



Research Article

Dynamics of Soil Organic Carbon, Bulk Density and Water Stable Aggregates in relation to Yield of Rice - Rice Crop Sequence as Affected by Exclusive Inorganic and Integrated Nutrient Management Practices

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ABSTRACT

An experiment was conducted with rice-rice crop sequence for seven consecutive years (from 1999 to 2006) on the same site of a *Vertic ustochrept* at the farm of Navsari Agricultural University, Main Campus, Navsari. Twelve treatments comprising of 50 and 100% of recommended dose of fertilizer N (RDN) and P (RDP) to both *kharif* and summer crops alone and in combination with P solubilizing bacteria (PSB), crop residues, FYM or pressmud or with bio-compost including one treatment having N, P and K as per soil test value to both the crops were followed to evaluate the dynamics of soil organic carbon (SOC), bulk density (BD) and water stable aggregates (WSA) in relation to crop yield. The results revealed that SOC, BD and WSA (> 1.0 mm) differed significantly with regards to inorganic and various INM treatments only after 4th, 6th and 7th crop sequence. However, treatment effect was non – significant for all the above parameters after rest of the crop sequences. Slight improvement of soil quality in terms of increase in SOC, reduction in BD and increase in percent of WSA > 1.0 mm though observed after 4th crop sequence under combined organic and inorganic treatments, yet significant improvement of these parameters were found after the 6th and 7th crop sequence. All the treatments receiving INM produced, in general, lower sequential grain and straw yields of rice. However, such improvement in soil quality under combined treatments from 5th crop sequence onwards could not boost the grain yield of sequence over other treatments, except the combined treatment of RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t ha^{-1} which produced either significantly higher yield or at par with some inorganic and inorganic+ organic combined treatments from 5th sequence onwards. Treatment receiving N, P and K as per soil tests yielded the higher sequential grain yield remaining at par with RDN and RDP as compared to all other treatments.

Key words: INM, rice-rice sequence, yield, bulk density, water stable aggregates, organic carbon, Dynamics

Introduction

Rice-rice system generally needs large amounts of nutrients to maintain high productivity. Puddling of rice-soils causes destruction of soil structure which in turn causes rapid disintegration of water stable aggregates of

soil and as a result not only soil organic carbon decreases but also soil physical properties like, bulk density and biological quality deteriorate. All these factors play crucial role in sustaining soil quality, agricultural production and environmental quality (Zhang *et al.*, 2003 and Andrews *et al.*, 2004). Application of organics along with inorganics under rice-rice system not only increases the nutrient use efficiency but also

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helps avert to a certain extent deterioration of soil physical properties which ultimately have positive effect on yield. Long-term experiments at many locations have indicated that application of recommended dose of inorganic fertilizers is not able to sustain high productivity of rice-rice system (Nambiar *et al.*, 1992). The system including organic sources act not only as macro and micro nutrient source, but also increases efficiency of inorganic fertilizers (Pandey *et al.*, 2007), modify physical properties like, bulk density, accumulate and conserve of soil organic matter, preserve soil aggregates quality (Zhang *et al.*, 2008) and ultimately sustain soil health and productivity in the long run (Mohanty *et al.*, 1992). The effect of inorganic alone and integrated nutrient management (INM) on dynamics of soil physical properties with reference to yield under rice cultivation on the same site has not been studied so far for South Gujarat area. Therefore in keeping with the above points in view an investigation was carried out in a rice- rice system consecutively on the same site for seven years to study the influence of both inorganics alone and different combinations of organic and inorganic fertilizers together on the dynamics of soil organic carbon (SOC), bulk density (BD) and Water Stable aggregates of soil in relation to crop yield under agro – climatic conditions of South Gujarat.

Materials and Methods

The experiment on rice-rice (var. *Gurjari*) crop sequence was initiated during *kharif* 1999 and continued for 7 years in 14 consecutive seasons (*kharif* and summer) till summer 2006 at Navsari Agricultural University, main campus, Navsari on the same site of *Vertic ustochrept* in the heavy rainfall agro climatic zone of South Gujarat. Twelve treatment combinations including recommended dose of N and P fertilizers (RDN & RDP) as were imposed in the experiment are mentioned as given below. Tillage operation before *Kharif* and summer rice as well as puddling operation before transplanting of rice was done as common for all the treatments. Details of the characteristics of the experimental soil, transplanted of *Kharif* and Summer rice and

on the application of different inorganic fertilizer, organic manure, PSB, crop residue (rice straw), pressmud, bio-compost etc. were followed strictly as described elsewhere by Desai *et al.* (2010). The initial BD of experimental soil (0-0.20 cm) was 1700 Kg m⁻³ and WSAs recorded were 19.2 and 52.8 per cent, respectively for 0.5-1 and >1.0 mm sized fractions.

Treatment details

- T₁ : Recommended dose of N (RDN) and P (RDP) to both *kharif* and summer rice crops.
- T₂ : RDN to both the *kharif* and summer rice crops + RDP to *kharif* rice only.
- T₃ : RDN to both the *kharif* and summer rice crops. + RDP to summer rice only.
- T₄ : RDN to both the *kharif* and summer rice crops + 50% RDP to both the crops + PSB
- T₅ : RDN to both the *kharif* and summer rice crops + crop residue (rice straw) @ 5 t/ha. + PSB
- T₆ : RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t/ha.
- T₇ : 50 % of both RDN and RDP to both *kharif* and summer crops + FYM @ 10 t ha⁻¹ to first crop only
- T₈ : 50 % of both RDN and RDP to both, *kharif* and summer crops + pressmud @ 10 t ha⁻¹ to first crop only.
- T₉ : 50 % of both RDN and RDP to both *kharif* and summer crops + Bio-compost @ 10 t ha⁻¹ to first crop only.
- T₁₀ : 50 % of both RDN and RDP to both *kharif* and summer crops + crop residues (rice straw) @ 5 t ha⁻¹.
- T₁₁ : RDN and RDP to both *kharif* and summer rice crops + 50 kg K ha⁻¹
- T₁₂ : N, P and K as per soil test to both *kharif* and summer rice crops.

The crops were harvested at maturity and grain and straw yields of rice were recorded for each season and year. Initial soil samples and samples from each plot after each sequence were

collected after the harvest of summer rice crop up to the seventh sequence and processed for analysis of organic carbon and water stable aggregates (WSA). WSA were determined by Yoder's wet sieving technique (Black, 1965), whereas Bulk density of soil was determined from core soil samples (Black, 1965).

Results and Discussion

Dynamics of Soil Organic carbon (SOC) in relation to crop yield

The effect of inorganic alone and different combinations of inorganic + organic (INM) treatments on SOC is presented in Figure 1, while the grain and straw yields of *kharif* and summer rice sequence obtained from seven consecutive sequences along with pooled data during the experimental period are presented in Table 1 and 2, respectively. Figure 1 revealed that SOC after each sequence in INM treatments i.e. from T₅ to T₁₀ exhibited higher values as compared to those under only inorganic treatments, except the 1st sequence. However, the improvement in SOC was not uniform with the advancement of year or sequence. Differences in SOC as to varying treatments were observed to be significant only after 4th, 6th and 7th crop sequence which indicated that T₁₀ (INM treatment) and T₁₁ after 4th, while T₉ (INM treatment) after 6th and 7th crop sequence, exhibited the highest SOC. However, after 4th

sequence, SOC (5.6 g kg⁻¹) under T₁₀ and T₁₁ were at par with those under T₁ & T₁₂ (Inorganic) and T₅, T₆, T₇, T₈ & T₉ (all INM) treatments. Similarly after 6th sequence, SOC (6.1 g kg⁻¹) under T₉ was at par with those under T₅, T₆, T₇ & T₈ (all INM) treatments and after 7th sequence, SOC (6.2 g kg⁻¹) under T₉ was at par with those under T₅, T₆, T₇, T₈, T₁₀ (all INM) treatments. Build up of SOC with the advancement of years was somewhat regular only in T₆ as compared to other INM treatments. The gradual improvement of SOC in zigzag pattern under INM treatments with the advancement of year or sequence was possibly due to resultant effect of fresh addition of varying organic matters coupled with their varying degree of mineralization, tillage and puddling of soil. Non-significant difference in SOC as to varying treatments after the 1st, 2nd, 3rd and 5th crop sequence (Fig.1) indicated that added organic matter as source of nutrients got mineralized to the maximum extent and as a result no significant difference was observed amongst treatments. However, it was observed that after 1st year, treatment T₉, T₁₀ gave the higher SOC (4.4 g kg⁻¹) followed by, T₁ through T₈, T₁₁ & T₁₂. Similarly, after 2nd, 3rd and 5th year, the order of SOC were T₁₀ > T₅ & T₆ > T₈ > T₉ & T₄ > others, T₇ > T₁₀ > T₆ > T₅ > T₈ > T₉ and T₇ > T₆ & T₉ > T₅ > T₈ > T₁₁ > others, respectively. So far as grain yield of *kharif* and summer rice sequence are concerned (Table1), treatment effects differed significantly

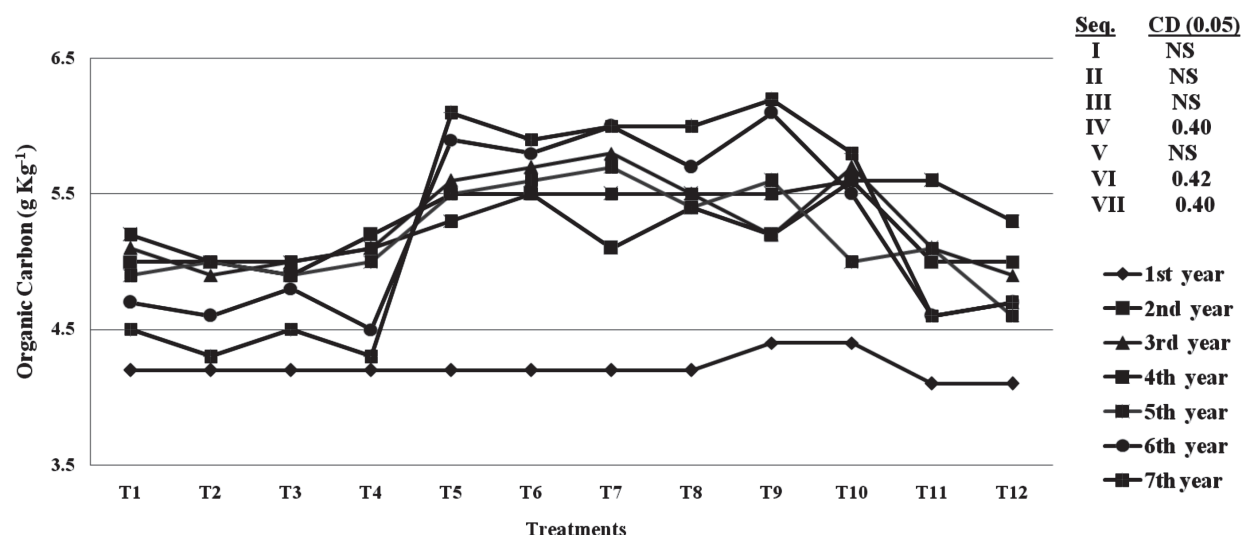


Fig. 1. Effect of different treatments on dynamics of Soil Organic Carbon (g Kg⁻¹) in Rice-Rice Crop sequence

Table 1. Effect of different treatments on sequential (*kharif*+summer) grain yield (kg ha⁻¹) of paddy-paddy crop sequence on same site

Treatment	1999-2000 (1 st Seq.)	2000-2001 (2 nd Seq.)	2001-2002 (3 rd Seq.)	2002-2003 (4 th Seq.)	2003-2004 (5 th Seq.)	2004-2005 (6 th Seq.)	2005-2006 (7 th Seq.)	Pooled
T ₁	8955	9322	12293	10156	10411	9944	8561	9949
T ₂	8648	9773	11926	9230	9880	9623	8082	9595
T ₃	8756	9143	11400	9729	8776	8756	8441	9286
T ₄	8700	8696	12568	10187	10383	10118	8533	9884
T ₅	8198	8493	11555	9159	9418	9029	8254	9158
T ₆	8170	9330	12494	9362	10510	9811	8963	9806
T ₇	7807	9083	11025	8497	8800	8612	7608	8776
T ₈	7297	8285	10865	9127	8828	8392	7444	8605
T ₉	7917	8134	10670	8557	9454	8808	7564	8229
T ₁₀	7400	8313	10136	8022	8589	8272	7237	8281
T ₁₁	9633	9721	12616	10048	10411	10385	8477	10184
T ₁₂	9087	10283	13505	9980	9713	10277	8513	10194
S.Em±	151	279	222	221	172	187	141	140
C.D.@ 5%	435	804	639	637	496	537	405	395
Y x T	-	-	-	-	-	-	-	NS

Table 2. Effect of different treatments on sequential (*kharif*+summer) straw yield (kg ha⁻¹) of paddy-paddy crop sequence on same site

Treatment	1999-2000 (1 st Seq.)	2000-2001 (2 nd Seq.)	2001-2002 (3 rd Seq.)	2002-2003 (4 th Seq.)	2003-2004 (5 th Seq.)	2004-2005 (6 th Seq.)	2005-2006 (7 th Seq.)	Pooled
T ₁	10387	9589	12460	10387	10766	10167	10191	10564
T ₂	10267	10088	12121	9450	10277	9829	9601	10226
T ₃	10247	9450	11623	9908	9071	9031	10048	9911
T ₄	10287	9091	12799	10467	10586	10407	10207	10549
T ₅	9908	8892	11762	9370	9868	9270	9817	9841
T ₆	9968	9510	12699	9609	10985	10008	10598	10482
T ₇	9270	9689	11204	8692	9430	8852	9023	9451
T ₈	8692	8772	11065	9350	9191	8652	8868	9227
T ₉	9350	8553	10835	8832	9848	8832	8995	9321
T ₁₀	8792	8712	10387	8254	9071	8333	8864	8916
T ₁₁	11503	10128	12799	10367	10885	10666	10064	10916
T ₁₂	10606	10626	13756	10287	10247	10586	10140	10893
S.Em±	182	296	222	219	210	178	141	144
C.D.@ 5%	525	852	639	632	603	512	406	407
Y x T	-	-	-	-	-	-	-	-

in all the sequences. T₁₁ (RDN + 50 kg K ha⁻¹ to both crops) recorded the highest sequential grain yield during 1st (9633 kg ha⁻¹) and 6th crop sequence(10385 kg ha⁻¹) while, T₁₂ (N, P and K as per soil test to both *kharif* and summer rice crops) registered the highest sequential grain yield

during 2nd (10283 kg ha⁻¹) and 3rd crop sequences(13505 kg ha⁻¹).Similarly,T₁ (RDN and RDP to both *kharif* and summer rice crops) yielded the highest sequential grain(10156 kg ha⁻¹) during 4th crop sequence and T₆ {RDN to both the *kharif* and summer rice crops + crop residues

(rice straw) @ 5 t ha⁻¹ produced the highest sequential grain during 5th (10510 kg ha⁻¹) and 7th crop sequence (8963 kg ha⁻¹). However, the sequential grain yield under T₁₁ in 6th crop sequence was at par with those under T₁, T₄ and T₁₂ (all inorganic treatments) whereas, the same under T₁₂ in 2nd crop sequence was at par with those under T₂ and T₁₁ (all inorganic treatments). Similarly, the sequential grain yield under T₁ in 4th crop sequence was at par with T₃, T₄, T₁₁ and T₁₂ (all inorganic) and T₆ (INM) in 7th crop sequence was at par with T₁. Except T₆ (INM), which boosted significantly the sequential grain yield of rice during 5th and 7th sequence, other INM treatments after 4th (except T₁₁) and 6th crop sequence, failed to impart sufficient positive effect in elevating sequential grain yield so as to be at par under T₆ or T₁ & T₁₁ (in 5th sequence) or T₁ (in 7th sequence) treatments. Though after 5th sequence, SOC under INM did not increase significantly, the magnitude of SOC was higher under INM treatments as compared to other treatments which in turn might have boosted the sequential grain significantly in T₆ (INM treatment) remaining at par with T₁ and T₁₁. With the increase in soil organic carbon, Acharya *et al.* (1988) observed increase in yield of crop. The result further revealed that addition of various organics along with 50 per cent reduction of inorganic dose (from T₇ to T₁₀), though exhibited higher SOC over inorganic treatments, measurably failed to raise the sequential grain yield to the higher level in all the sequences which might be due to low availability of nutrients from organic sources as a result of slow mineralization and lack of synchronization between mineralization of organics and crop demand. Pooled data revealed that application of N, P and K as per soil test (T₁₂) to both crops, showed significantly the highest grain yield (10194 kg ha⁻¹) remaining at par with T₁, T₄, T₆ and T₁₁. The pooled data over seven consecutive years indicated that though the sole inorganic treatment T₁₂ produced the highest sequential rice grain yield on the same site, treatment T₆ i.e. RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t/ha was at par indicating superiority of this INM treatment over

other INM, which might be due to uniform elevated SOC over the years, better nutrient availability as per crop demand and improved physical and biological status of soil.

Influence of SOC on sequential straw yield in all the sequences followed almost similar trend as that of rice grain, except 4th sequence, where T₄ portrayed the highest sequential straw yield (Table 2) remaining at par with T₁, T₃, T₁₁ and T₁₂. Pooled data revealed that treatment T₁₁ produced the highest sequential straw yield at par with T₁, T₄ and T₁₂.

Bulk density (BD) of soil in relation to crop yield

The effect of different inorganic and combinations (INM) of organic and inorganic treatments on soil bulk density is presented in Figure 2. After the 1st crop sequence bulk density of soil under varying treatments could not be determined and hence was not included. The result (Figure 2) clearly revealed that under all INM treatments i.e. from T₅ to T₁₀, BD of soil has generally decreased, (excepting 2nd and 3rd crop sequence) as compared to those under inorganic treatments for all the years, indicating a general improvement in soil physical condition. The reason might be the higher SOC in those treatments. With the advancing years BD was found to decrease gradually under all the INM treatments may perhaps be due to slight improvement of SOC. Soil BD differed significantly with respect to varying treatments only after 4th, 6th and 7th crop sequence following the same trend as that of SOC. The lowest BD after 4th year (1670 kg m⁻³) was recorded under T₁₁ which was at par with T₅, T₆, T₇, T₈, T₉, T₁₀ (all INM), T₁₂ and T₃. Similarly, the lowest BD after 6th year (1650 kg m⁻³) was registered under T₅, T₆ & T₁₀ which was at par with T₇, T₈ & T₉ (all INM). Similarly, the lowest BD after 7th year (1630 kg m⁻³) was observed under T₇, T₈, T₉ & T₁₀ (1640 kg m⁻³) which was at par with T₅, T₆ (all INM). The BD values under INM treatments after 4th, 6th and 7th year were either at par or significantly lower than those under inorganic treatments, and perhaps were responsible for good

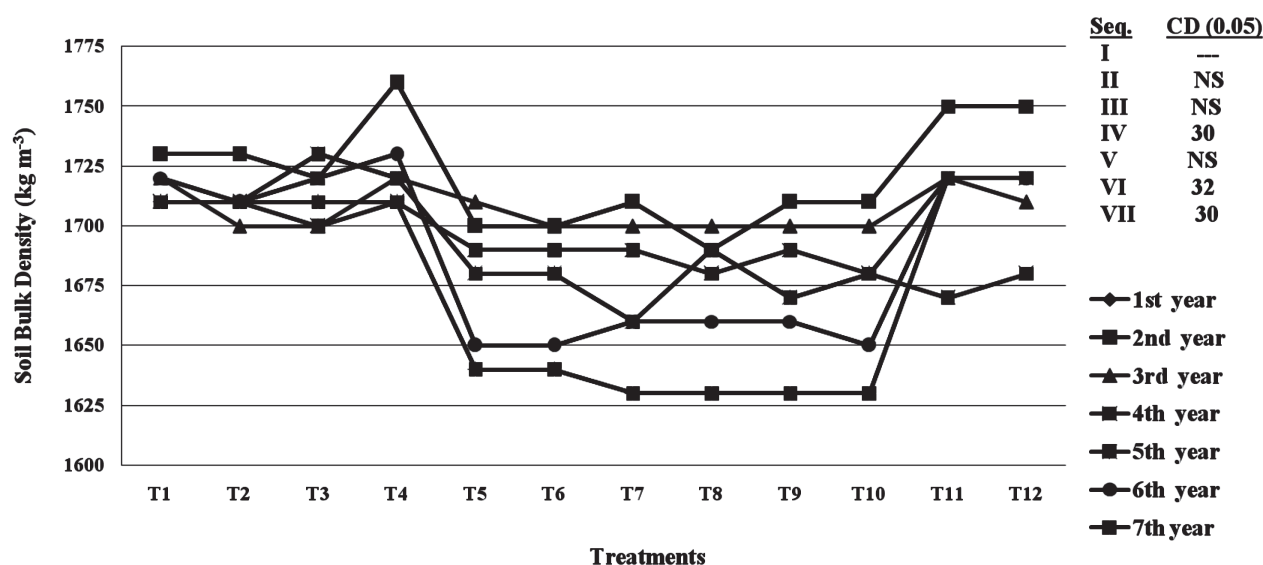


Fig. 2. Effect of different treatments on dynamics of Soil Bulk Density in Rice-Rice Crop sequence

physical environment/ status of soil under these treatments. Though after 5th sequence the bulk density of soil in INM plots did not decrease, its magnitude was lower in INM plots as compared to that in other treatments. Such lower bulk densities in all INM (T5 to T10) coupled with slightly higher level of SOC, very likely released higher available nutrients and improved physical status of soil and as a consequence helped in boosting rice grain yield (Table 1). With the decrease in BD, significant increase in crop yield was also observed by Verma and Bhagat (1992). The result revealed that though the BD under INM treated plot was slightly lower after 2nd and 3rd crop sequence, its positive effect could not boost the grain yield over those under inorganic treatments (Table 1). Significant reduction in soil BD after 4th crop sequence in T₁₁ might have boosted the grain yield significantly. However, the highest grain yield was observed under T₁ (10156 kg ha⁻¹) which was at par with T₃, T₄, T₁₁, T₁₂ i.e. under inorganic treatments only. However, the sequential grain yield of 5th crop sequence was significantly higher (10510 kg ha⁻¹) under T₆ i.e. under INM treatments with RDN to both the *kharif* and summer rice crops + crop residues (rice straw) and at par with T₁ and T₁₁. Though the bulk density did not differ significantly with varying treatments, after 4th sequence,

comparatively lower bulk density under T₆ (INM treatment) might have contributed positively in boosting the crop yield of 5th sequential. After 6th crop sequence, though there was significant improvement in soil BD under INM treatments, the improved bulk density could contribute positively to raise the yield during 7th year to the highest level (8963 kg ha⁻¹) only under T₆ treatment (RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t/ha). Amongst different INM treatments, only T₆ (RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t/ha) could remain at par with T₁₂ which produced the highest sequential pooled grain yield. Better uniformity in elevated SOC in conjunction with comparatively lower BD might possibly have led to better nutrient availability, physical and biological status of soil higher grain yield under T₆.

Influence of soil BD on sequential straw yield of rice in all the sequences followed almost similar trend as that of rice grain, except 4th sequence, where T₄ portrayed the highest sequential straw yield (Table 2) and at par with T₁, T₃, T₁₁ and T₁₂. Pooled data revealed that treatment T₁₁ produced the highest sequential straw yield at par with T₁, T₄ and T₁₂.

Water stable Aggregates (WSA > 1.0mm) ver- sus crop yield

The effect of different inorganic and combinations of organic and inorganic treatments (INM) on soil water stable aggregates (WSA>1.0mm and 0.5-1.0mm) are presented in Figures 3 & 4. Out of these two WSA, WSA>1.0 mm may be considered as macro-aggregates.

Figure 3 revealed that under all INM treatments i.e. from T₅ onwards up to T₁₀, WSA>1.0 mm of soil generally increased, over those under inorganic treatments in all the years due to higher SOC content influencing higher macro- aggregate formation and resulting in the decrease in soil BD (Mathan and Kannan, 1993). In general, tillage and puddling operations lead to higher disintegration of macro aggregates/structures.

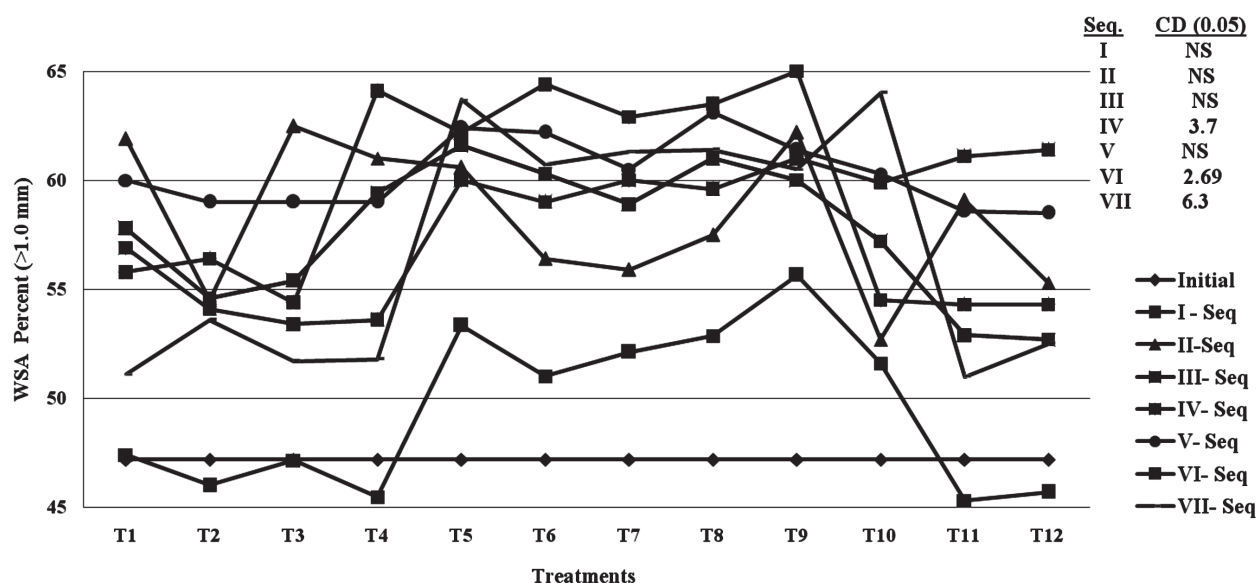


Fig. 3. Effect of different treatments on dynamics of Water Stable Aggregates (WSA >1.0 mm) percent in Rice-Rice Crop Sequence

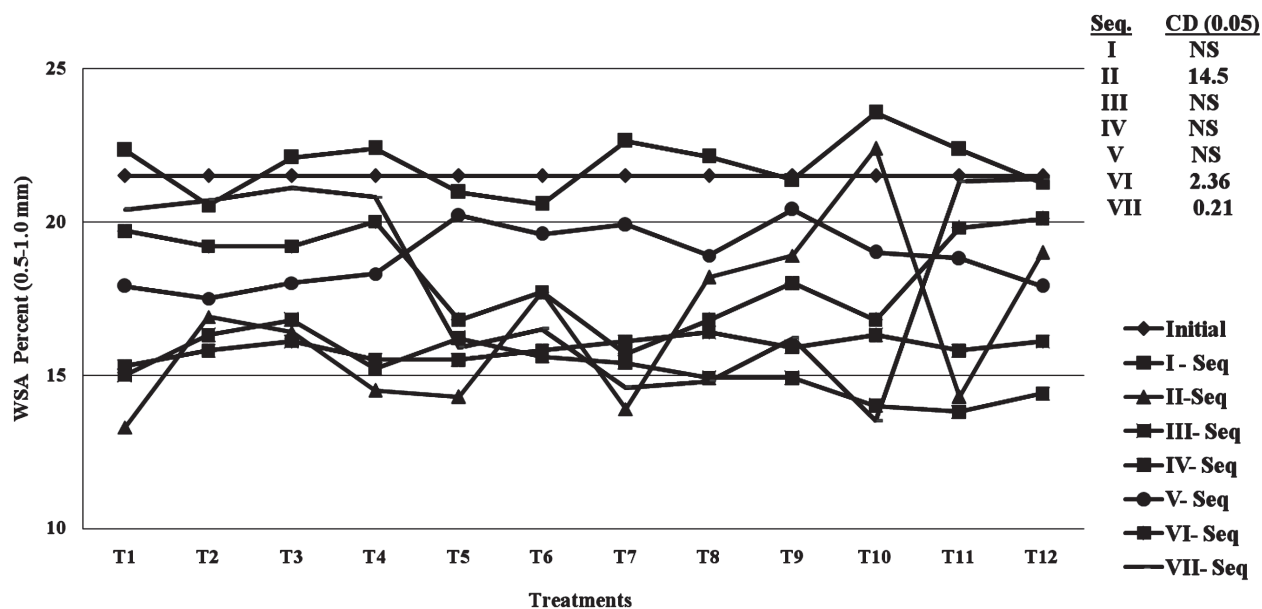


Fig. 4. Effect of different treatments on dynamics of Water Stable Aggregates (WSA, 0.5-1.0 mm) percent in Rice-Rice Crop sequence

Here, application of varying organics have helped to improve the percent of WSA>1.0mm (macro-aggregates). However, soil WSA>1.0 mm differed significantly only after 4th, 6th and 7th crop sequence with the same trend as that of SOC and BD. Though after 5th sequence the WSA>1.0 mm of soil in INM plots did not increase significantly, the magnitude of WSA>1.0 mm was higher in INM plots as compared to that in other treatments. Significant increase in crop yield with increasing WSA was reported by Acharya *et al.* (1988). The result further revealed that though the WSA>1.0mm under INM treatment was slightly higher after 1st, 2nd and 3rd crop sequence, yet its positive effect could not boost the grain yield over those under inorganic treatments (Table1). Though WSA>1.0 mm increased significantly in INM treatments and T₁₁ & T₁₂ over others after 4th crop sequence, the significantly highest sequential grain yield was observed under T₁ (10156 kg ha⁻¹) at par with T₃, T₄, T₁₁, T₁₂ i.e. under inorganic treatments only. Though WSA>1.0 mm under different treatments after 5th crop sequence did not differ significantly, yet comparatively higher WSA>1.0 mm under INM treatments including T₆ might play as one of the positive factors in boosting sequential crop yield. After 6th crop sequence though there was significant improvement in water stable macro aggregates under INM plots the improved macro-WSA of soil could not contribute much to the yield to the highest level as that under inorganic treatments. But, the sequential grain yield of 7th crop sequence was significantly higher (8963 kg ha⁻¹) under T₆ i.e. under RDN to both the *kharif* and summer rice crops + crop residues (rice straw) @ 5 t/ha reaming at par with T₁. The higher percent of macro WSA after 6th crop sequence under T₆ might have played a significant role towards improving sequential grain yield of rice.

So far as WSA (0.5- 1.0 mm) percent is concerned, after 2nd, 6th and 7th years the treatment effect differed significantly and after other sequences the same was non- significant. In all the INM treatments the percent of WSA (0.5- 1.0 mm) was found to decrease from initial status up to the 7th sequence exhibiting somewhat up-down trend.

The treatments receiving organics with inorganics showed higher percentage of WSA>1.0mm possibly at the expense of certain percent of WSA (0.5- 1.0 mm) due to higher degree of aggregation as a result of higher content of SOC. The per cent of WSA (0.5- 1.0 mm) did not show any impact on the grain and straw in all the treatments.

Conclusions

There was slight improvement of soil quality in terms of increase in SOC, reduction in BD and increase in water stable aggregates of 1.0 mm and higher fraction after 4th crop sequence under combined organics and inorganics treatments, yet significant improvement in the above parameters was found after the 6th and 7th crop sequence with significant increase in SOC, reduction in BD and significant increase in per cent of WSA > 1.0 mm. All the treatments receiving INM produced, in general, lower sequential grain and straw yield of rice. The overall study clearly indicated that for sustenance of soil health in terms of higher organic carbon, lower BD and WSA (> 1.0 mm), application of organic manures in combination with inorganic fertilizers is quite worth to be considered in the present day context for cultivation of rice.

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Received: 26 June 2012; Accepted: 29 November 2012