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Management of surface cracks in black Vertisols (Typic chromusterts) by soil amendments and land uses in Chambal region, India

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ABSTRACT

Soil cracks provide an opportunity for water recharge during rainy season thereby reducing risks of soil erosion and increasing soil moisture reserve in the semi-arid regions. Despite their importance, scientific knowledge on managing cracks in Vertisols in India is scanty. Thus, the objective of this study was to quantify effect of different soil amendments *i.e.,* wheat-straw (S_1), farm yard manure or FYM (S_2), saw-dust (S_3), gypsum (S_4), and flyash (S_5) on cracks formation in a Vertisols. Initially, an incubation study was conducted with four levels *i.e.,* 0, 2.5, 5.0 and 10 g kg^{-1} of each amendment. Results indicated that use of wheat straw caused the least crack volume followed by that with FYM, sawdust, gypsum and flyash. Increased rate of application of soil amendments had significant effect on reduction of the crack volume. A follow-up field experiment was conducted under three different land uses *i.e.,* cropland [intercropping of sorghum (*Sorghum biocolor* L.) + pigeon pea (*Cajanus cajan* L.) at 1:1 ratio], grassland (dhaman grass- *Cenchrus ciliaris L.*), fallow land (cultivated fallow) with two levels *i.e.,* 10 Mg $ha^{-1}$and 20 Mg ha^{-1} of soil amendments. The least crack volume was observed with wheat straw followed by that with sawdust, FYM, fly ash, and gypsum. Increasing the rate of application significantly reduced the crack volume. Further, a significant negative correlation (R^2= 0.62, $P \leq 0.01$) was observed between soil moisture content and the crack volume. Crop yields significantly increased with the addition of different soil amendments by as much as 38% over that of the control. However, the yield of grass was not affected by these amendments.

1. INTRODUCTION

Rajasthan, a state that covers the largest area (34.2 m ha) in India and has about 72% of its arable land under rainfed farming, typifies soils and environment of arid eco-regions. Vertisols constitute a major soil group supporting rainfed farming in India. These soils cover 73 m ha of land constituting almost 22.5% of the geographical area of India (Murthy *et al.,* 1982). In south-eastern Rajasthan, medium-deep (1.5-2 m) Vertisols occupy ~ 0.97 m ha. This region is among the most productive parts of the state (Shyampura and Sehgal, 1995). However, Vertisols have specific challenges to many agronomic practices. When wet and fully saturated, these soils have massive structure with low infiltration rate, poor trafficability, impeded aeration, a narrow workable soil moisture range, excessive surface runoff and accelerated erosion during the rainy season. These factors result in a significant loss of plant nutrients and adverse effect on crop production (Chan and Hodgson, 1981; Coulombe *et al*., 1996).

Vertisols have a high swell and shrink capacity associated with changing soil moisture regime (Taboada, 2003). Cracks are unique feature and are used as one of the criteria in defining Vertisols in Soil Taxonomy (Soil Survey Staff, 2010). Soil cracks improve water recharge through preferential flow during the rainy season (Shaw and Yule, 1978; Gardner and Coughlan, 1982; Hulugalle *et al*., 2001 and Bauderand Brock, 1992). A network of surface and sub-surface cracks is also a pre-requisite to the formation of pot-hole (Somasundaram *et al*., 2011, 2014). Cracks also extend the soil-air interface in the soil profile (Hulugalle *et al*., 2001). Thus, the evaporation loss is high from surface and sub-surface cracks which also increase the number of wetting/drying cycles (Dexter, 1986; Pillai and McCarry, 1999 and Hulugalle *et al*., 2001). Loss of soil water in rainfed regions can severely jeopardize crop productivity. Yet, scientific information on the effects of land use and soil amendments on crack formation and crop yields is scanty for this region. Thus, there exists a strong need to understand the cracking patterns in medium-deep Vertisols of the region for management of cracks and to minimize loss of profile soil moisture. Soil amendments can improve several specific soil functions (*viz*., nutrient deficiencies, plant growth and vigour) by improving soil physical quality. Commonly used amendments are the residual materials or by-products from other processes and include municipal biosolids, manures, litters, wood ash or saw dust, coal combustion products, neutralizing lime products, compost, and traditional agricultural fertilizers (USDA, 2006). Therefore, the present study was conducted to evaluate the effects of different soil amendments and land uses on the cracking behavior of Vertisols in Chambal region of Rajasthan, with the hypothesis that surface cracks can be managed by addition of soil amendments. This study describes the effects of selected soil amendments on soil cracks and crop yield.

2. MATERIALS AND METHODS

Study Site

The study was conducted at ICAR-Indian Institute of Soil and Water Conservation (ICAR-IISWC), Research Farm at Kota in south-eastern Rajasthan. Climate of the study site is semi-arid with mean annual rainfall of 748 mm. The research farm has two distinct soil series (e.g., Kota and Chambal) which are characterized by reddish and dark brown to black colour, respectively. Soil is classified as a Typic Chromusterts (Vertisols). It is clay loam in texture, with pH of 7.8, soil organic carbon concentration of 0.51% and EC of 0.46 dS m^{-1}. The available nutrients reserve include nitrogen at 269 kg ha^{-1}, phosphorus at 12.5 kg ha^{-1} and potassium at 395 kg ha^{-1}. Five soil amendments were selected for this study considering their availability in the region as well as farmers' preference. The treatments were Control (S0), Wheat-straw (S1), FYM (S2), Saw-dust (S3), Gypsum (S4) and Flyash (S5).

Laboratory Study

An incubation study was conducted to evaluate the effects of soil amendments on crack characteristics in a Completely Randomized Design (CRD). Surface soil samples from plough layer (0-20 cm) were collected. A known quantity of soil was filled in plastic tray having dimension of 0.3m width x 0.4m length x 0.25m height. Different soil amendments *viz*., Control (S0), Wheat-straw (S1), FYM (S2), Saw-dust (S3), Gypsum (S4) and Flyash (S5), were mixed into the soils at the rate of 0, 2.5, 5.0 and 10 g kg^{-1}. Soil moisture content was maintained at the maximum water holding capacity during the initial stage of incubation. These trays were kept in shade without any disturbances for monitoring the crack development. Cracks have started appearing on the surface as the soil moisture was depleted by evaporation process. Cracks characteristics e.g., length, width and depth were measured at full opening stage of the cracks by adopting a standard procedure (Dasog *et al*., 1988; Dasog and Shashidhara, 1993). Crack length and depth were measured by a tape.

Field Experiment

On the basis of the incubation study, a field experiment was conducted at Research Farm of ICAR-IISWC, Research Centre, Kota to revalidate the effects of different soil amendments and land uses on surface crack parameters and soil properties. The study was conducted in split-plot design with three land uses *viz*., crop land [intercropping of sorghum (*S. biocolor L.*) + pigeon pea (*C. cajan* L.) at 1:1 ratio], grassland (dhaman grass- *C. ciliaris*) and fallow land (cultivated fallow) as main plot treatment (Fig.1 a,b,c) and soil amendments as sub-plot treatments. Additional experimental details are given in Table 1.

The study site had a very gentle slope gradient of < 1%. The soil was initially prepared with a spring tyne cultivator, and leveled with a plank. The net plot size was 6 x 5 m. Crops and cultivars used for the study were sorghum (*cv*. GSH-5) and pigeon pea (local). Soil amendments were incorporated thoroughly into the soil to 15 cm depth before the onset of monsoon (Fig. 2). Crops and grass were sown after the onset of monsoon in July. Crops were harvested as and when they attained maturity by September. The yield data were recorded at harvest.

Crack Measurement

Crack parameters were measured on 1 m^2 in each treatment. Crack parameters *viz*., length, depth, and width were measured by adopting standard procedure for all three different land uses (Fig. 3 and Fig. 4). Crack length and depth were measured by using a twine and a metallic tape, respectively. The depth was measured at 50 cm intervals by inserting a 2 mm metallic tape until it encountered resistance to further penetration. The widths at the same points were measured 1 cm below the surface by using an adjustable tape. Total crack volume was computed by the method proposed by Dasog *et al*. (1988) and Dasog and Shashidhara (1993). Total crack volume was computed by using:

Total crack volume V= Σ 0.5 wdl …(Eq. 1)

Where, d is depth of the cracks (m), l is length of the cracks (m) and w is width of cracks.

These data were statistically analyzed for two-way ANOVA without replication using PAST statistical software to draw valid interpretation by adopting standard

Fig. 1a. Crop land (Sorghum + Pigeon pea at 1:1 ratio)

Fig. 1b. Grassland (*Cenchrus ciliaris)*

Fig. 1c. Fallow land (No cultivation)

Fig. 2. Application of soil amendments

Fig. 3. Cracking pattern in black soils

Fig. 4. Crack measurement

Table: 1
Experimental details

Main Plot: Land uses	Sub plot treatments: Soil amendments	Sub sub-plot Treatments: Levels
1. Crop land (intercropping of sorghum+pigeon pea at 1:1 ratio)	S0-Control	Level 1: 10 Mg ha^{-1}
2. Grassland (Cenchrusciliaris)	S1-Wheat straw, S2-FYM	Level 2: 20 Mg ha^{-1}
3. Fallow land (No cultivation).	S3-Saw dust, S4-Gypsum*, S5-Fly ash	
	*Gypsum was applied as 100% and 200% based on Gypsum requirements	

procedure (Hammer *et al*., 2001). Post-harvest samples were also collected from the experimental plots for analysis of pH, EC, OC and aggregate size distributions by adopting standard procedures.

3. RESULTS AND DISCUSSION

Crack Volume under Laboratory Study

The incubation study results are given in Fig. 5. It is evident from the study that addition of soil amendments was very effective in reducing the crack formation/ volume. Irrespective of the soil amendments, increased rate of application of soil amendments had significant effect on reduction of crack volume (Fig. 5 and Fig. 6). Among various amendments studied, wheat straw recorded the lowest crack volume followed by FYM, Sawdust, Gypsum and Flyash. Similarly, soil moisture content also recorded higher value under wheat residue amended soil @ 10 g kg^{-1}of soil compared to other treatments and control.

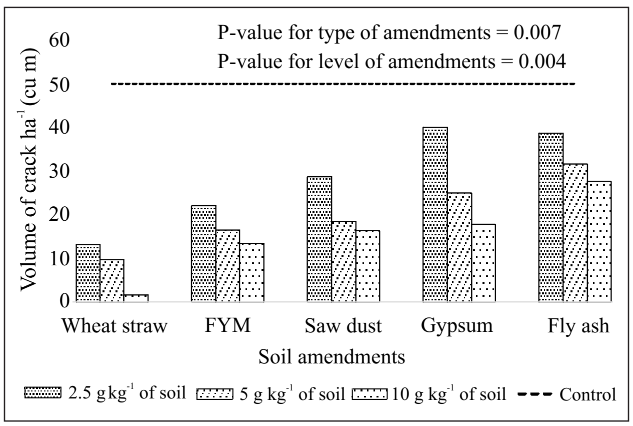

Fig. 5. Volume of crack as influenced by different soil amendments: in lab

Data on percent decrease of crack volume in amendments added @ 2.5 g kg^{-1} of soil over control has revealed that highest reduction (-74%) was observed under wheat straw and the lowest reduction (-23%) was registered under Flyash. Beneficial effect of residue addition on reduction of crack parameters was also reported (Srivastava *et al*., 1989; Bhushan and Sharma, 2002; Mohanty *et al*., 2006). As the dose of amendments increased *i.e.,* from 2.5 to 10 g kg^{-1} of soil, the percent reduction was also greatly increased. From the results, it is evident that soil amendments result in reduction of crack volume.

Crack Volume under Field Study

Irrespective of the land use systems, wheat straw recorded the lowest crack volume followed by Sawdust, FYM, Flyash, and Gypsum (Fig. 7). Increased rate of application of soil amendments had significant effect on reduction of crack volume. Results of lab study are corroborated well with field study with the exception of Flyash. Similar findings have been reported by Srivastava *et al*. (1989) and Bhushan and Sharma (2002). Among different land use systems, grassland system recorded lower crack volume which was significantly different compared to other land uses (Fig. 8), whereas crop land and fallow land use systems were at par in respect of crack volume. Highest crack volume recorded under fallow was ascribed to direct exposure to sunlight, which results in greater evaporation and loss of soil moisture. Both type and level of amendments had a significant effect on crack volume (Fig.7). Earlier, Bandyopadhyay *et al*. (2003) reported that cracks can be managed through conjunctive application of NPK and FYM in black Vertisols of Central India.

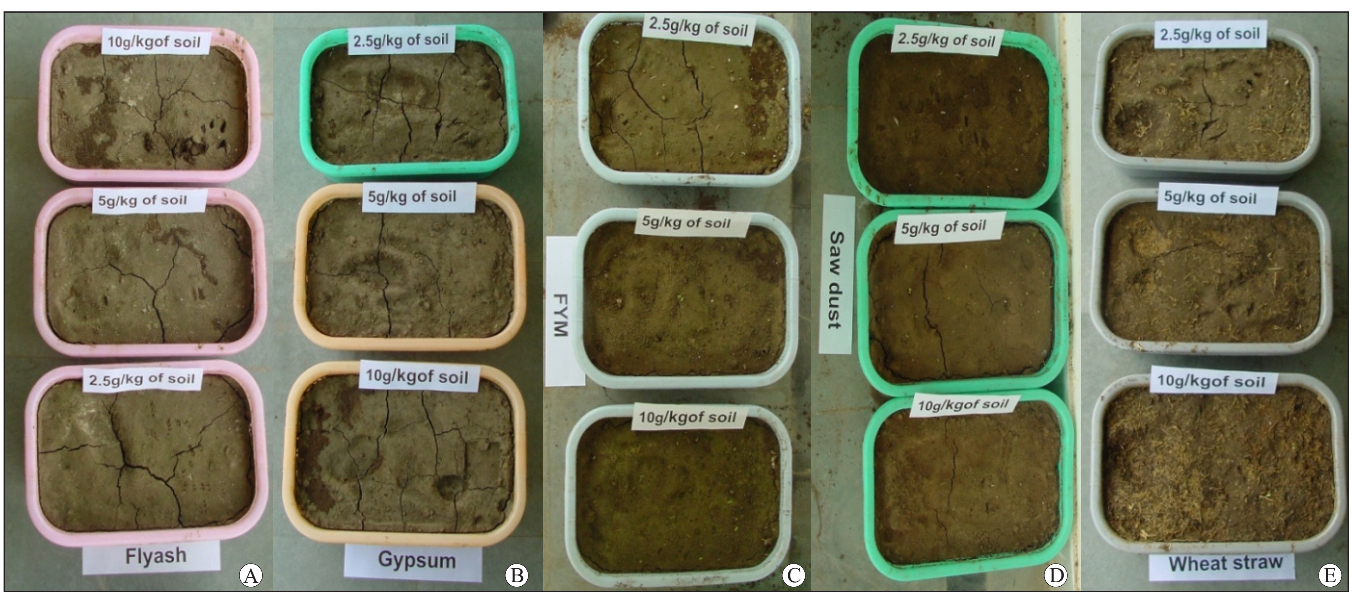

Fig. 6. Cracking as influenced by different soil amendments (A) fly-ash (B) gypsum (C) FYM (D) Saw dust and (E) wheat in medium-deep black Vertisols

Data on percent decrease of crack volume over control revealed that the highest reduction (-55%) was observed under wheat straw amended plots and the lowest reduction (-5%) was observed under gypsum. As the level of application of amendments increased *i.e.*, from 10 to 20 Mg ha^{-1}, the percent reduction also increased. The percent reduction of crack volume in soil amendments applied @ 10 Mg ha^{-1} varied from -5 to -33; -9 to -48; -10 to -33 for crop land, grassland and fallow land, respectively. Whereas, soil amendments applied @ 20 Mg ha^{-1} recorded -18 to -49%; -18 to -55%; -18 to -43% reduction of crack volume for agriculture, grassland and fallow land, respectively. The highest reduction (-55%) was observed under wheat straw amended plots (applied @ 20 Mg ha^{-1}) in grassland, which was possibly due to fibrous root system as well as better aggregation. According to Bhushan and Sharma (2002), crack volume and surface area decreased by 36-76% and 19-37%, respectively by long-term addition of biomass. Mohanty *et al.* (2006) reported that reduction of cracking after harvest of rice crop was registered due to less puddling and residue retention of previous (wheat) crops. Similarly, Mousavi *et al.* (2012) have also reported that addition of rice straw increased soil moisture content, decreased bulk density and delayed crack formation in silty clay soil.

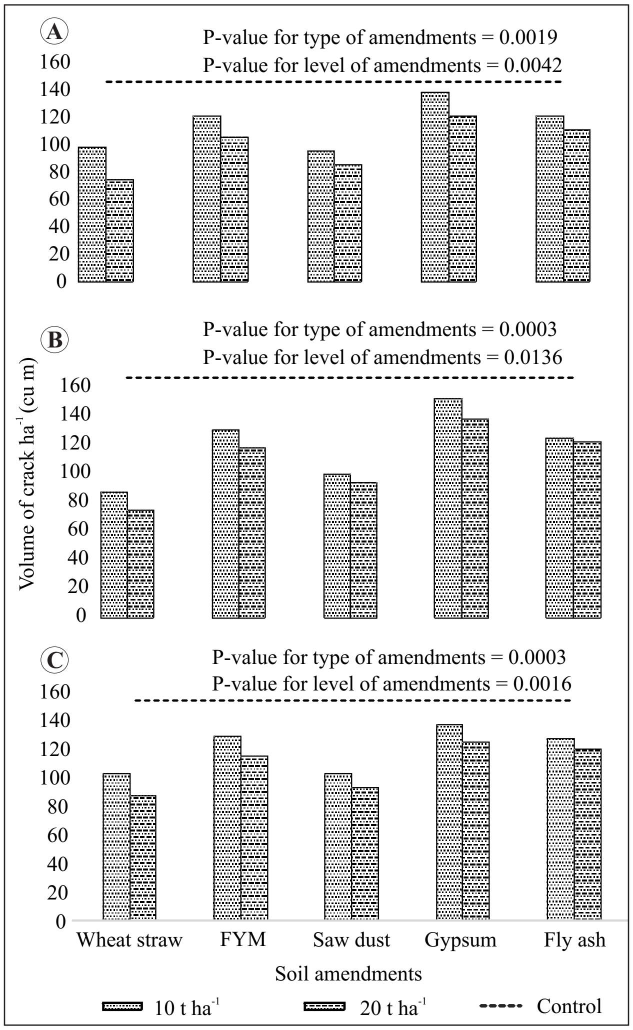

Fig. 7. Volume of cracks as affected by soil amendments (A) agriculture, (B) grass land (C) fallow land

Effect of Soil Amendments on Soil Properties

Post-harvest samples were analyzed for pH, EC, Organic Carbon (OC) and aggregate size distribution after completion of one crop cycle. Results revealed that pH, EC and OC were not significantly affected by addition of soil amendments under different land use systems (Table 2 to Table 4). It has also been observed that increased rate of application of soil amendments significantly reduced the crack volume in the field. Further, a significant negative correlation (R^2= 0.62, P≤ 0.01) was found between moisture content and crack

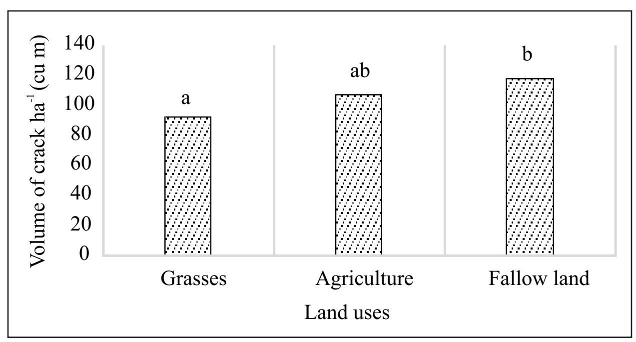

Fig. 8. Volume of crack among different land uses (average over treatments and levels) (different letters indicate significant difference between treatments at p<0.05)

Table: 2
Physico-chemical properties under crop land (0-15 cm)

	pH		EC (dS m^{-1})		OC (%)	
	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}
Wheat straw	8.23	8.33	0.9	0.24	0.55	0.48
FYM	8.33	8.26	0.23	0.33	0.49	0.54
Saw dust	8.35	8.43	0.31	0.28	0.51	0.49
Gypsum	8.39	8.38	0.27	0.35	0.46	0.49
Fly ash	8.32	8.29	0.34	0.3	0.55	0.46
Control	8.34		0.29		0.41	
P-value$_{amendments}$	0.69		0.47		0.36	
P-value$_{levels}$	0.25		0.68		0.84	

Table: 3
Physico-chemical properties under grassland (0-15 cm)

	pH		EC (dS m^{-1})		OC (%)	
	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}
Wheat straw	8.80	8.85	0.35	0.21	0.51	0.49
FYM	8.86	8.64	0.26	0.31	0.49	0.48
Saw dust	8.74	8.84	0.28	0.25	0.49	0.51
Gypsum	8.79	8.79	0.23	0.37	0.46	0.48
Fly ash	8.73	8.83	0.23	0.31	0.46	0.49
Control	8.84		0.27		0.44	
P-value$_{amendments}$	0.92		0.69		0.44	
P-value$_{levels}$	0.89		0.99		0.009	

Table: 4
Physico-chemical properties under fallow land (0-15 cm)

Soil amendments	pH		EC (dS m^{-1})		OC (%)	
	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}	10 Mg ha^{-1}	20 Mg ha^{-1}
Wheat straw	8.35	8.62	0.29	0.24	0.46	0.48
FYM	8.69	8.49	0.34	0.21	0.47	0.45
Saw dust	8.61	8.67	0.25	0.22	0.47	0.44
Gypsum	8.59	8.59	0.28	0.23	0.46	0.43
Fly ash	8.48	8.58	0.24	0.24	0.49	0.48
Control	8.67		0.23		0.40	
P-value$_{amendments}$	0.56		0.07		0.60	
P-value$_{levels}$	0.59		0.73		0.83	

volume. This indicated that moisture depletion in soil leads to crack formation to a large extent (Fig. 9). Cabangon and Tuong (2000) reported that straw mulching helped conserve moisture in the soil profile and reduced the mean crack width by 32% over control.

Aggregate size distribution data indicated that macro aggregate (>250 µm) percent was not affected either by under different land uses or by soil amendments (Fig.10). However, wheat straw, FYM, gypsum and Flyash amended plots (@ 10 Mg ha^{-1}) recorded relatively higher percent micro aggregate (<250 µm) under cropland, whereas wheat straw and gypsum recorded higher percent of micro aggregate under fallow land use (Fig. 11). Addition of soil amendments @ 20 Mg ha^{-1} results in higher micro aggregate percent under cropland and grassland system. Evidently, this micro-aggregate act as a nuclei or building blocks for formation of macro-aggregate (Tisdall and Oades, 1982). Bouajila and Sanaa (2011) reported that addition of organic amendment had a significant improvement in the structural stability of silty clay soil. Such behavior might be the result of elevated organic matter content and important microbial activities. Moreover, continuous addition of soil amendments with better management practices may be helpful in bringing conspicuous changes in soil properties in the long run.

Effect of Soil Amendments on Crop Yield

Results showed that level and type of amendments significantly ($P<0.05$) affected the crop yield. As the level of amendment increased from 10 to 20 Mg ha^{-1}, sorghum equivalent yield was increased by 5, 14, 24, 10 and 3% under wheat straw, FYM, saw dust, gypsum, and Flyash, respectively. Shah *et al*. (2013) concluded that different organic amendments such as FYM, gypsum and saw dust significantly increased the wheat yield by improving the soil properties. At the higher level of amendments *i.e.,* 20 Mg ha^{-1}, FYM recorded higher yield (38% over control plots) followed by wheat straw (33% over control plots) and saw dust and remaining treatments were found on par in terms of yield (Fig. 12). These increases in crop yield over the control were attributed to many reasons. Sinkevičienė *et al.* (2009) found that organic amendments significantly moderates the soil temperature and it is well established fact that reduction of soil temperature is of great importance in countries with hot climate conditions like India. Further, these amendments facilitate better soil aggregation and higher soil moisture content during crop growth period and also increase nutrients availability

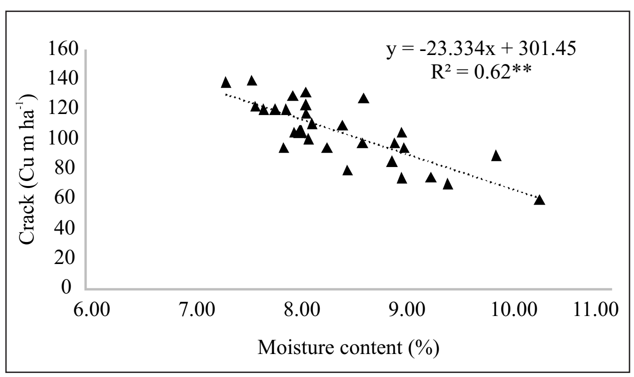

Fig. 9. Relationship of crack volume vs moisture content

especially phosphorus, which resulted in higher grain production (Hue and Silva, 2000). In grassland, FYM applied @ 20 Mg ha^{-1} recorded the highest air-dry fodder yield compared to other treatments. However, both type and level of amendments did not have significant effect on air-dry fodder yield (Fig.13).

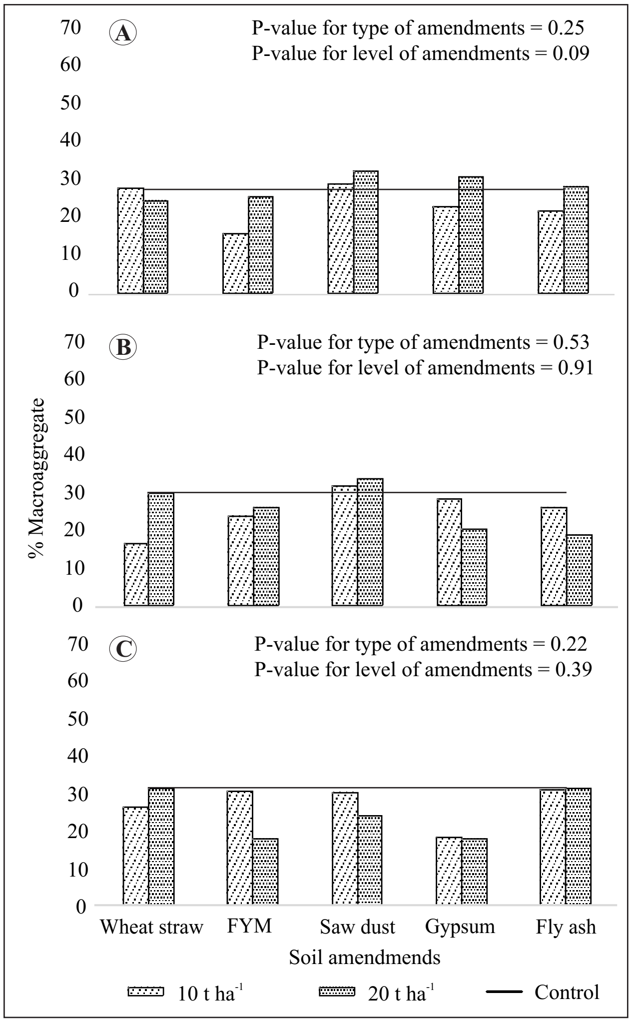

Fig. 10. Macro-aggregate percent under different land use namely Agriculture (A), Grassland (B) and Fallow land (C)

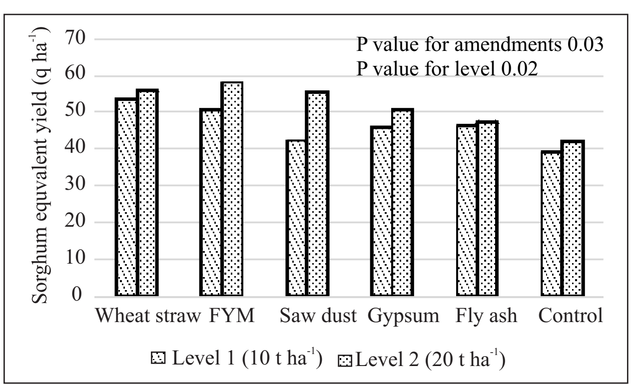

Fig. 12. Effect of different soil amendments on Sorghum grain equivalent yield

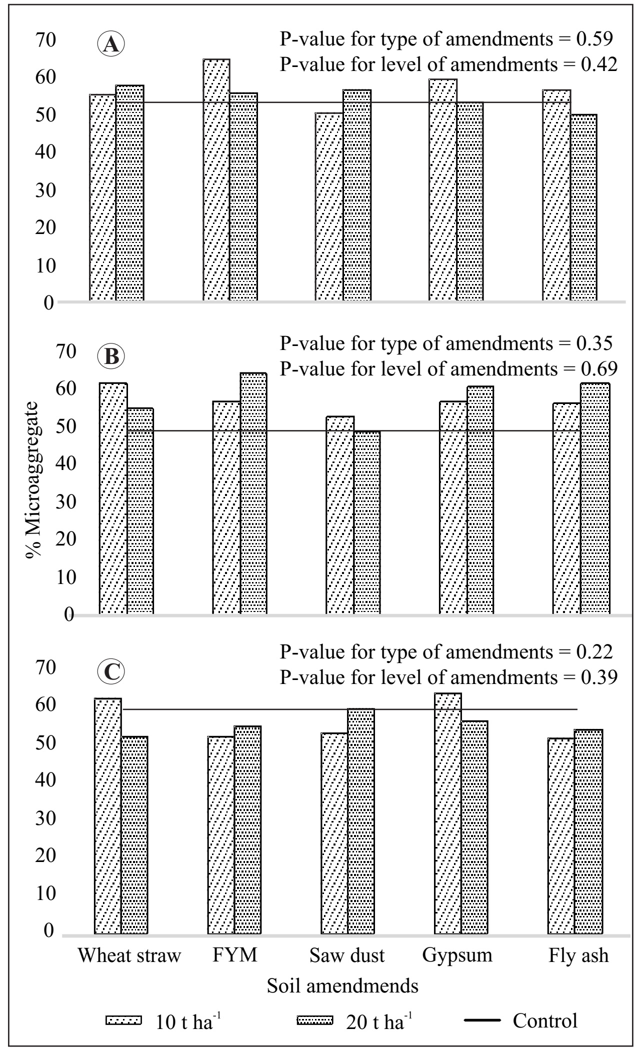

Fig. 11. Micro-aggregate percent under different land use namely Agriculture (A), Grassland (B) and Fallow land (C)

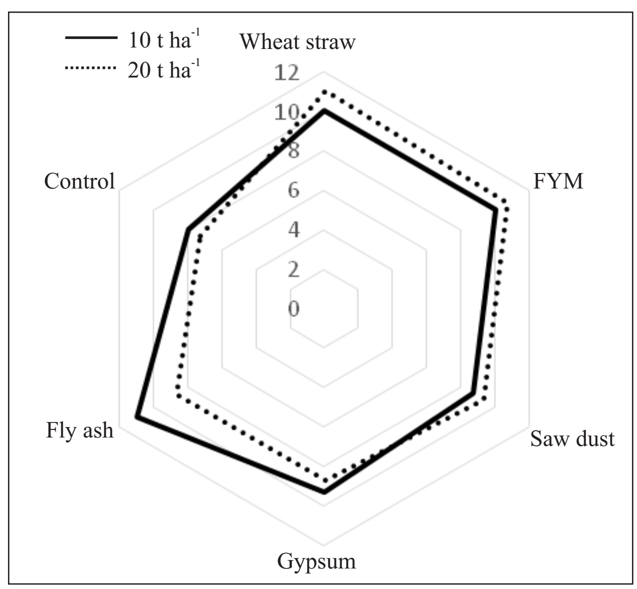

Fig. 13. Effect of different soil amendments on air-dry fodder yield

4. CONCLUSIONS

In this study, the effects of different soil amendments and land uses on soil crack and crop yields were investigated. It is evident that soil amendment incorporation in soil significantly reduces crack volumes in Vertisols. Among the different soil amendments, wheat-straw had the greatest impact followed by FYM > Flyash > Saw dust > Gypsum in terms of reducing the crack volume in the laboratory as well as field condition. Among different land uses, crack volume reduction was in order of grass land > agriculture > fallow land. Furthermore, a high significant correlation between soil moisture and crack volume under all land uses and soil amendments indicated that crack observed in clay rich soil is driven with moisture content of the soil. Thus, incorporation of wheat residue up to 10 Mg ha^{-1} in soil not only helps in reducing crack formation but also helps in better soil aggregation and improved soil health. Moreover, these practices may be considered/followed as sustainable management practices for managing Vertisols in the long run.

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