m\(^{-3}\). Higher values of BD (1.36 to 1.38) were observed for the treatments which received either N or NP or No NPK. The continuous addition of manure along with fertilizer in clay loam soil might have released organic substances which inturn would have improved the soil structure and lower BD values in the FYM applied plots. Also, recommended dose of fertilizer application would have facilitated better plant root growth which on decomposition released organic substances might
have resulted in better soil structure and lower BD values. This was supported by Anderson et al. (1990) who revealed, annual additions of barnyard manure for 100 years in continuous wheat - corn - timothy cropping systems decline in BD on average, by 0.12 g cm⁻³ compared to unfertilized plots due to increased SOM and soil structure. As expected the soil with lower BD values registered significantly higher cumulative infiltration after 60 min and hydraulic conductivity which was 34.1 and 2.92 for 100% NPK plus FYM (T₈) as against 21.4 and 1.48 in control (T₁) respectively. Those treatments that received 100% NPK either alone or in combination with Zn registered relatively higher infiltration rate and hydraulic conductivity which were 26.7 (T₇) 26.8 (T₅) and 2.05 and 1.92 respectively. This might be due to better soil aggregation by continuous application of soil organic matter and mineral fertilizers which would have led to increased the amount of hydrophilic C=O groups (O and N containing hydroxyl and Carboxyl groups) relative to that of hydrophobic CH groups. Hydrophilic characters depend on carboxyl and hydroxyl groups which affects the water storage capacity of soil. This was supported by the Babbu Singh Brar et al (2015) who revealed that the increase in infiltration rate may be due to increase in micropores and macropores in the soil resulting from better aggregation by cementing of soil particles together due to higher SOM and favorable living conditions for soil organisms. Also, Bhattacharyya et al. (2007) who revealed, application of N fertilizers had increased significant SOC, which increases the infiltration rate.

**Soil chemical properties**

**Major nutrients (N, P and K):** The status of available major nutrients in the post harvest soils of cropping system was highest under 100% NPK + FYM (T₈) which had respectively N, P and K of 280, 28.95 and 807 kg ha⁻¹ in Finger millet and 225, 26.61 and 635 kg ha⁻¹ in Maize crop (Table 1). Increasing recommended NPK from 50% to 150% significantly increased available N. Continuous addition of N alone (T₇) did not influence available N remarkably instead available N was reduced when compared to NPK treatments. The highest N was recorded in 100% NPK + FYM (T₈) of 240 and 225 kg ha⁻¹ in finger millet and maize respectively.

Application of FYM at 10 t ha⁻¹ along with 100% NPK increased the available N status and increased N availability due to additional and slow release of N from manures added to soil. The increase in available N status may be due to organic manure application which would helped for multiplication of microbes leading to mineralization and enhanced conversion of organically bound N into inorganic forms thus enhanced N availability.

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**Table 1:** Grain and straw yield of finger millet and maize (kg ha⁻¹).

| Treatment Structure | Finger millet (100%) | Maize (101%) |
|---------------------|----------------------|--------------|
| Grain Yield         | Straw Yield          | Grain Yield  | Straw Yield |
| T₁ -50 % NPK        | 2084                 | 3233         | 5132        | 7029        |
| T₂ -100 % NPK       | 2623                 | 4142         | 5378        | 8271        |
| T₃ -150 % NPK       | 2917                 | 4637         | 5492        | 8514        |
| T₄ -100 % NPK + HW  | 2476                 | 3893         | 5311        | 8149        |
| T₅ -100 % NPK + Zn  | 2870                 | 4557         | 5432        | 8458        |
| T₆ -100 % NP        | 2525                 | 3977         | 5213        | 8134        |
| T₇ -100 % N         | 1742                 | 2655         | 4256        | 6933        |
| T₈ -100 % NPK + FYM | 3071                 | 4956         | 6057        | 9379        |
| T₉ -100 % NPK (-S)  | 2594                 | 4092         | 5349        | 8221        |
| T₁₀ control         | 1413                 | 2101         | 3012        | 5242        |
| SEd                 | 124                  | 87           | 137         | 165         |
| CD (P = 0.05)       | 211                  | 148          | 233         | 281         |

**Table 2:** Soil Physical properties after harvest of finger millet - maize cropping cycle (kg ha⁻¹).

| Treatment Structure | Bulk density (Mg m⁻³) | Hydraulic conductivity (cm hr⁻¹) | Infiltration rate (mm hr⁻¹) |
|---------------------|-----------------------|---------------------------------|-----------------------------|
| T₁ -50 % NPK        | 1.35                  | 1.45                            | 23.2                        |
| T₂ -100 % NPK       | 1.32                  | 1.94                            | 25.6                        |
| T₃ -150 % NPK       | 1.33                  | 2.05                            | 26.8                        |
| T₄ -100 % NPK + HW  | 1.33                  | 1.84                            | 24.1                        |
| T₅ -100 % NPK + Zn  | 1.30                  | 1.92                            | 26.7                        |
| T₆ -100 % NP        | 1.36                  | 1.75                            | 24.2                        |
| T₇ -100 % N         | 1.37                  | 1.53                            | 22.7                        |
| T₈ -100 % NPK + FYM | 1.25                  | 2.92                            | 34.1                        |
| T₉ -100 % NPK (-S)  | 1.32                  | 1.88                            | 25.7                        |
| T₁₀ control         | 1.38                  | 1.48                            | 21.4                        |
| SEd                 | 0.03                  | 0.05                            | 0.60                        |
| CD (P = 0.05)       | 0.06                  | 0.08                            | 1.02                        |
to crops. Organic manures besides being a store house of nutrients also prevents the loss of nutrients by leaching. The decrease in available N status in the absolute control may be due to the continual removal of soil N in the absence of external supply of N through fertilizers and manures. This result was corroborated with the findings of Dong et al. (2012) who reported dynamic changes of soil available nitrogen significantly increased with organic manure and NPK treatments, suggesting that the long-term soil organic matter played a major role in releasing soil available nitrogen. As all the treatments except control, received nitrogen for all the crops, its availability in the post harvest soils was maintained more or less same quantity as that of initial available N value (199 kg/ha).

Regarding the P status, the lowest available P status was found in control (7.66 and 6.45 kg ha⁻¹) while a high value of 28.95 and 26.61 kg ha⁻¹ was recorded for the application of FYM at 10 t ha⁻¹ along with 100% NPK in the post-harvest soil of finger millet and maize respectively (Table 3). Available P status of the soil was the lowest in control due to exclusion of P fertilizers from the nutrient schedule. Available P status was significantly higher in treatments receiving P fertilizers than in the treatments without P. Higher availability of P in 100 % NPK + FYM treatment may be attributed to high residual P by low P sorption as organic anions released during the decomposition of FYM would have adsorbed on sorption sites thereby making more P availability in soil. This was in line with the findings of Varinderpal Singh and Brar Dhillon (2006) who found relatively large amount of residual P in NPK + FYM treatments. Further, those treatments that received phosphatic fertilizer continuously showed P built up as compared to initial available P (12.3 kg/ha).

The continuous application of inorganic nutrients and FYM significantly increased the soil available K when compared to the K skipping treatments. The highest soil K was observed in NPK + FYM of 807 and 635 kg ha⁻¹ in finger millet and maize crops respectively. Soil available K declined in all the treatments from the initial value of experimental soil. Regarding the treatments, continuous addition of organic manure along with FYM and optimum K fertilization recorded higher value over control. Within the treatments, INM practice recorded higher value which might be due to mineralizing action of organic matter and

Table 3: Available nutrient status in post harvest soil of finger millet and maize cropping system.

| Treatment Structure | Finger millet (kg ha⁻¹) | Maize (kg ha⁻¹) |
|---------------------|-------------------------|-----------------|
|                     | N          | P       | K     | N    | P    | K     |
| Tₜ-50 % NPK         | 190        | 19.78   | 635   | 171  | 17.51| 521   |
| Tₜ-100 % NPK        | 218        | 23.61   | 682   | 194  | 21.06| 555   |
| Tₜ-150 % NPK        | 232        | 26.32   | 741   | 222  | 24.82| 584   |
| Tₜ-100 % NPK + HW   | 218        | 22.36   | 689   | 196  | 20.92| 550   |
| Tₜ-100 % NPK + Zn   | 225        | 22.69   | 696   | 201  | 20.47| 542   |
| Tₜ-100 % NP         | 223        | 21.36   | 672   | 195  | 18.66| 403   |
| Tₜ-100 % N          | 204        | 13.21   | 617   | 195  | 10.48| 499   |
| Tₜ-100 % NPK + FYM  | 240        | 28.95   | 807   | 225  | 26.61| 635   |
| Tₜ-100 % NPK (-S)   | 222        | 24.60   | 664   | 189  | 21.23| 546   |
| Tₜ-50 % NPK         | 162        | 7.66    | 623   | 148  | 6.45 | 471   |
| CD (P = 0.05)        | 12.4       | 0.43    | 34.3  | 4.2  | 0.243| 11.99 |

*(Initial soil available N (199 kg ha⁻¹), P (12.3 kg ha⁻¹) and K (907 kg ha⁻¹) kg ha⁻¹ in 1972 since inception of the experiment).

Table 4: DTPA – extractable micronutrient status in post harvest soil of finger millet and maize cropping system (µg g⁻¹).

| Treatments     | Finer millet (100⁰) | Maize (10¹) |
|----------------|---------------------|-------------|
|                | DTPA - Zn | DTPA - Fe | DTPA - Mn | DTPA - Cu | DTPA - Zn | DTPA - Fe | DTPA - Mn | DTPA - Cu |
| Tₜ-50 % NPK    | 0.600    | 1.816    | 5.360    | 0.895    | 0.755    | 2.062    | 6.240    | 0.865    |
| Tₜ-100 % NPK   | 0.602    | 2.060    | 5.395    | 0.907    | 0.760    | 2.232    | 6.298    | 0.852    |
| Tₜ-150 % NPK   | 0.607    | 2.055    | 5.431    | 0.931    | 0.793    | 2.289    | 6.193    | 0.869    |
| Tₜ-100 % NPK+HW| 0.620    | 1.984    | 5.248    | 0.907    | 0.758    | 2.133    | 6.034    | 0.812    |
| Tₜ-100 % NPK+Zn| 1.953    | 1.925    | 5.408    | 0.928    | 2.133    | 2.120    | 6.142    | 0.847    |
| Tₜ-100 % NP    | 0.650    | 1.925    | 5.179    | 0.862    | 0.769    | 2.155    | 6.775    | 0.835    |
| Tₜ-100 % N     | 0.378    | 1.837    | 5.211    | 0.909    | 0.678    | 1.794    | 5.937    | 0.792    |
| Tₜ-100 % NPK+ FYM| 0.589   | 1.805    | 5.842    | 0.803    | 0.910    | 2.225    | 6.375    | 0.828    |
| Tₜ-100 % NPK (-S)| 0.497   | 1.720    | 5.323    | 0.827    | 0.726    | 2.082    | 5.728    | 0.795    |
| Tₜ-50 % NPK    | 0.365    | 1.871    | 5.170    | 0.874    | 0.503    | 2.051    | 6.141    | 0.803    |
| CD (P = 0.05)  | 0.04     | 0.32     | 0.24     | 0.12     | 0.032    | 0.050    | 0.154    | 0.023    |

*(Initial soil available Zn (18.66 kg ha⁻¹), Fe (23.61 kg ha⁻¹) and Cu (0.931) kg ha⁻¹ in 1972 since inception of the experiment).
release of nutrients to the soil labile pool. The decreased availability of K in N, NP and absolute control treatments may be attributed to the higher uptake of K by crops resulting in depletion of K in the absence of K addition. This was in line with the findings of Dong et al. (2012) who revealed NPK treatment significantly increased available K content. However, irrespective of the treatments, soil potassium depletion was observed as compared to initial soil available potassium (907 kg/ha) which may be due to considerable removal of potassium by both the crops and fixation of K in clay minerals (Madaras et al., 2014).

**Micro nutrients (Zn, Fe, Mn and Cu):** The DTPA extractable micronutrients like zinc, iron, manganese and copper ranged from 0.36-1.95, 1.72 – 2.06, 5.17 – 5.84 and 0.80 - 0.93 and 0.50 – 2.13, 2.05 – 2.28, 5.72 – 6.77 and 0.79 –0.86 mg kg⁻¹ in post-harvest experimental soil of finger millet and maize respectively (Table 4). There was no significant change observed in DTPA extractable iron, copper and manganese in post harvest soil of finger millet. Significantly higher availability of 1.95 and 2.13 mg kg⁻¹ of Zn was noticed in 100 % NPK + ZnSO₄ in the soils of finger millet and maize respectively. This might be attributed to the fact that good amount of Zn was contributed by continuous addition of ZnSO₄ along with 100% NPK. This was supported by the findings of Sunil Panwar et al. (2017) who observed that soil available Zn was highly significant in 100 % NPK + FYM. The continuous removal of micro nutrients by the crops under continuous cropping of finger millet - maize cropping sequence may be attributed to lesser content of DTPA-Zn for those treatments that did not receive zinc sulphate fertilizer (Keram et al., 2012). While available copper, iron and manganese content were not influenced due to different treatments in the post harvest soil of finger millet. However, available copper and iron were found below critical values (Cu -1.2 ppm and Fe-3.7 ppm) in all the treatments which may be due to non application of these two nutrients coupled with removal of this nutrients by both the crops every year. (Singh et al., 2010).

**CONCLUSION**

It is concluded from the foregoing pages that the long term fertilizer application with different treatments resulted in significant variation on the grain yield, soil physical properties and nutrient availability in finger millet – maize cropping sequence in *Vertic Ustropept* in swell shrink cropping sequence. Application of recommended dose of fertilizer along with FYM maintained significant improvement in grain yield of finger millet and maize, soil physical and chemical properties as well as nutrient balance over the years as compared to other treatments. Among the nutrients, the study revealed that maintenance of available N, built up of P and depletion of available K was observed as compared to initial available status. Non application of micronutrients fertilizer also resulted in depletion of micronutrients in post harvest soil. This suggests that mineral fertilizer with organic manure shall be adopted for sustaining crop yield and soil fertility in continuous cropping system.

**REFERENCES**

Arnold, P.W. (1960). Nature and mode of weathering of soil potassium reserves. *J. Sci. Food Agric.* **11**: 285-292.

Babu Singh Brar, Jagdeep Singh, Gurbir Singh and Gurpreet Kaur. (2015). Effects of long term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. *Agronomy*. **5**: 220-238.

Berzsenyi, Z., Györfy, B and Lap, D.Q. (2000). Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. *Eur. J. Agron*. **13**(2-3): 225-244.

Bhattacharyya, R., Chandra, S, Singh, R, Kundu, S, Srivastva, A and Gupta, H. (2007). Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat-soybean rotation. *Soil Till. Res*. **94**: 386–396.

Dong, W., Hu, C, Zhang, Y and Wu, D. (2012). Gross mineralization, nitrification and N₂O emission under different tillage in the North China Plain. *Nutrient Cycling in Agro Ecosystems*. **94**: 237–247.

Garz J., Schliephake, W and Merbach, W. (2000). Changes in the subsoil of long-term trials in Halle (Saale), Germany, caused by mineral fertilization. *J. Plant Nutr. Soil Sci*. **163**: 663–668.

Govindarajan, S.V and GopalaRao, H.G. (1978). Studies on soils of India. N fertilization and problems of N availability. Vikas Pub. House, NewDelhi. pp. 276-290.

Jalali, M. (2007). Phosphorous status and sorption characteristics of some calcareous soils of Hamadan, western Iran. *Environ. Geol*. **53**: 365–374.

Kumar, B., Gupta, R.K and Bhandari, A.L. (2008). Soil fertility changes after long-term application of organic manures and crop residues under rice wheat system. *Journal of Indian Society of Soil Science*. **56**(1): 80-85.

Linsay, W.L and Norvell, W.A. (1978). Development of a DTPA- micronutrients soil test for Zn, Fe, Mn and Cu. *Soil Sci. Soc. Am. Proc*. **42**: 421- 428.

McDowell, R., Sharpley, A and Folmar, G. (2001). Phosphorus export from an agricultural watershed: linking source and transport mechanisms. *J. Environ. Qual*. **30**: 1587-1595.

Merbach, W., Garz, J, Schliephake, W, Stumpe, H and Schmidt, L. (2000). The long-term fertilization trials in Halle – Introduction and overview. *J. Plant Nutr. Soil Sci*. **163**: 627–636.

Nambiar, K.K.M. (1985). All India Coordinated Research Project on Long Term Fertilizer Experiments and its research achievements. *Fert. News*. **30**: 56-66.

Olsen, S.R., Cole, C.V, Watenabe, F.S and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S.D.A. Circ.* 939; U.S. Govt. Printing Office, Washington, DC.
Panse, V.G and Sukhatme, P.V. (1985). Statistical Methods for Agricultural Workers. Publication and information Division. ICAR, New Delhi.

Selvi, R and Augustine Selvaseelan, D. (1997). Effect of mushroom spent rice straw compost on soil physical properties of alluvial and laterite soils. Madras Agric. J. 84(1): 15-19.

Singh, N.P., Sachan, R.S, Pandey, P.C and Bishit, P.S. (1999). Effect of a decade long fertilizer and manure application on soil fertility and productivity of rice wheat system in a mollisol. J. of the Indian Soc. of Soil Sci. 47(1):72-80.

Sparks, D.L and Huang, P.M. (1985). Physical chemistry of soil potassium. In: Potassium in agriculture. [R.D. Munson (ed.)] American Society of Agronomy, Madison, WI, P. 201-276.

Stanford, S and English, L. (1949). Use of flame photometer in rapid soil tests of K. Can. J. Agron. 41: 446-447.

Subbiah, B.V and Asija, G.C. (1956). A rapid procedure for estimation of available nutrients in soils. Curr. Sci. 25: 259-260.

Takeda, A., Hiraume Tsukada, Masami Nannya, Yuichi Takaku, ToyokazuUemura, Shunichi Hisamatsu et al. (2005). Effect of long term fertilizer application on the concentration and solubility of major and trace elements in a cultivated Andisol. SoilSci Plant Nutr. 51(2): 251—260.

Temphare. B.R. (2002). Long term effects of intensive cropping and fertilizer on available potassium- a changing scenario in a Haplustert. In: National Seminar on Developments in Soil Science, 67th Annual convention, Nov pp.11-15, held at Jawaharlal Nehru Krishi VishwaVidyalaya, Jabalpur.

Turner, B.L., Richardson, A.E and Mullaney, E.J. (2007). Inositol Phosphates: Linking Agriculture and the Environment. CAB International, Wallingford, UK, p 304.

Varinderpal Singh, Dhillon, N.S, Brar, B.S. (2006). Influence of long-term use of fertilizers and farmyard manure on the adsorption–desorption behaviour and bioavailability of phosphorus in soils. Nutrient Cycling in Agro ecosystems. 75(1–3):67–78.

Wiater, J and Chwil, S. (2005): The influence of mineral fertilization on the content of mineral nitrogen forms in the medium soil. FragAgron. 22: 613–623.