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Effect of farmyard manure and fertilizer application on crop yield, runoff and soil erosion and soil organic carbon under rainfed pearl millet (*Pennisetum glaucum*)

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ABSTRACTS

A field experiment with four treatments namely control- no application of manure and fertilizer (T1), application of farmyard manure (FYM) at the rate of (@) 5 tonnes/ha/year (T2), application of FYM @ 5 tonnes/ha/year + N:P:K @100: 60: 40 every year (T3) and application of FYM @ 10 tonnes/ha/year + N:P:K @ 100: 60: 40 every year (T4) in pearl millet *(Pennisetum glaucum* (L.) R. Br. emend. Stuntz) was conducted on sandy loam soils of central Gujarat from 2009 to 2011 under rainfed condition. Plants under T4 were 14 cm, 40.4 cm and 34.2 cm taller than T1 at 30 DAS, 60 DAS and at the time of harvest respectively. Plant height in T3 at the time of harvest was at par with T4. Final biomass under T4 was 25.3, 94.4, and 36.6% higher than T1 during 2009, 2010, and 2011 respectively that gave overall gain of 59.2% in pooled data. Biomass under T4 was 1.2, 5.9 and 11.1% higher as compared to T3 at the time of harvest during 2009, 2010 and 2011 respectively. Effect of application of higher dose of manures in combination with fertilizer (T4) was more prominent in terms of yield as compared to plant height and biomass. Yield under T4 was 153.9, 112.8, and 20.2% higher than T1, T2 and T3 respectively during 2010 whereas it was 70.5, 34.4 and 21.7% higher during 2011. All growth parameters under T2 and T3 were intermediate between T4 and T1. Runoff coefficient was in the range of 22.7 to 30.2% during 2010 and 12.3 to 13.4% during 2011 that was in decreasing order from T1 to T4. As compared to T1, T4 registered 27.7 and 30% per cent low seasonal soil loss in 2010 and 2011 respectively. Application of FYM@ 5 tonnes/ha/year (T2) over the control (T1) had more prominent effect in reducing runoff and soil loss where as application of NPK @ 100:60:40 in addition to FYM@ 5 t/ha (T3) showed no significant effect on runoff and soil loss. Sediment concentration was high in initial few runoff events, highest under T1 and lowest under T4. Strong linear relation ($R^2 > 0.92$) of sediment concentration under T1 with sediment concentration under rest of the treatments was observed. Total soil organic carbon up to depth of 90 cm was 3.43 kg/m^2 under T4 that was higher by 0.13 kg/m^2 as compared to T1. Improvement in SOC was more prominent in 0-15 cm layer and it was 23.8% higher in T4 as compared to T1. Irrespective of the depth of samples, SOC were high in water stable aggregates (WSA) of size > 0.5 mm. Higher SOC in WSA of 0-15 cm soil as compared to deeper soil were recorded in all the treatments with highest in case of T4. Application of FYM @ 10 tonnes/ha/year + N:P:K @ 100: 60: 40 showed high gain during favourable weather condition in terms of better crop growth parameters, higher yield, lower runoff, lower soil loss and built-up of SOC.

Key words : Plant height, Runoff coefficient, Sediment concentration, Soil organic carbon, Water stable aggregates

More foodgrain production is needed to feed current population where as maintaining environmental condition is must to support future population. Compromising with environment for high immediate gain from agriculture has led to disaster in the past therefore pre assessment for environmental impact is necessary for any proposed activities.

Pearl millet (*[Pennisetum glaucum* (L.) R. Br, emend. Stuntz.), a very important traditional crop for small and marginal farmers, occupies an area of 9.43 million hectare in India that gave production of 10.37 million tonnes during 2010-11(Indiaagristate.com 2010-11). During *kharif* 2011-2012, pearl millet occupied 0.672 million hectare in Gujarat. Average yield of pearl millet has increased more than three folds since independence but even the current (2010-11) average national yield of 1 069 kg/ha is far below

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than the desired. Pearl millet is mostly grown in rainfed conditions as area under irrigation, last reported during 2007-08 was merely 9.5%. Average yield of *kharif* pearl millet in Gujarat is 829 kg/ha whereas summer pearl millet which is gaining popularity in Gujarat and grown under irrigated conditions have average yield of 1 788 kg/ha (2011-12). Considering the limited availability of irrigation water, focus on increasing productivity of rainfed pearl millet is must.

Increase in productivity of pearl millet is likely to have high socioeconomic impact as it is cultivated by small and marginal farmers. Importance of the pearl millet in low cost agriculture of small and marginal farmers was highlighted during annual pearl millet workshop held at Junagadh Agricultural University on 23 March 2013 (ICAR 2013). In the workshop, pearl millet was described as a future crop under climate change scenario. Tolerance to drought and heat and better adaptability of pearl millet to climate change has been reported from African Sahel (CO2 Science 2011).

With availability of public as well as private bred high yielding varieties, more focus is required on inputs and management to realize high productivity. Response of pearl millet to fertilizer and manures application have been widely reported (Kumar *et al.* 2009, Diwedi and Diwedi 2007, Bhagchand and Gautam 2000, Kumar *et al.* 2007). Among the treatments comprising equivalent nutrients, better response of inorganic fertilizer (recommended N:P:K @ 40:20:0) in terms of pearl millet yield as well as net returns was observed under rainfed condition by Kumar *et al.* (2009). Recommendations are being modified to suit requirement of high yielding varieties. Application of 80 to 120 kg/ha of N to *kharif* pearl millet (Agrisco 1986), application of FYM @ 10 tonnes/ha/year along with N @ 120 kg/ha/year to pearl millet in pearl millet-wheat cropping system have been recommended for central Gujarat (Agrisco 2001). FYM @ 5 tonnes/ha along with recommended dose of N:P:K (@ 75:37:0) has been found best in terms of productivity and soil health in a long term (25 years) experiment under rainfed conditions in Gujarat (Kurothe *et al.* 2013)

In addition to improve productivity, application of manures and fertilizers also affect runoff, soil loss (Gilley and Risse 2000) and soil physical conditions (Odes 1984, Pinamonti and Zorzi 1996) that has larger significance in long run for soil and water environment and sustainability. Application of FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat resulted to improvement in the soil organic C, total N, P and K status (Kaur *et al.* 2005). Increasing dose of fertilizer and application of manures are advised for higher production but so far detailed study regarding environmental effects especially erosion aspect has not been conducted. The experiment was conducted with the hypothesis that application of FYM and fertilizer under rainfed conditions has certain effect on pearl millet production, runoff and soil loss and soil physical conditions.

MATERIALS AND METHODS

The experiment was conducted from 2009 to 2011 on deep, well drained, coarse loamy mixed Hyperthermic Typic Fluventic Ustochrepts on ravine top on research farm of Central Soil and Water Conservation Research and Training Institute, Research Centre, Vasad, Gujarat, India (Long: 73.0806°E, Lat: 22.4574°N) at slope of 2% - a representative slope of ravine hump and adjacent table land. Initial surface soil organic carbon, soil pH and electrical conductivity were in the range of 4.0 to 5.5 g/kg, 7.67 to 8.04 and 0.22 to 0.25 dS/m respectively. Surface soil bulk density ranged from 1.48 to 1.56 g/cm^3 whereas infiltration capacity was in the range of 1.6 to 2.7 cm/h. Average annual rainfall of experimental site is 871 mm with 94% concentrated in the months of June to September. July-August combine receives 61% of annual rainfall.

Soil profile study revealed increasing clay content in layer at depth more than 30 cm in one direction of plots (width wise) therefore randomised block design with two blocks and four treatments were used. Pearl millet was grown with T1: control- no application of manure and fertilizer, T2: application of farmyard manure @ 5 tonnes/ha/year, T3: application of farmyard manure @ 5 tonnes/ha/year and 100 kg of nitrogen (N), 60 kg of phosphorous (P) and 40 kg potassium (K) (100: 60: 40) every year, T4: application of farmyard manure @ 10 tonnes/ha/year and N:P:K @ 100: 60: 40. Urea, Diammonium Phosphate (DAP) and Muriate of Potash (MOP) were sources of N, P and K. Farmyard manure was incorporated in top 5 to 10 cm soil manually at the time of final field preparation. Half of the N with 100% of P and K were applied as basal dose at the time of sowing. Remaining half of the nitrogen was top dressed at first opportunity available (in terms of rainfall) between 25 to 30 days of sowing. FYM applied in different years contained 22 to 26% organic carbon and 0.14 - 0.19% total N.

Eight parallel laid runoff plots each of 40.04 sq m area bounded from three sides with brick masonry wall was used for the experiment. Runoff of past twenty-four hours was measured by means of collecting runoff in first tank that overflow in second tank via 5:1 slot divisor. Runoff depth was computed from runoff volume (volume in first tank $V_1 + 5 * $ volume in second tank V_2) by dividing it with the area of the plot. Runoff collected after thorough mixing in tanks were filtered and/or, dried to get sediment concentration. Rainfall data was collected from agro-met observatory located at distance of 50 m from the experimental site. Time for collection of runoff data was kept same as that of rainfall data.

For assessing plant growth parameters (plant height and above ground biomass), three representative plants were removed at 30 days after sowing (DAS), 60 DAS and at the time of harvest. For crop yield and total above ground biomass, three samples of 1.82 m^2 (1.82 m × 1 m) area from each plot were harvested separately. Soil organic carbon was determined using Walky and Black's method as described by Black (1965). A correction factor of 1.298 was used to compensate undigested organic carbon. Bulk density was determined up to 90 cm depth using core sampling method. Soil structural analysis was performed through Yoder wet sieving method as described by Kemper and Chepil (1965) and Jaiswal (2003). Organic carbon in water stable aggregates of size = 0.5 mm and size < 0.5 mm was determined separately. Soil moisture up to depth of 90 cm in six layers, each of 15 cm thickness was determined by gravimetric method at 10 to 15 days interval. Statistical analysis was performed for randomized block design using the procedure as described by Gomez and Gomez (1983)

RESULTS AND DISCUSSION

Monthly rainfall of crop growing season from 2009 to 2011 as against long term average (past 50 years) show very low rainfall during 2009. Due to no rainfall during grain filling period (September) in 2009, crop failed to set grain and crop yield data of 2009 is not included in the analysis. Only one runoff event was witnessed during 2009. Uncertainty is the part of weather but low rainfall in June during experimental period as compared to long term average was observed.

Crop growth-plant height

Perusal of individual year as well as pooled data in Table 1 revealed highest plant height under T4 (FYM @ 10 tonnes/ha and N: P: K @ 100: 60: 40) and lowest under T1 (control) at 30 DAS, 60 DAS and at the time of harvest, even during 2009- a drought year. Plants under T4 were on an average 14.3 cm, 40.4 cm and 33.8 cm taller than T1 at 30 DAS, 60 DAS and at the time of harvest respectively. Plant height under T2 and T3 were intermediate between T1 and T4. The response shows ability of pearl millet to utilize nutrients from higher dose of manures and fertilizers. Plant height at every stage was less during drought year (2009) that corroborates the necessity of soil moisture for proper uptake and utilization of nutrients even if it is applied to the soil. Response of treatments on plant height was highly weather dependent as highest plant height in all treatments could be observed during 2010-a good rain distribution year. Plant height under T3 at the time of harvest was statistically at par with T4. Nutrients supply under T3 (Farmyard manure @ 5 tonnes/ha and N:P:K @ 100: 60: 40) was sufficient to express full plant height under favourable rainfall condition and further addition of FYM @ 5 tonnes/ha under T4 did not show any advantage in terms of plant height. Agber *et al.* (2012) had similar observation at Benue State, Nigeria. Though they recorded tallest millet plant in case of application of NPK @ 80:50:50 + 3.0 tonnes of poultry manure per hectare but plant height under the application of NPK @ 80:50:50 + 1.5 tonnes of poultry manure as well as under application of NPK @ 80: 50: 50 were also statistically at par with that of course, higher than those in case of lower doses. Positive response of application of organic manure in combination with nitrogen and phosphorous in terms of plant height were also reported by Awodun *et al.* (2007) and Singh *et al.* (2007). Plant height within levels of nitrogen fertilizer were greatest in case of N @ 90 kg/ha as compared to lower doses, in Sub Saharan Africa (Hassan and Bibinu 2010).

Crop growth-biomass

Above ground biomass followed almost same trend as plant height. Highest biomass was recorded in T4 and lowest in T1 at 30 DAS, 60 DAS and at the time of harvest during every year of experiment (Table 1). Unlike plant height which was statistically same in T3 and T4 at the time of harvest, biomass under T3 was significantly lower than T4 at the time of harvest in 2010, 2011 whereas similar during 2009. Final biomass under T4 was 25.3, 94.4, and 36.6% higher during 2009, 2010, and 2011 respectively as compared to T1 that gave overall gain of 59.2% in pooled data. Biomass under T4 was 1.2, 5.9 and 11.1% higher as compared to T3 at the time of harvest during 2009, 2010 and 2011. Irrespective of the treatments, highest biomass was recorded during 2010. During this year, total above ground biomass at the time of harvest under different treatments were significantly different from each other. Pearl millet could better utilize nutrients from FYM and fertilizer for higher biomass production than for plant height, more efficiently during a good rain distribution year. Less advantage from application of higher dose of FYM in combination with fertilizer (T3 and T4) during drought years and high response during good rain distribution shows low resistance of the system to weather uncertainties but high resilience as it bounce to high production during favorable conditions. Higher biomass under integrated use of mineral and organic fertilizer in fodder pearl millet has been observed by Abd El-Lattief (2011). Bhagchand and Gautam (2000) recorded best dry matter accumulation in case of application of 40 kg N + 20 kg P_2O_5 per hectare as compared to lower doses. Higher biomass under application of organic manure in combination with nitrogen and phosphorous was also observed by Awodun *et al.* (2007).

Pearl millet yield

Higher plant height and biomass were well translated in terms of yield, more under T4. Highest yield was recorded under T4 and lowest under T1. Effect of application of manures and fertilizer was more prominent in terms of yield as compared to plant height and biomass as yield recorded under different treatments were significantly different from each other except during 2009 when crop failed to set grain due to extreme weather (Table 1). Yield under T4 was 153.9, 112.8, and 20.2% higher than T1, T2 and T3 respectively during 2010 whereas during 2011 it was 70.5, 34.4 and 21.7% higher. In T4, more biomass was translated to grain as for producing 559.4 kg extra grain as compared to T3, only 692.6 kg additional biomass was produced during 2010 (Table 1). During 2011, additional grain to additional biomass ratio under T4 as compared to T3 was 0.40 whereas overall ratio for different treatments

Table 1 Plant height and above ground biomass at 30 DAS, 60 DAS and at the time of harvest and yield under different treatments during 2009 to 2011

	2009				2010				2011				Pooled data		
	30 DAS	60 DAS	Harvest		30 DAS	60 DAS	Harvest		30 DAS	60 DAS	Harvest		30 DAS	60 DAS	Harvest
Plant height (cm)															
T1	23.3	103.5	108.0		29.0	124.8	145.5		28.0	117.5	138.7		26.8	115.2	130.7
T2	26.4	109.7	110.7		34.6	147.1	163.1		33.8	139.7	163.3		31.6	132.2	146.5
T3	28.8	120.7	123.4		47.6	169.5	184.6		42.1	163.6	179.3		39.5	151.2	162.4
T4	33.9	120.6	125.4		47.9	172.6	186.4		41.7	173.5	181.8		41.1	155.6	164.5
CD	3.4	4.6	2.7		2.6	10.2	3.4		4.0	11.1	3.6		2.4	6.5	3.1
Biomass and crop yield in kg/ha															
		Biomass		*Yield**		*Biomass*		*Yield*		*Biomass*		*Yield*		*Biomass*	
T1	300.0	2159.3	2281.5	25.0	372.2	5631.1	6388.9	1323.7	312.6	5607.4	6425.9	1163.8	328.3	4465.9	5032.1
T2	371.5	2092.6	2255.6	43.7	458.1	6651.9	7566.7	1567.2	386.3	6818.5	7718.5	1476.0	405.3	5187.7	5846.9
T3	501.9	2537.0	2825.9	40.0	701.9	10333.3	11729.6	2776.0	505.6	6822.2	7885.2	1630.9	569.8	6564.2	7480.2
T4	502.2	2563.0	2859.3	43.7	803.0	10974.1	12422.2	3335.4	631.1	7681.5	8759.3	1984.3	645.4	7072.8	8013.6
CD	89.9	202.7	324.0	30.1	60.8	934.3	555.0	264.5	143.5	392.4	711.5	138.22	56.2	106.3	168.8

*Crop failed during 2009 due to extreme dry conditions

were in the range of 0.21 to 0.27 during 2010 and 0.18 to 0.23 during 2011 with highest value under T4. Advantage of applying higher dose of FYM could be better realized in terms of crop yield than plant height and above ground biomass, more during better rain distribution year. Abd El-Lattief (2011) observed highest value of all growth parameters in fodder pearl millet fertilized with NPK @ 135:41:45 + FYM@ 5 tonnes/ha/year as compared to lower doses of manures and/or fertilizers. Highest above ground biomass and pearl millet yield under FYM @ 5 tonnes/ha along with N:P:K (@ 75:37:0 was observed as compared to manures alone or with fertilizer at lower doses in a long term experiment conducted on sandy loam soil of central Gujarat (Kurothe *et al.* 2013). The highest grain and stover yield of pearl millet were found with treatments in which FYM was used to replace 50% requirements of the chemical fertilizers (Bagla *et al.* 2008).

Runoff and runoff coefficients

Runoff is output of interaction of rainfall with soils, surface conditions and vegetation, conditioned by slope. Highest runoff in T1 for almost all event and lowest in T4 during crop growing period was recorded (Fig 1). During 2011 same trend was observed in crop growing season except one event that was witnessed before the sowing of pearl millet (Fig 1B). Seasonal average runoff coefficient computed as ratio of runoff to rainfall ratio, expressed as percentage was in the range of 22.7 to 30.2% during 2010 and that was in decreasing order from T1 to T4. Runoff coefficient during 2011 was in the range of 12.3 to 13.4 with highest under T1. Seasonal runoff as sum of all event runoff observed during crop growing season was in the range of 171.0 to 228.0 mm during 2010 and 88.8 mm to 112.3 mm during 2011 (Table 2). Seasonal runoff was in the decreasing order from T1 to T4. Runoff produced under T2 and T3 were statistically similar. Only one runoff event without any defined trend among treatments was witnessed during 2009. Increased water holding capacity of the soil due to soil bulk modification, higher canopy interception due to better crop condition, barrier effect of more tillering and leaf fall, barrier cum channeling due to better root spread of the crop and more evapotranspiration loss between two consecutive rainfall events due to better crop conditions are possible mechanisms through which effect of application of FYM in crop got expressed on runoff. Effect of inorganic fertilizer on runoff is expressed mainly through crop improvement. Effect of application of FYM @ 5 tonnes/ha/year (T2) had more prominent and statistically significant effect in reducing runoff over the control (T1) in 2010 as well as in 2011. No significant reduction in runoff could be observed in case of additional application of fertilizer (N: P: K @ 100:60:40) under T3 over T2. Similar hydrological behavior under marginally better crop coverage in T3 as compared to T2 and minimal soil conditioning under addition of inorganic fertilizer in (T3) over FYM (T2) are partial explanations. However further addition of FYM @ 5 tonnes/ha under T4 over T3 reduced runoff by 8 to 20%. Substantial

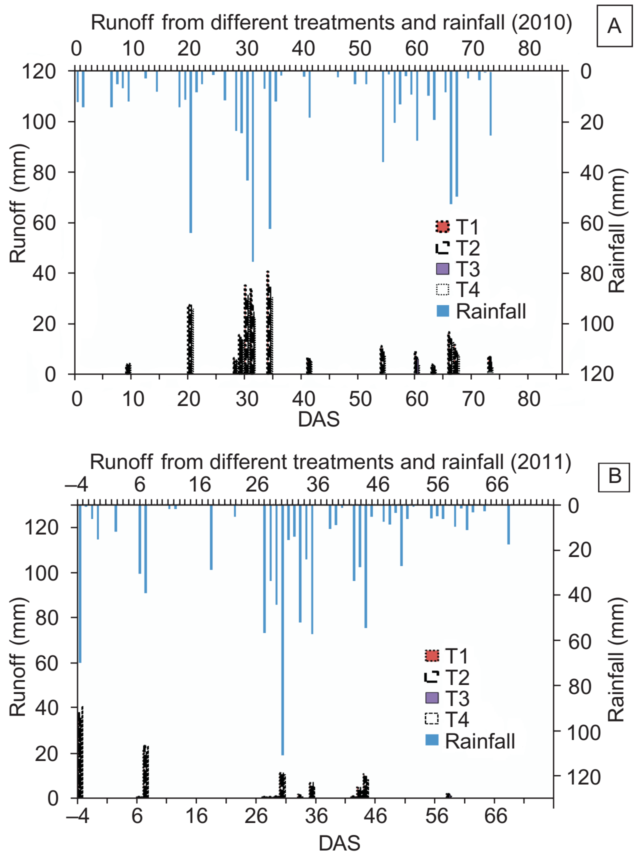

Fig 1 Daily rainfall and treatmentwise runoff during crop growing season in 2010 (A) and 2011 (B)

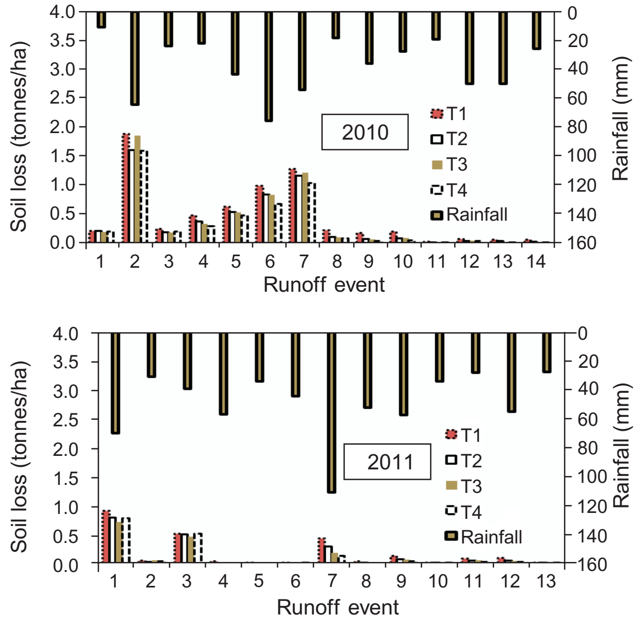

Fig 2 Eventwise soil loss under different treatments during crop growing season of 2010 and 2011

improvement in crop condition under T4 in addition to the better soil bulk condition due to application of FYM might be the reason. Gilley and Risse (2000) have reported a reduction of 2 to 62% in runoff due to application of manures. Reduction in runoff due to application of manures has been observed in other studies too (Westerman *et al.* 1983, Edwards *et al.* 1994, Sukataatmaaja *et al.* 2002). Runoff reduction by 11.3, 3.3 and 12.2% for 2, 4 and 6 tonnes/ha manure application respectively as compared to the control has been reported in an experiment conducted in south eastern Ethiopian highland (Birru *et al.* 2012)

Soil loss, sediment concentration and organic carbon loss

Soil loss under different treatments shares same trend and explanation as of runoff. Highest soil loss was recorded under T1. Irrespective of treatments, more soil loss took place in initial few events (Fig 2) due to high availability of erosive materials because of the preparatory tillage. Effects of treatments were relatively more visible in case of later events during 2010 as well as 2011 (Fig 2). T4 registered 27.7 and 30 per cent low seasonal soil loss as compared to T1 in 2010 and 2011 respectively (Table 2). In case of soil loss too, application of FYM @ 5 tonnes/ha/year (T2) as compared to control had more prominent effect whereas application of NPK @ 100:60:40 in addition to FYM @ 5 tonnes/ha/year showed no significant effect on reduction in soil loss. Sediment concentration was also highest under T1 and lowest under T4 (Fig 3). Strong linear relation ($R^2 > 0.92$) among event-wise sediment concentration of different treatments was observed. The equation developed for T2:T1, T3:T1 and T4:T1 can be used for predicting sediment concentration under any treatments if sediment concentration

Table 2 Seasonal runoff, soil loss and organic carbon loss under different treatments

	Seasonal runoff (mm)			Seasonal soil loss (tonnes/ha)			Organic carbon loss (kg/ha)		
	2011	2010	2009	2011	2010	2009	2011	2010	Pooled
T1	112.3	228.0	12.2	2.3	6.5	0.7	21.7	54.2	37.8
T2	93.5	195.0	9.9	1.7	5.3	0.7	18	48.4	33.2
T3	96.0	191.6	10.1	1.6	5.5	0.7	15.4	46.9	31.1
T4	88.8	171.0	10.5	1.6	4.7	0.6	14.8	40.5	27.7
CD	19.57	29.1	2.8	0.55	1.0	0.7	4.12	8.0	5.8

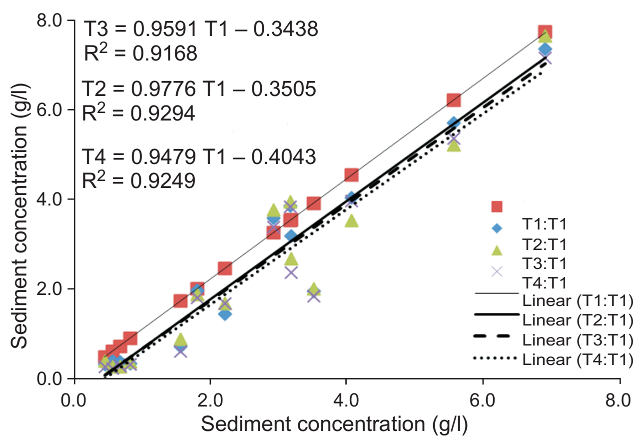

Fig 3 Relation between sediment concentration in T1 with T2, T3 and T4

of any other treatment is known. Sediment concentration was high in initial few events due to preparatory tillage. Inter-culture operation made available erosive materials thus increased sediment concentration during the crop growing season. Average sediment concentration witnessed during July (two runoff events in 2010 and three events in 2011) was in the range of 4.26 to 4.64 g/l, highest under T1. Average sediment concentration in rest of the runoff events (Aug-Sept) was in the range of 1.07 to 1.87 g/l.

Soil loss as a function of soil detachment by raindrop, erosive power of runoff as a function of depth thus velocity of runoff (Gajri *et al.* 2002), rain drop splash transportation and transportation through runoff are well understood and reported (Gajri *et al.* 2002, Kinnell 2004). Preparatory tillage makes available large quantity of detached materials. In the present experiment, tillage is common to all treatments but more rain drop impact due to less crop cover in T1 and more runoff thus more scouring and transportation of sediment were responsible for relatively higher soil loss. Improvement in moisture holding capacity of soil due to FYM application may also be a reason for better crop as well as low runoff under T4, which could not be corroborated in this experiment. Gilley and Risse (2000) reported 15 to 65% reduction in soil loss in manured plots as compared to non-manured plots. Effect of application of manure and fertilizers in reducing soil loss are more prominent at higher slope and with more erosive soil type (Sukataatmaja *et al.* 2002, Wood *et al.* 1999, Vories *et al.* 1999). Rees *et al.* (2011) also observed reduction in soil loss from potato field as a result of application of poultry manure. Soil loss reduction by 32.2% in manured plots as compared to control has been reported by Sauer *et al.* (1999). Reduction in soil loss as a result of application of FYM was also reported by Ekwue *et al.* (2009).

Loss of soil organic carbon by erosion under different treatments (Table 2) show 33.2 and 46.6% higher carbon loss under T1 as compared to T4 during 2010 and 2011 respectively. Organic carbon loss was in the range of 40.5 to 54.0 kg/ha during 2010 and 14.8 to 21.7 kg/ha during 2011. Being lighter in density, organic matter, if available in detached condition has more chance to come in suspension. However, FYM application did not increase total carbon loss, because of its incorporation into soil, less runoff generation and relatively less sediment concentration from manured plots.

Soil moisture

Soil profile moisture and total rainfall received between consecutive moisture measurements shows 20.8 to 48.2 mm soil moisture in top 15 cm soil, during crop growing season in 2010 under different treatments. After the rainy season soil moisture in 0-15 cm soil decreased gradually and reached to 9.5 to 9.9 mm on 17 February 2011. In the same layer, minimum soil moisture of 5.7 to 6.3 mm was observed at the end of June just before onset of monsoon. During pearl millet growing season of 2011, soil moisture was in the range of 27.3 to 52.3 mm. Soil profile moisture up to 90 cm depth was in the range of 137 to 296.7 mm during 2010 and 200.2 to 317.3 mm during 2011. Minimum soil profile moisture of 136.9 to 143.4 mm was recorded at the end of June. Soil moisture trend in all treatments is though partially explained by the amount of rainfall received after the previous measurement but authors are unable to interpret the differences observed among treatments at different time. More precise and frequent measurement is required for detection of small difference among the treatments. Relatively lower profile moisture for a considerable period in T3 and relatively higher moisture in T1 may be due to chance allocation of plots with low and high clay in deeper layer respectively to the treatments. As mentioned in methodology, there is increasing trend in clay content in deeper soil profile from plot number 1 to plot number 8. In randomization, plot allotted to T1 was towards higher clay content in both the blocks (plot No. 4 and 8) while reverse was case with T3 (Plot No.1 and 5). Though this difference is likely to have minimum effect on runoff which is mainly governed by surface soil conditions, but effect on profile moisture content (composite of to 90 cm) was noticeable.

Soil organic carbon-aggregates

Quantifying change in soil organic carbon is more meaningful for long term experiment. Small changes in total SOC is difficult to detect because of natural variability and high background (Blair *et al.* 1995, Carter 2002). There was variability in SOC between two replications and the mean values were interpreted. Soil profile organic carbon determined in different layer each of 15 cm thickness up to 90 cm depth, show improvement under T4 (FYM@ 10 tonnes/ha/year + N: P: K @ 100:60:40) as compared to control (Table 3). Total soil organic carbon up to depth of 90 cm was 3.43 kg/m^2 under T4 that was higher by 0.13 kg/m^2 as compared to T1. Improvement in SOC was more prominent in top 15 cm layer, as it was 23.8% higher in T4 as compared to T1. Direct addition of organic matter, addition from more biomass recycling due to better crop (Table 1) and less erosion loss (Table 2) are reasons for improvement in SOC. Gain in SOC under T4 as compared to T1 was 433 kg C/ha/year. Moharana *et al.* (2012) observed significant increase in TOC in FYM treated plots in six year pearl

Table 3 Soil profile organic carbon (kg/m^2) up to depth of 90 cm under different treatments

Depth (cm)	Organic carbon (December 2011)			
	T1	T2	T3	T4
0-15	0.88	0.94	1.05	1.09
15-30	0.63	0.68	0.68	0.65
30-45	0.57	0.56	0.52	0.51
45-60	0.42	0.40	0.38	0.44
60-75	0.39	0.45	0.42	0.4
75-90	0.42	0.39	0.34	0.34
Total	3.30	3.42	3.39	3.43

millet-wheat cropping system and TOC in surface soil were in the order of treatments FYM (11.48 g/kg) > FYM + NPK (11.08 g/kg) > NPK (8.50 g/kg) > unfertilized control (7.53 g/kg). Integrated use of farmyard manure with 100% NPK have been proved efficient in accumulating organic C in soil and the treatment sequestered highest amount of organic C @ 731 kg C/ha/year (Rudrappa *et al.* 2006). Combined application of nitrogen, phosphorus, and potassium fertilizers with FYM @ 10 tonnes/ha/year for 21 years period improved carbon storage by 5.6 tonnes/ha in Australia (Dersch and Bo¨hm 2001). Increased SOC accumulation under balanced application of NPK fertilizers and organic manure has been well documented (Meng *et al.* 2005).

Water stable aggregates (WSA) in soil profile samples were separately analysed for organic carbon in two size groups, i e WSA of diameter = 0.5 mm and diameter < 0.5 mm. Irrespective of the depth of samples, SOC were high in aggregate of size = 0.5 mm. Higher SOC in aggregates of 0-15 cm soil as compared to soil from deeper layer were recorded in all treatments with highest in case of T4. Low SOC was observed in WSA of deeper profile in both size groups of WSA. Stability of aggregates of deeper soil profile despite of low SOC is a subject of study.

Nutrient supply under application of FYM @ 5 tonnes/ ha/year + N:P:K @100: 60: 40 every year (T3) was sufficient to realize highest plant height as it was at par with plant height under application of FYM @ 10 tonnes/ ha/year + N:P:K @ 100: 60: 40 every year (T4). Effect of application of higher dose of manures in combination with fertilizer (T4) was more prominent in terms of yield as compared to plant height and biomass but was highly weather dependent as significant difference among treatments was observed during favourable condition with highest biomass and yield under T4 and lowest under T1 (no application of manure and fertilizer). During drought year (2009), no advantage of application of high dose of FYM in combination with fertilizer could be realized. Growth parameters recorded under T2 and T3 were intermediate between T4 and T1. Application of FYM@ 5 tonnes/ha (T2) had more prominent effect in reducing runoff and soil loss as compared to control (T1) whereas application of N: P: K @ 100: 60: 40 in addition to FYM@ 5 tonnes/ha showed no significant effect on runoff and soil loss. Sediment concentration under T1 was linearly ($R^2 > 0.92$) related with sediment concentration under rest of the treatments. SOC built up @ 433 kg/ha/year under T4 as compared to T1 with higher built up in surface layer. SOC was high in aggregates of size > 0.5 mm, higher in aggregates from 0-15 cm soil in all treatments with highest in case of T4. Application of FYM @ 10 tonnes/ha/year + N: P: K @ 100: 60: 40 every year, showed high gain during favourable weather condition in terms of better growth parameters, yield, lower runoff, soil loss and built-up in SOC. It is high time to change perception about pearl millet as poor cop and poor man's crop because with better management, high yield can be realized without degrading soil.

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