Effect of Soil Management on Soil Micro-organisms

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Soil fertility depends on the balance between physical, chemical and biological properties of soil. Soil biological property comprises the number, the biomass and the activity of soil flora and fauna. They are influenced by the changes in physical and chemical conditions of soil.

Soil management is practised to maximize the potential of crop species or cultivars and to enhance efficient use of water, fertilizer or manure and soil resources. It is now increasingly documented that soil management practices greatly affect the size and the diversity of soil biota (Doran and Linn, 1994). Their influences can be through the trophic interaction among organic matter, soil flora and soil fauna, which results from the alteration of physical and chemical factors in surface soil.

There are various forms of practising soil management. One of the most common practices is tillage. In some regions, tillage is believed to have detrimental effects on the soil, such as loss of surface soil or rapid decrease in organic matter (Lal, 1989). Tillage disturbs the soil surface, which leads to increased aerobic micro-organisms and subsequently leads to rapid decomposition of organic matter and increased nutrient mineralization (Hendrix et al., 1986). However, in semi-arid tropics (SAT), tillage may have some valuable function in increasing crop production.

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Table 1: The Selected Treatments for Soil Microbiological Study from QDPI-ICRISAT Project Experiment

Treatment and abbreviation*	Crop				
	1988	1989	1991	1992	1993
Zero tillage and bare (ZTB)	Millet	Sorghum	Maize	Maize	Sorghum
ZTB + FYM at 15 t ha^{-1} (ZTF)	Millet	Sorghum	Maize	Maize	Sorghum
ZTB + rice straw at 5 t ha^{-1} (ZTS)	Millet	Sorghum	Maize	Maize	Sorghum
Deep tillage to 20 cm and bare (DTB)	Millet	Sorghum	Maize	Maize	Sorghum
DTB + FYM at 15 t ha^{-1} (DTF)	Millet	Sorghum	Maize	Maize	Sorghum
DTB + rice straw at 5 t ha^{-1} (DTS)	Millet	Sorghum	Maize	Maize	Sorghum
Cenchrus ciliaris with zero-tillage (C)	C	C	C	Maize	Sorghum
Stylosanthes hamata with zero-tillage (S)	S	S	S	Maize	Sorghum

* FYM = Farmyard manure.

In SAT, it is common that rainfall is scarce and erratic. It is crucial to capture the scarce rainfall by configuring the soil surface at the proper timing. Otherwise, the scarce rainfall will be lost by runoff. Organic amendment is also an often practised soil management technique in SAT aiming to reduce erosion, to increase infiltration and to supplement nutrients. Soil management like tillage or application of organic material brings about the changes in moisture regime and soil nutrient status, which in turn, alter the size and the make-up of soil organisms. Therefore, it is important to understand soil biological processes affected by different soil management practices.

A project was established in 1988 by ICRISAT and the Queensland Department of Primary Industry (QDPI), Australia at ICRISAT Asian Center to study the response of soil processes to the modification of soil structure of an Alfisol (Table 1) (Smith et al., 1992). A long-term manurial trial was initiated in 1985 at the Research Station, Andhra Pradesh Agricultural University (APAU), Anantapur, Andhra Pradesh, India, to study the effect of addition of organic materials and chemical fertilizers (Table 2). As these two experiments have various soil surface amendments including tillage and organic amendments, these experiments would provide useful information on the effect of soil amendments on soil microorganisms. Here, we discuss soil microbial activity by collating our observations with other published observations.

Table 2: Treatments in a Long-term Manurial Trial with Groundnut, Initiated in 1985 at the Research Station, Andhra Pradesh Agricultural University (APAU), Anantapur

Treatment and abbreviation
No fertilizer (NF)
N-P-K fertilizer at 20-26-34 kg ha^{-1} y^{-1} (NPK)
N-P-K fertilizer at 10-13-17 kg Ka^{-1} y^{-1}(NPKhf)
Groundnut shells at 4 t ha^{-1} y^{-1} (GN)
FYM at 4 t ha^{-1} every 2 ys. (FYM)
NPKhf + GN (NPKGN)
NPKhf + FYM (NPKFYM)
NPK + $ZnSO_4$ at 50 kg ha^{-1} every 3 ys. (NPKZn)
FYM at 5 t ha^{-1} y^{-1} (FYMhi)

Soil Microbial Biomass (SMB)

In our study at ICRISAT, the means of SMB-C and -N, measured one time each year for three years are shown in Table 3. The trend showed that perennial treatments have higher SMB-C and significantly lower in deep tillage without organic amendment than in any other treatment.

The mean of SMB-N for three years was significantly higher in previous *Stylosanthes hamata* treatment than in any other treatment.

Table 3: Soil Microbial Biomass C and N (μg g^{-1} soil)* in the Soil of Selected Treatments from QDPI-ICRISAT Project Experiment

	Treatment**								LSD
	ZTB	ZTF	ZTS	DTB	DTF	DTS	C	S	(0.05)
Soil microbial biomass C	60.1	67.4	61.2	50.6	67.3	64.6	76.0	87.1	18.75
Soil microbial biomass N	15.1	15.4	15.6	15.9	15.6	15.4	18.4	24.5	3.57

* Values are the mean of three samplings during 1991, 1992 and 1993.
** Abbreviations as per Table 1.

There are increasing reports on the comparison in SMB between different tillages (Doran, 1987), between straw applications (Saffigna et al., 1989; and Ocio et al., 1991) or between inclusion of legumes (Doran et al., 1987). In most studies, SMB is higher in zero-tillage, in straw application or in leguminous crop included treatment. In our study, there is a trend that zero-tillage bare treatment shows higher SMB-C, but there is no such trend in SMB-N. The SMB was measured at 50 days after emergence to inflorescence stage of maize or sorghum each year. It was observed that the tillage effect in terms of runoff diminished in a short period because of intensive rainfall and soil structure (Rao et al., 1994). No clear-cut difference between zero tillage bare and deep tillage bare is thought to be due to this quick diminishment of tillage effect. Likewise, it may be possible that straw or FYM covering the soil surface nullified the tillage effect.

The treatment, *Stylosanthes hamata* during 1988 to 1991, showed the highest SMB-C and -N even during the period of 1991 to 1993 during which *S. hamata* was not planted. Although SMB-C or N was not measured during the period of 1988 to 1991, it is surmised that SMB-C or -N increased due to leguminous pasture as other reports show (Doran et al., 1987) and that their residual effect remained, as even non-leguminous crops were grown.

Root-nodule Bacteria

Root-nodule bacteria were counted using pigeonpea as a test plant from selected treatments in our ICRISAT study (Table 4). There was no significant difference between zero-tillage and deep-tillage when comparison was made within annual treatments. Within perennial treatments, pigeonpea and *Cenchrus ciliaris* significantly increased the population of root-nodule bacteria compared to previously *S. hamata* cropped treatment. At present, we can't explain why non-legume, *C. ciliaris*, treatment increased the population of pigeonpea-nodulating bacteria as many as previously pigeonpea cropped treatment.

Table 4: Root-nodule Bacteria (log 10 g^{-1} dry soil) in the Soil of Selected Treatments from QDPI-ICRISAT Project Experiment

	Treatment*									LSD
	ZTB	ZTF	ZTS	DTB	DTF	DTS	P	C	S	(0.05)
No. of root-nodule bacteria	4.41	3.37	3.11	3.97	4.46	2.89	4.83	5.15	3.54	0.588

*Note that P is perennial pigeonpea with zero-tillage which is not listed in Table 1. Pigeonpea was planted in 1988-1991 similarly to C and S.

There are many reports on the effect of soil management on the population of rhizobia introduced by artificial inoculation (Pene-Cabriales and Alexander, 1983). However, less has been reported on the population of indigenous rhizobium affected by soil management. Conventry and Hirth (1992) examined the effects of tillage and lime on *Rhizobium trifolii* populations and survival in wheat-subterranean clover rotation in Australia. In the autumn of the 4th year of this rotation, minimally disturbed soil treatment (the direct-drill) increased the number of rhizobia in the limed soil, and there was interaction between tillage and lime. In spring, this interaction was not present, but the direct-drill and lime increased the number of rhizobia. They suggest that this interaction is due to a combination of the higher surface soil pH and retention of organic matter favouring rhizobia survival. Although there is no mention about the reason for increased rhizobia population due to the direct-drill treatment alone, it may be surmised that the direct-drill treatment resulted in retention of more organic matter compared to conventional tillage.

In our study, there was no significant difference between two tillage methods. Furthermore, rice-straw treatments which, not all but at least in part, are supposed to serve as a supplier of organic matter did show the trend of decrease in the number of rhizobia. At present, we cannot explain why organic amendment did not provide favourable conditions for indigenous rhizobia to increase.

Soil Enzymatic Activity

Soil enzymes catalyze various biochemical reactions in the soil. They originate from microbial cells, plant residue or secretion of micro-organisms on plant root. Frankenbuger et al. (1983) state, "Because assays are done in vitro under controlled conditions (temperature, buffers, excess substrate, etc.), it is difficult to relate activities to those occurring in-situ. Nevertheless, studying soil enzyme activities provides insight into biochemical processes in soils and is sensitive as a biological index."

The dehydrogenase activity was ıeasured at ICRISAT in 1994 (Table 5). The highest activity was found in the previous *S. hamata* treatment followed by two FYM treatments. Although the previous *C. ciliaris* is a perennial treatment, it had the lowest activity. It would be an interesting topic to know if this difference is due to the difference between legume and non-legume.

Table 5: Dehydrogenase Activity (μg Formazen Released g^{-1} Soil 24 h^{-1}) in the Soil of Selected Treatments from QDPI-ICRISAT Project Experiment

	Treatment*								LSD
	ZTB	ZTF	ZTS	DTB	DTF	DTS	C	S	(0.05)
Dehydrogenase activity	2.86	3.83	1.80	3.38	4.71	2.02	2.86	5.48	0.813

*Abbreviations as per Table 1.

In the Anantapur study too, the dehydrogenase activity was measured in 1995 (Table 6). All treatments with FYM had the highest activity followed by the treatment with groundnut shell. No fertilizer or chemical fertilizer treatments showed the lowest activity. At the same time in this study, acid phosphatase was also measured, but there was no significant difference among the treatments (data not shown).

Table 6: Dehydrogenase Activity (μg Foreman Released g^{-1} Soil 24 h^{-1}) in the Soil of a Long-term Manurial Trial at APAU Research station, Anantapur.

Treatment*	Dehydrogenase activity
NF	5.63
NPK	8.34
NPKhf	7.96
GN	9.39
FYM	11.75
NPKGN	8.79
NPKFYM	10.30
NPKZn	7.64
FYMhi	10.19
LSD (0.05)	1.440

*Abbreviation as per Table 2.

The effects of soil management including organic amendment on soil organic C have been well documented as seen in various long-term experiment reports, but relatively less is known about the effects of soil management on soil enzymatic activity. Haynes and Knight (1988) reported that urease and protease activities were significantly higher in the surface, 5 cm under no-till practices than under conventional tillage practices. Phosphatase and sulphatase activities were higher under no-tillage practice to a depth of 10-20 cm. In general, soil enzyme activities are higher in no-till soil than ploughed soil (Dick, 1984). The tilling is usually associated with soil disturbance. This results in increased exposure of soil to air and increased soil organic matter decomposition which leads to decreased microbial activity.

Addition of green manure or FYM has been reported to increase soil enzymatic activities (Kirchner et al., 1993; Dick, 1992). The application of organic matter to soil increases soil organic matter levels, improves soil moisture status, at least at the interface between soil and organic matter, and subsequently improves soil structure. Inorganic fertilizers can also provide similar conditions, depending on cropping systems. As Kirchner et al. (1993) stated, greater crop yields result in greater crop residue, providing increased substrate for microbial growth. Increased crop growth due to fertilization would increase root biomass and thus quantities for root exudate. Increased residues, root biomass and root exudate will result in higher levels of soil organic matter, which in turn, contribute to better soil structure, infiltration and soil water-holding capacity. These improved organic matter status and physical conditions provide favourable conditions to soil enzymes to exert their activities.

Vesicular-Arbuscular Mycorrhiza (VAM)

Root Colonization of VAM

The VA mycorrhizal infection was monitored for three years in our ICRISAT study (Table 7). As mentioned earlier, SMB-C and -N were higher in perennial treatments. On the contrary, VA mycorrhizal infection was lower in perennial treatments. Deep tillage treatments, except the one with FYM, showed higher infection. In the Anantapur study, VA mycorrhizal infection in groundnut roots was much lower than that of millet and sorghum in our ICRISAT study (Table 8). At present, we don't know whether this difference between two studies is due to crops or due to locations or soils. However, in Anantapur, there is a trend that FYM application without chemical fertilizer increases VA mycorrhizal infection although overall infection was low.

Table 7: Vesicular-arbuscular Mycorrhizal Infection (% Root Colonization) in the Crop Roots of Selected Treatments from QDPI-ICRISAT Project Experiment

	Treatment**								LSD
	ZTB	ZTF	ZTS	DTB	DTF	DTS	C	S	(0.05)
VAM infection	44	48	42	58	42	55	36	35	11.0

* Values are the mean of three samplings during 1991, 1992, 1993.
** Abbreviation as per Table 1.

Table 8: Vesicular-arbuscular Mycorrhizal Infection (% Root Colonization) in Groundnut Roots of a Long-term Manurial Trial at APAU, Research station, Anantapur

Treatment*	VAM infection
NF	9
NPK	10
NPKhf	8
GN	10
FYM	14
NPKGN	9
NPKFYM	8
NPKZn	10
FYMhi	13
LSD (0.05)	3.5

* Abbreviation as per Table 2.

Wright and Millner (1994) summarized the effect of soil disturbance, such as tillage on VAM and stated that, "A major consequence of soil disturbance on VAM is the disruption of hyphal networks. Disturbance of these hyphae by tillage can lead to decreased root colonization by VAM". Evans and Miller (1988) observed that VA mycorrhizal infection was higher in maize grown in zero-tillage soil than in disturbed soil. Our observation mentioned above was contrary to these observations. Deep-tillage treatments without amendment and with straw application increased VAM, and perennial treatments, which are zero-tillage in terms of soil surface management, showed decreased VA mycorrhizal infection. At present, we cannot explain the reasons for our observation being contrary to general observations. However, it may be possible that increased VA mycorrhizal infection in deep tillage treatments is associated with increased dispersal of infective hyphae or propagules by disturbing soil.

Harinikumar and Bagyaraj (1989) observed that FYM application stimulated VAM. The application of FYM did not affect VA mycorrhizal infection in our ICRISAT study, but did slightly in the Anantapur study.

Organic matter, such as FYM may directly stimulate the effectivity of VAM and increase the incidence of VAM in the soils low in organic matter. However, its indirect effects through improved soil structure and through alteration of P nutrient status may be also important. More examinations are required in both studies to know whether FYM has been added to the soil to such an extent that soil structure or other soil properties were altered.

Interactions among Soil Management, VAM and Earthworm

VA mycorrhiza requires mobile vectors or living roots for its translocation and dispersal. Many vertebrates and invertebrates have been suggested as potential vectors of VA mycorrhiza (MacIlveen and Cole, 1976; Harinikumar and Bagyaraj, 1994), and earthworms are considered to be important vectors for the dispersal of VAM (Rabatin and Stinner, 1988).

As earthworm activity has been found in the field of our ICRISAT study (Reddy et al., 1997), a study was conducted on the effect of soil management on the earthworms' casting activity (Lee et al., 1995) (Table 9). Three treatments were selected for this study: zero tillage with rice straw at 5 t ha^{-1} $year^{-1}$, 20 cm-deep tillage without organic amendment (bare) and previous perennial cropping of *S. hamata* without tillage. These three treatments were selected based on our observation of earthworm casts on the soil surface. The zero-tillage treatment showed the largest number of casts among annual crop treatments, the previous cropping of *S. hamata* treatment showed the largest number of cast and the deep-tillage-bare produced medium numbers of cast among all the treatments (Reddy et al., 1997).

Table 9: VA Mycorrhiza Spores and MPN of Infective VA Propagules from Earthworm Cast and Surrounding Soil of Selected Treatments in QDPI-ICRISAT Project Experiment

Soil management[a]	Cast		Soil
		– No. of spores (g^{-1} soil) –	
ZTS	23.2		13.8
DTB	63.1		25.7
P	21.4		19.3
LSD (0.05)		17.37	
		– MPN of propagules – (g^{-1}· soil × 10^3)	
ZTS	24.0		11.7
DTB	102.0		23.3
P	16.7		3.1
LSD (0.05)		36.00	

[a]See Table 1 for treatment details.

The mean of spore counts and infective propagules of VAM were significantly higher in earthworm casts than in field soil across the three soil management treatments. There was no significant difference in the number of VAM spores or propagules among field soils from the three different soil management treatments, but the number of VAM spores and propagules in the earthworm casts from the deep-tillage-bare treatment was significantly higher than in the earthworm casts from the other two treatments. In the deep-tillage-bare treatment, the number of spores and infective propagules were significantly higher in earthworm casts, than in field soil.

There are increasing numbers of reports on the effect of soil management on earthworm activities (Reddy et al., 1997; Hendrix et al., 1986; Lavelle, 1988). In general, zero- or minimum-tillage agroecosystem and organic amendment bring about the greater abundance and biomass of earthworm. However, there seems to be no report on the effect of soil management on the interaction between VAM and earthworms. In our study, the greatest numbers of VAM spores and propagules were found in the deep tillage bare either in earthworm casts or in field soil. The extent to which earthworms concentrate the spores and the propagules was also the greatest in this soil management treatment. At present, we cannot explain why deep tillage concentrated the spores and the propagules most among three soil management treatments. It may be possible that earthworms feeding on decaying roots high in VAM infection produce casts containing high densities of spores and propagules.

CONCLUSION

The effect of soil management on soil micro-organism including VAM and their activities was investigated on two Alfisols in semi-arid tropical India. These results were collated with those in other published reports.

Soil microbial biomass was the greatest in previous zero-tillage planted to *S. hamata*. This result is in agreement with the other published paper in which the inclusion of legumes increased soil microbial biomass. The effect of tillage on soil microbial biomass was not observed in our study. This may be attributed to the disappearance of tillage effect in early growth stage of crop due to intensive rainfall in early rainy season and due to soil structure.

One of the soil enzymes, dehydrogenase, generally showed higher activity in organic amendment treatment than non-organic amendment treatment. This observation is consistent with other published reports. However, it should be kept in mind that greater crop residue or greater root biomass result from greater crop yield, greater crop residue can also result from inorganic fertilizer treatment which increases soil organic matter, which in turn, enhances soil enzyme activity.

The response of VA mycorrhizal activity to tillage in our study was not consistent with other published reports in which VA mycorrhizal activity is higher in zero-tillage than deep-tillage. We are assuming that the disturbance of soil by deep tillage treatment in our study helped VAM to disperse their infective hyphae or propagules.

Earthworms were found to be the mobile vector for VAM translocation and dispersal in our study, too, and earthworm casts contained greater number of spores and infective propagules than field soil. The extent to which earthworms concentrate the spore and the propagule was the greatest in deep tillage without organic amendment. To our knowledge, there is no report on the effect of soil management on the interaction between earthworms and VAM.

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