Research Article

Agricultural Land Management of Eroded Soil to Restore Productivity, Organic Matter (OM) Stock and Physical Properties

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Abstract | This research aimed to investigate management strategies for rehabilitation of soil quality and crops productivity on eroded agricultural land. The research was conducted with three cropping patterns viz wheat after maize, lentil after maize and wheat-lentil intercrop after maize in main plots and four fertilizer treatments viz the control, farmer's practice (FP) ($N:P_2O_5$ @ 60:45 and 15:30 kg ha^{-1} for cereals and lentils), recommended dose (RD) ($N:P_2O_5:K_2O$ @ 120:90:60 and 30:60:0 kg ha^{-1} for cereal and lentils) and integrated nutrient management (INM) ($N:P_2O_5:K_2O$ + FYM @ 60:90:60 kg + 20 t ha^{-1} for cereals and 7:30:0 kg + 20 tons ha^{-1} for lentils) were applied in sub-plots (20 m^2) of an RCB design. In INM, significant ($p<0.05$) improvement in wheat and lentil yield (by 9 and 13%, respectively) was noted over the RD whilst both showed statistically similar crude protein content. Compared to the control, INM significantly ($p<0.05$) improved the wheat and lentil yield by 128 and 87%, respectively, and the crude protein by 17%. Yield improved by 13% for wheat in intercrop over the wheat after maize and by 46% for lentil after maize over the lentil in intercrop. The INM treatment showed 94% higher OM, 10% reduced bulk density (ρ_b) and 12, 20 and 48% higher porosity (f), saturation (ω) and available water (θ), respectively over the fertilizer control, whilst amongst cropping patterns, lentil after maize effect was significantly ($p<0.01$) superior over the wheat after maize and wheat+lentil intercrop after maize for improving soil properties. Significant correlation existed between bulk density and yield (r^2=0.96 and 0.91) and soil OM and yield (r^2=0.84 and 0.75) for wheat and lentils, respectively, as well as among soil properties (OM and bulk density and bulk density and available water content in soil, r^2=0.84 and 0.92, respectively). The study concluded that plant nutrition under eroded conditions should be based on INM where half of the recommended N and recommended P and K fertilizers should be applied in combination with legume crop inclusion in cropping patterns for eroded soil yield and fertility restoration.

Received | January 26, 2017; **Accepted** | October 14, 2019; **Published** | November 12, 2019
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Citation | Ahmad, W., F. Khan, M. Sharif and M.J. Khan. 2019. Agricultural land management of eroded soil to restore productivity, organic matter (OM) stock and physical properties. *Sarhad Journal of Agriculture,* 35(4): 1144-1154.
DOI | http://dx.doi.org/10.17582/journal.sja/2019/35.4.1144.1154
Keywords | Degraded soil, Farmyard manure, Inorganic fertilizers, Legumes, Wheat yield

Introduction

Population rise to 9 billion by 2050 (Nesse, 2012) shall need 60% more food than the present (Alexandratos and Bruinsma, 2012). However, agricultural land may show an increase of another 2% upto 2040. (FAOSTAT, 2012). Even today, score of the undernourished people worldwide has touched the figure of 1 billion (FAO, 2012). Modern day agricultural sector should, objectively, strive not only to boost up yields for flaring population but to optimize it across a complex landscape (Dumanski et al., 2006) through improved management (Banerjee and Adenaeuer, 2014). In the wake of population rise and agricultural resource shrinkage, the principle of soil conservation is neglected widely and especially in the developing countries causing human induced land degradation (Dumanski and Peiretti, 2013).

Soil organic carbon content on sloping cultivated soil depends on the types of agriculture (Kenneth et al., 2016). Subsistence agricultural farming with low nutrient input and no residues/organic fertilizer management would further aggravate the conditions whilst wise and scientific farm management help not only to modify the climate change patterns but reduce its effects on soil in the form of soil and nutrient loss and productivity declination. However, the challenge of optimized crop production on sustained basis still remains substantial for agricultural scientists in Pakistan. In such circumstances, ways and means commensurate to local conditions are needed for yield improvement and lowering pressures on quality of the current soil resources (Godfray et al., 2010).

Understaning soil erosion effects on sloping soil under intensively cultivated mono cropping is necessary wherein water erosion remove significant amount of soil C and clay particles (Kenneth et al., 2016) through its sorting action from the soil surface leaving coarse soil and gravels behind (Troeh et al., 2004). The underlying outcome is the deterioration of soil properties and the jeopardized soil productivity (Khan et al., 2004; Ahmad and Khan, 2018). Negligence regarding the restoration of soil organic matter status further weaken the soil structure, increase soil susceptibility to compaction, low water infiltration and further high rates of soil erosion. These characteristics make monoculture systems less resilient to stress condition (Zuo and Zhang, 2009).

Maintenance of soil physical properties is fundamental for optimum yield (Abdulkadir and Habu, 2013; Ahmad et al., 2014). Cultivation of degraded soils aiming soil fertility rehabilitation would require farmers to change their conventional management strategies which may include crop nutrition from other sources and inorganic NPK fertilizers (Mussgnug et al., 2006; Ahmad and Khan, 2014; Ahmad and Khan, 2018). Generally, the soil characteristics improve when manures are incorporated (Ould Ahmed et al., 2010) integrated with inorganic fertilizers (Ali et al., 2018). The problem of insufficient availability of manure can be covered by including restorative crops (legumes) into the cropping patterns (Rahman et al., 2011) and crop nutrition from combined organic and inorganic fertilizers (Hossaen et al., 2011). Beneficial impact of organic fertilizer on soil physical properties has already been depicted by Ahmad et al. (2014) and Ali et al. (2018). Legumes not only contribute nitrogen rich organic matter but also protect the soil from erosion (Ahmad et al., 2014; Ahmad and Khan, 2018). It was assumed that the general recommended NPK dose, no doubt, is meant to supplement the NPK status of a particular soil necessary for crop production but cannot explore the yield potential of a crop on poor soils owing to other soil limitations like degraded physical and biological properties and deficiencies of micronutrients. The current work being conducted on poor soils (suffering from past erosion) was, therefore, hypothesized that, besides inorganic NPK, organic fertilizer application is required for soil rehabilitation and potential crop production. However, in order to save N toxicity through blind application of organic fertilizers in combination with inorganic NPK, the quantity of organic fertilizer was calculated based on 50% of the required N content whilst reducing 50% of inorganic N from the recommended NPK dose keeping in view up to 30% of nutrients release by FYM at first year of its application. Upon this calculation, 20 t ha^{-1} FYM with 1.06% N was expected to release 63 kg N which is approximately equal to 50% of the recommended N (120 kg ha^{-1}).

Materials and Methods

The experimental site was located in District Swabi (34° 10' 28" N, and 72° 34' 73" E), Pakistan. According to Soil survey reports (1973) the experimental site was on severely eroded Missa gullied soil series and the soil were classified as coarse silty, mixed, hyperthermic, Udic Haplustalf (USDA, 1998). Textural classification of soil was silty clay loam, low in nutrient content, non-saline and alkaline in reaction (Table 1).

The experiment was conducted in RCB split plot design wherein three cropping patterns viz wheat (*Triticum aestivum* L.) after maize (*Zea mayse* L.), lentil (*Lens culinarus* M.) after maize and wheat+lentil intercrop after maize were evaluated in main plots and fertilizer treatments viz the control, farmer's practice (FP) ($N:P_2O_5$ @ 60:45 and 15:30 kg ha^{-1} for cereals and lentils), recommended dose (RD) ($N:P_2O_5:K_2O$ @ 120:90:60 and 30:60:0 kg ha^{-1} for cereal and lentils) and integrated nutrient management (INM) ($N:P_2O_5:K_2O$ + FYM @ 60:90:60 kg + 20 t ha^{-1} for cereals and 7:30:0 kg + 20 t ha^{-1} for lentils) were applied in sub-plots (20 m^2). FYM (Table 2) was added to the field 15 days prior to cultivation. For N, P and K the sources were Urea, SSP and SOP (K_2SO_4). Half Urea and the SSP and SOP doses were applied soil just before sowing whilst other half of the Urea was applied at second irrigation. Azam, Uqab and NM-89 were the varieties used for maize, wheat and lentils, respectively. Maize was sown on 8th, July and harvested on 5th, October each year, wheat and lentils were cultivated on 5th November and harvested on 30th April each year. The experiment was repeated for four consecutive crop seasons (Kharif, 2006; Rabi, 2006-07; Kharif, 2007; Rabi, 2007-08) in the same fixed layout. Rainfall data (Figure 1) recorded by Pakistan Tobacco Company, Charbagh, Swabi were obtained for the experiment.

Table 1: *Characteristics of the soil sampled from the experimental site before crop sowing.*

Property	Units	Surface soil (0-20 cm)	Sub-surface soil (20-40 cm)
Sand	(%)	14.74	13.93
Silt	″	53.15	49.11
Clay	″	32.11	36.96
Textural Class	----	Silty clay loam	Silty clay loam
Bulk Density	($Mg\ m^{-3}$)	1.49	1.52
Porosity	(%)	43.9	42.5
Saturation	″	20.1	17.7
Available Water	($g\ kg^{-1}$)	140.9	141.3
pH (1:5)	……	7.96	8.2
EC. (1:5)	$dS\ m^{-1}$	0.15	0.14
Organic matter	$g\ kg^{-1}$	3.4	2.6
Total N	″	0.09	0.13
Mineral N.	$mg\ kg^{-1}$	12.25	5.54
AB-DTPA extractable			
P	$mg\ kg^{-1}$	2.1	2.25
K	″	80.6	68.9

For agronomic data, the plant height was recorded from the base to the flag leaf just before the harvest. Four central rows $plot^{-1}$ were harvested and sun dried. Pod and spike length and number of grains were determined in 10 lentil plants and wheat tillers at random. Sun dried bundles were threshed with micro plot thresher. Normal 200 grains from each plot were counted at random, weighed and multiplied by 5 for 1000 grain weight calculation. Grains from each plot were cleaned, air dried and weighed to record grain yield.

Table 2: *Farmyard manure analysis before the Experiment.*

Property	Unit	Value
Moisture	%	47.5(±4.58*)
Total N	$g\ kg^{-1}$	10.6(±0.36)
O.C	″	206.4(±25.54)
C/N ratio	-	19(±1.73)
Total P	$mg\ kg^{-1}$	479(±10.23)
Total K	$g\ kg^{-1}$	2.9(±0.39)
Fe	″	0.11(±0.02)
Cu	$mg\ kg^{-1}$	23(±2.08)
Zn	″	42(±2.37)
Mn	″	122(±9.09)

Nutrients (kg) per 20 t FYM							
Total N	Total O.C	AB-DTPA extractable					
		P	K	Fe	Zn	Mn	Cu
212	4128	9.57	58	2.2	0.45	0.85	2.44

** standard deviation out of three analysed samples.*

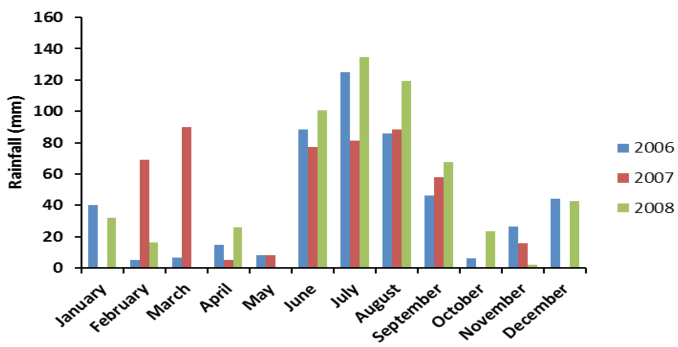

Figure 1: *Rainfall data for 2006, 2007 and 2008 at the study site.*

Treatment plots were sampled at two depths; 0-20 cm (surface) and 20-40 cm (sub-surface) after each crop harvest, prepared and analysed during 2009. Standard procedures were adopted for determination of soil texture (Tagar and Bhatti, 1996), total N in farmyard manure and soil (Bremner, 1996), Total P, K and micronutrients in farmyard manure (Kue, 1996), AB- DTPA extractable P, K, Zn, Fe, and Mn in soil (Soltanpour and Schwab, 1997), pH (Nelson and Soomers, 1982), Electrical conductivity and Lime content (USDA HB 60, 1954), Mineral N in soil (Mulvaney, 1996), OM (Nelson and Sommers, 1982), bulk density (ρ_b) (Black and Hartge, 1984), total porosity (f) (Danielson and Sutherland, 1986), saturation percentage (ω) (Gardner, 1986) and available water content (θ) (Raza et al., 2003).

Table 3: *Soil amendments and cropping patterns effect on wheat and lentil yield and quality parameters averaged over two year data.*

Soil amendments	PH (cm)	BY (t ha^{-1})	SL/PL(cm)	GS/GP	GY (kg ha^{-1})	GW (g)	CP (%)
	Wheat						
Control	72.2	4.7	8.7	35.6	2072	40	12.0
Farmer practice (FP)	81.1	7.2	10.1	41.3	3116	41	12.9
Recommended dose (RD)	89.8	11.3	12.8	52.4	4349	43	14.9
Integrated nutrients (INM)	95.4	12.7	13.5	55.5	4730	44	14.5
$LSD_{(<0.05)}$	2.86	0.6	0.39	1.59	106.9	0.7	0.83
Cropping patterns							
Maize-wheat (MW)	83.0	8.8	10.6	42.9	3482	42.1	13.4
Maize-intercrop (MI)	86.2	9.2	11.9	49.5	3652	42.4	13.7
T-test	0.67	ns	0.44	0.36	Ns	ns	Ns
C x T	*	ns	Ns	ns	Ns	*	Ns
Soil amendments	Lentils						
Control	21.3	2.4	2.6	1.1	619	19	26.5
Farmer practice (FP)	23.8	2.9	3.0	1.3	866	20	26.7
Recommended dose (RD)	30.2	4.0	3.9	1.7	1035	21	28.5
Integrated nutrients (INM)	33.8	4.5	3.9	1.8	1112	22	28.8
$LSD_{(<0.05)}$	0.90	0.5	0.12	0.06	42.6	0.6	2.51
Cropping patterns							
Maize-wheat (MW)	26.4	3.5	3.2	1.51	1031	24	28.4
Maize-intercrop (MI)	27.4	2.6	3.6	1.44	785	18	26.9
T-test	ns	0.12	0.44	0.78	0.085	0.00	Ns
C x T	**	**	Ns	ns	**	**	Ns

PH: plant height, BY: biological yield, SL: spike length, PL: pod length, GS: grains per spike, GP: grain per pod, GY: grain yield, GW: grain weight, CP: crude protein.

Data were averaged over seasons and treatments and analysed through analysis of variance (ANOVA) procedure for RCB-design (Gomez and Gomez, 1984) using Statistix 8.1 software. Variation amongst significantly different means was determined using LSD test (Steel and Torrie, 1980). Correlation amongst soil properties and yield as well as among different soil parameters were determined using MS Excel software. Economic analysis of the fertilizer treatments were performed based on difference between the values of the product in a particular treatment and the control.

Results and Discussion

Soil organic carbon (SOC) and physical characteristics are fundamental to underpin soil fertility and crop production. Application of soil amendments from combined manure and inorganic NPK (INM) significantly (p<0.01) improved the wheat and lentil yield parameters over the recommended NPK dose (RD). Wheat plant height increased by 6%, biological yield by 12%, spike length by 5.6%, number of grains per spike by 5.6%, 1000 grain weight by 2% and grain yield by 9% over the recommended dose and 24, 170, 36, 35.8, 10, 128 and 17% over the control, respectively. Crude protein in the INM was statistically at par with the RD and significantly higher over the FP and the control (Table 3). Lentil plant height was higher by 10%, biological yield by 12.5%, number of grains per pod by 5.5%, grain yield by 7.4%, 1000 grain weight by 4.7% and crude protein by 1%, in INM over the RD whilst these were 42, 87, 37.4, 79, 16 and 8% higher over the control, respectively (Table 3). Pod length in INM was statistically similar to RD but 47% higher over the control. Inorganic NPK supports growth during early stages whilst FYM ensures nutrients availability during the latter growth stages. Nutrients supply over the entire crop growth period by INM treatment resulted in improved yield and quality parameters in wheat and lentil crops under degraded conditions. Improved grain yield with farmyard manure application on degraded soil was reported by Mussgnug et al. (2006). Supplementation of nutrients improve grain formation and grain weight and increase total grain yield of the crop as indicated by their significant correlation (r^2= 0.96 and 0.60 for wheat and lentil, respectively) (Figure 2).

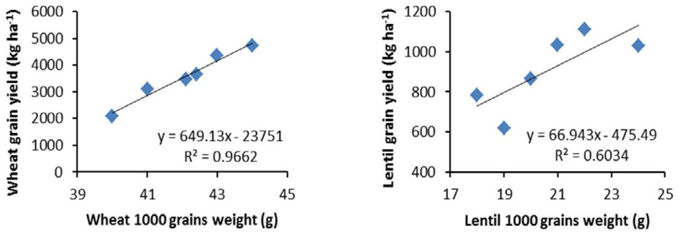

Figure 2: *Correlation between 1000 grain weight and grain yield of the wheat and lentil crops.*

Fertilizer application to preceding maize crop might have carry over effect on the succeeding lentil crop (Ali et al., 2008) due to improved soil environment for improved lentil growth (Anderson, 2005). No improvement in yield parameters and crude protein of wheat grown in intercrop with lentils after maize was observed over the wheat grown alone after maiz. However, plant height, spike length and grain spike^{-1} improved significantly (by 7, 11 and 13%, respectively) due to lentils effect as intercrop with wheat. The difference might be ascribed to improved soil OM content in wheat-lentil intercrop plots over the sole cereals. Correlation between soil OM and crop yield (r^2: 0.84 and 0.75 for wheat and lentil, respectively) and soil properties and crop yield (r^2: 0.91 and 0.96 for wheat and lentil, respectively) was highly significant (Figure 3).

Low OM in maize-wheat cropping (Table 5) might have caused the associated limitations for crop growth (Ahmad and Khan, 2014). On the other hand, the wheat in intercropping with lentil might have availed wider space and sufficient sunlight due to low lentil plant height both being favourable for improved wheat crop growth. The cropping pattern effect was also significant on lentil yield parameters (Table 3). In lentils grown after maize, biological yield, grain protein, grain yield and 1000 grain weight were 46, 5, 31 and 32% higher, respectively, over the lentils in intercrop with wheat, whilst the cropping pattern effect on plant height and crude protein was non-significant (Table 3). The lentil after maize produced higher grain yield than lentils in the intercrop with wheat where they suffered from wheat shadowing effect resulted in reduced biological nitrogen fixation at flowering stage (Fujita et al., 1992).

Significant interaction ($P<0.05$) between cropping patterns and soil amendments on wheat plant height and 1000 grain weight also depicted the favourable legumes intercrop effect on wheat. The interaction effect between cropping patterns and soil amendments on lentil plant height, biological yield, grain yield and 1000 grain weigt was highly significant showing that lentils in maize-lentil cropping pattern were benefitted by fertilizer application as compared to maize-wheat+lentil intercropping where it was affected by wheat shadowing.

Economic analysis revealed 16 and 14% higher net economic return (NER) for wheat and 0.4 and 4% for lentil by INM over the RD during 2006-07 and 2007-08, respectively (Table 4). Benefit to cost ratio (BCR) for wheat in INM over the RD was stable during both years. However, associated benefit with INM like higher net return in a populous country like Pakistan and the expected improved soil properties make it more preferable and superior over the RD. The higher BCR in FP cannot be considered for competition amongst the soil amendments because of very low NER that does not commensurate well with population needs and the expected deterioration in soil properties. Very low BCR in INM compared to the RD and FP for lentil is due to FYM addition that was additional to the nutritional requirement for lentils and was helpful in the restoration of the degraded soil properties. Even then, the stable NER in case of INM saves any economic loss during both years. Higher NER and BCR during 2007-08 compared to 2006-07 represents positive influence of SA over the years.

Soil characteristics

Soil amendments significantly ($p<0.01$) improved soil organic matter (OM) content in surface (0-20 cm) and sub-surface (20-40 cm) soil. Results (Table 5) revealed 37% increase in OM in INM over the RD, 74% over the FP and 94% over the control in surface whilst 101% over the RD, 121% over the FP and 150% over the control in sub-surface soil. Application of soil amendments from combined organic and inorganic sources, is a recommended land management practice for soil OM build up in agricultural soil (Jiang et al., 2014). Increase in OM in our results to more than twice with soil amendments is because of initially very low OM in soil (Table 1). However, despite 150% increase, it could hardly touched marginal range in surface (10.2 g kg^{-1}) whilst

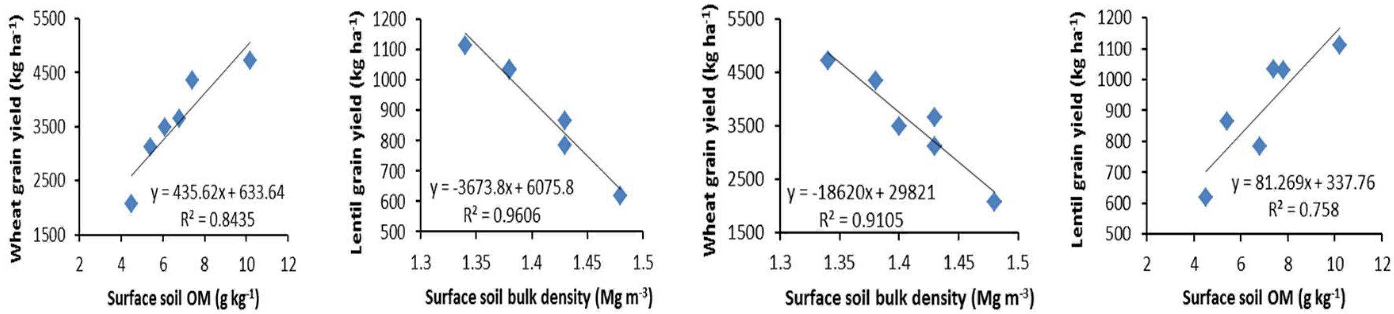

Figure 3: *Correction between surface soil properties on wheat and lentil grain yield. Economic analysis revealed 16 and 14% higher net economic return.*

Table 4: *Economic analysis of fertilizer for what and lentil during winter 2006-07 and 2007-08.*

Treatment		Yield Value (USD)	Value incr. (USD)	Yield Cost (USD)	NER (USD)	BCR	Yield Value (USD)	Valued incr. (USD)	Yield Cost (USD)	NER (USD)	BCR
		2006 - 07					2007- 08				
Wheat	Cont.	451					587				
	FP	664	214	50	163	3.2	886	299	48	251	5.2
	RD	954	504	138	366	2.6	1286	700	97	602	4.7
	INM	1058	608	182	425	2.6	1415	828	141	688	4.9
Lentil	Cont.	456					560				
	FP	487	32	18	14	0.8	777	217	16	201	12
	RD	602	146	35	111	3.1	938	378	32	345	10.6
	INM	658	203	91	112	1.2	1010	450	88	362	4.1

Cont.: Control, Incr.: increased, NER: Net economic returen, BCR: Benefit to cost ratio USD. (United States Dollar) exchange rate with Pak Rupee: 2007: Rs. 60.3, 2008: Rs. 66.7. Mineral fertilizer price source: Agriculture Statistics of Pakistan (2006 & 2007), Grain yield, Straw and FYM price source: Local Market.

Table 5: *Effect of soil amendments and cropping patterns on soil physical parameters based on averaged data over four seasons.*

Parameters	Depth(cm)	Cont.	FP	RD	INM	LSD (<0.05)	MW	ML	MI	LSD (<0.05)
		Soil amendments					Cropping patterns			
OM (g kg^{-1})	0-20	4.5	5.4	7.4	10.2	0.7	6.1	7.8	6.8	0.5
	20-40	3.8	4.9	5.9	6.5	0.7	4.9	5.7	5.2	0.6
ρ_b(Mg m^{-3})	0-20	1.48	1.43	1.38	1.34	0.01	1.4	1.38	1.43	0.02
	20-40	1.52	1.49	1.45	1.40	0.02	1.47	1.44	1.49	0.02
f (%)	0-20	43.9	45.7	47.7	49.3	0.47	46.7	47.5	45.8	0.72
	20-40	42.3	43.6	44.8	46.7	0.59	44.1	45.5	43.5	0.59
ω (%)	0-20	26.2	27.8	29.7	31.5	0.69	28.4	29.4	28.5	0.62
	20-40	24.4	26.6	28	29	0.78	26.7	27.4	27.0	Ns
θ (g kg^{-1})	0-20	114	134	156	169	2.8	141	147	142	2.54
	20-40	99	112	131	147	3.0	124	121	121	Ns

$\rho_{b:}$ bulk density; f: total porosity; ω: Saturation percentage; θ: available water; Cont.: Control; FP: Farmers practice; RD: recommended dose; INM: integrated NPK and FYM; MW: maize-wheat; ML: maize-lentil; MI: maize-intercrop.

still deficient in sub-surface (6.5 g kg^{-1}) soil (Table 5). This asserts the importance of plants nutrition on eroded soil from the organic sources co-applied with inorganic NPK since these soils suffer continuously from soil OC losses (Olson et al., 2014; Kenneth et al., 2016) and higher rate of OC mineralization (Cai et al., 2016). The changing soil C stocks with soil amendments application as well as the suspected increase in below ground biomass as indicated by Cai et al. (2016) resulted in visible improvement in the soil physical properties (Khan et al., 2007).

Soil amendments effect on bulk density (ρ_b), soil total porosity (f), soil saturated water (ω) and the available water (θ) content was highly significant ($p<0.01$) both in the surface and sub-surface soil. Soil ρ_b decreased by 9.4 and 7.9% in INM, 6.8 and 4.8% in the RD and 3.4 and 2% in the FP, respectively, over the control (Table 5) in the surface and sub-surface soil, respectively. Consequent upon this reduction in ρ_b, increase in f was 12.3 and 10.4% in INM and 9 and 6% in the RD in surface and sub-surface soil, respectively, over the control. The INM recorded 20 and 19% increase in ω, the RD recorded 13 and 15% and the FP 6 and 9% in surface and sub-surface soil, respectively, over the control. Again, the maximum increase in θ (48.2%) was observed in INM, followed by RD (36.8%) and FP (17.5%) in surface and 48, 32 and 13% in sub-surface, respectively, over the control (Table 5). These results further revealed the significantly improved soil $\rho_{b,}$ f, ω and θ with sole NPK application but its application in combination with FYM was unequivocally favourable. Reduced subsoil compaction with manure application (Mosaddeghi, 2000) and increased root growth with NPK explains this improvement. There was significantly high correlation between soil OM content and soil bulk density (r^2: 0.85 and 0.88) as well as soil bulk density and available water holding capacity (r^2: 0.92 and 0.85) of both the surface and sub-surface soils, respectively (Figure 4). Soil porosity depends on mass percentages of different sized particles, however, within the same textured soil, it varies with type and level of OM content and the extent of soil aggregation. As such, difference in the type and extent of organic amendment affect f through soil particles rearrangement. Essien (2011) reported a 7% increase in soil f in a sandy loam soil with the application of 70 t ha^{-1} goatyard manure.

Cropping patterns effect on soil parameters was also significant in both depths. The maize-lentil cropping pattern showed 28 and 12% more OM in surface soil than maize-wheat cropping pattern and maize-wheat+lentil intercropping. In sub-surface soil, this difference was 16 and 8%. As cited above (Khan et al., 2007), this difference in OM explains 1.4 and 2% reduction in ρ_b in maize-lentil cropping pattern over the maize-wheat in the surface and sub-surface soil, respectively. Due to lower $\rho_{b,}$ f in maize-lentil cropping pattern was 0.7 and 3.7% higher over the maize-wheat and maize-wheat+lentil intercropping in surface soil. In the sub-surface soil, 3.1 and 3.6% higher f over maize-wheat and maize-wheat+lentil intercropping was observed (Table 5). Lower ρ_b and higher f in the maize-lentil ensured 3.5 and 4% higher ω and θ over the maize-wheat and 3 and 3.5% higher ω and θ over the maize-wheat+lentil intercropping, respectively (Table 5). Lower ρ_b and higher f in legume based cropping pattern might be attributed to its higher OM than the one having sole cereals (Li et al., 2007) whilst decrease in OM resulted in decreased f, reduced infiltration and water and air storage capacities (Celik, 2005). Generally, the more the OM the soil contains, the more the water it will retain (Gupta and Gupta, 2008).

Temporal variation in soil properties as a result of the combined soil amendments and cropping patterns was limited to soil OM and ω (Table 6) that significantly ($p<0.01$) increased both in the surface and sub-surface soil. Soil OM after fourth season (winter 2007-08) was 125% higher in the surface and 78% higher in the sub-surface over the first seasons (summer 2006) (Table 6). Increase in ω during the second, third and fourth seasons were 10, 11.5 and 17.9% over the first season (26%) in the surface and 9, 11% and 22% higher ω over the first season (24.4%) in the sub-surface soil, respectively. Researchers reported both the long-term (Rasool et al., 2008) and short-term (Mosaddeghi et al., 2009) significant effect of FYM application on soil physical properties. Manure application over a long period has been efficient management practice to enhance soil organic C (Cai et al., 2016). However, in our case after four seasons application soil amendments the insufficiency of OM (< 1%) explains the non-significant improvement in $\rho_{b,}$ f and θ over the seasons both in the surface and sub-surface soil (Table 6). However, positive trend of improvement in soil ρ_b, f and θ indicated the role of manure incorporation and legumes inclusion in crop rotation.

Cropping patterns and soil amendments interaction was significant ($p<0.05$) on soil OM in surface and highly signinificant ($p<0.01$) on ρ_b and f in sub-surface soil (Table 7) indicating that OM build up in soil is the result of both CP and SA applications which in turn resulted in improvement of ρ_b and f in the sub-surface soil. The significant interaction between seasons and soil amendments in surface and sub-surface soil over the OM and associated physical properties explains soil OM build up with manure

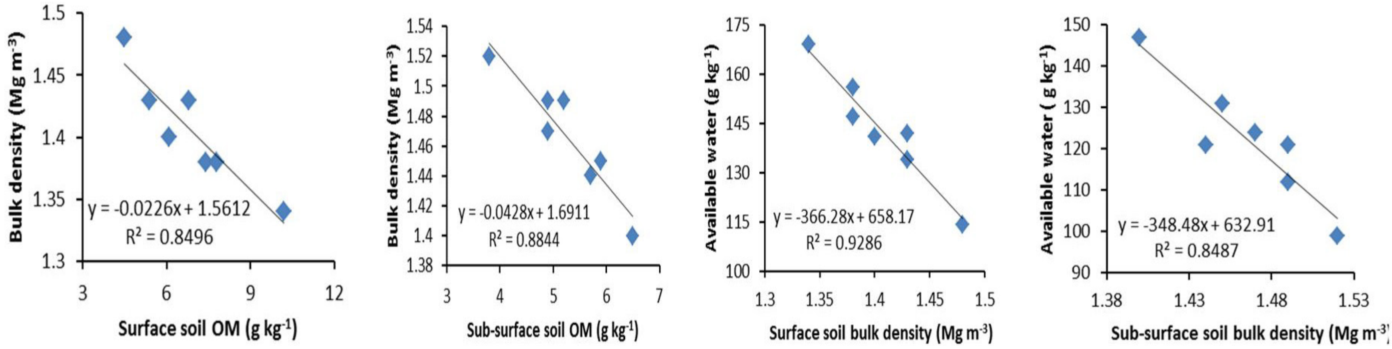

Figure 4: *Correlation between soil OM and bulk density and soil bulk density and available water both in the sureace (0-20 cm) and sub-surface (20-40 cm) soil.*

Table 6: *Temporal variation in soil physical properties.*

Parameters	Depth (cm)	Summer 2006	Winter 2006-07	Summer 2007	Winter 2007-08	LSD (<0.05)
OM (g kg^{-1})	0-20	3.5 d	6.7 c	8.2 b	9.2 a	0.5
	20-40	3.4 d	5.0 c	6.0 b	6.7 a	0.7
ρ_b (Mg m^{-3})	0-20	1.44	1.42	1.39	1.38	ns
	20-40	1.49	1.46	1.46	1.46	ns
f (%)	0-20	45.4	46.2	47.3	47.7	ns
	20-40	43.4	44.8	44.5	44.7	ns
ω (%)	0-20	26.2 c	28.8 b	29.2 b	30.9 a	0.71
	20-40	24.4 c	26.6 b	27.1 b	29.8 a	0.87
θ (g kg^{-1})	0-20	136	145	145	146	ns
	20-40	116	125	128	120	ns

$\rho_{b:}$ bulk density; f: total porosity; ω: Saturation percentage; θ: available water.

Table 7: *Interactions between soil amendments (SA), cropping patterns (CP) and seasons (S) on soil OM and physical characteristics.*

Parameters	Depth (cm)	S × SA	S × CP	CP × SA	S × CP × SA
OM (Mg m^{-3})	0-20	**	*	*	ns
	20-40	**	ns	ns	ns
ρ_b (Mg m^{-3})	0-20	**	**	**	ns
	20-40	*	ns	ns	*
f (%)	0-20	**	**	**	ns
	20-40	*	ns	ns	*
ω (%)	0-20	*	ns	ns	ns
	20-40	**	ns	ns	ns
θ (g kg^{-1})	0-20	**	**	ns	ns
	20-40	**	ns	ns	ns

application over the seasons and the resultant soil physical improvement (Table 7). Significant seasons and cropping pattern interaction on physical properties except ω in surface soil also depicts the positive effect of legumes in crop rotation on soil physical properties over the seasons.

Conclusions and Recommendations

Crop growth and yield significantly improved with recommneded dose of NPK compared to farmer's practice and the control. However, nutrients application from integrated organic and inorganic sources (INM) proved significantly superior over the recommended inorganic NPK in restoring the degraded soil properties, yield and improving net economic return despite saving 50% of the inorganic N fertilizer. Legumes in crop rotation fetch additional benefits to degraded soils in the form of providing rigorous soil cover, higher OM content and physical properties restoration in interaction with soil amendments.

Acknowledgement

Authors thank the Higher Education Commission of Pakistan for financial support to the research under Indigenous Ph.D Fellowship Program Batch II.

Novelty Statement

The challenge of optimized crop production on sustained basis still remains substantial for agricultural scientists in Pakistan. The general recommended NPK dose only supplement the NPK of a particu-lar soil but cannot explore the yield potential of crops on poor soils. In such circumstances, ways and means commensurate to local con-ditions are needed for yield improvement and lowering pressures on quality of the current soil resources. The current research shall suggest farmers for sustained crop production as well as soil rehabilitation under degraded soil properties.

Author's Contribution

Wiqar Ahmad conducted the research, Farmanullah Khan supervised and was involved in planning and execution of the study, Muhammad Sharif helped in research planning and execution and analysis and Muhammad Jamal Khan helped in paper write-up.

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