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Soil moisture retention and rainfed wheat yield variations by the addition of gypsum and green manure

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In rainfed tract, the success of agriculture depends on conservation and efficient use of soil moisture and nutrients availability that directly linked with the presence of moisture in soil. The moisture can be conserved through several means including green manures and gypsum addition. The experiment was conducted to investigate the integrated effect of green manures and gypsum for moisture conservation and their impact on wheat production under rainfed conditions. The experiment was planned at six sites with five treatments including gypsum at 1 t ha^{-1}, green manure (Guar 40 days old) and gypsum+green manuring were compared with control (untreated) and farmer practice (traditional). Results showed a significant increase (up to 38 to 76%) in wheat grain yield with the application of gypsum and green manure while soil moisture contents were enhanced up to 34 to 65% compared to control. It was also noticed that the treatments altered the soil properties (pH, Electrical conductivity (Ece), Organic Matter, Available Phosphorous and Extractable Potash) positively by improving soil water relationship over the control.

Key words: Gypsum, green manure, moisture contents, soil properties, conservation, wheat yield.

INTROUCTION

Rainfall is highly variable in the Pothwar Plateau (altitude and longitude) of Pakistan. Two third of rainfall received as high intensity rainstorms during monsoon season from July to September. Wheat crop was sown in the months of October and November; therefore, the success of the crop is directly related to the success in the conservation of moisture received during the monsoon months (Rashid et al., 2016). The moisture conservation mainly depends on soil type, soil organic matter and management practices like green manuring and tillage operations. The soil moisture stress and low soil fertility at critical growth stages are the factors that affect the productivity of Pothwar Plateau. The suitability of a soil for crop production depends on its physical, chemical and biological characteristics. By adapting water conservation and its judicious utilization, the cropping intensity can be increased up to 200% in medium to high rainfall zones of rain fed areas increasing the yield up to 50%. The application of fertilizer along with water conservation practices increased cereal crop yield significantly (Shafiq et al., 2003). Gypsum and polyacrylamide improved soil condition resulted in increased moisture contents. Also,

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the availability of soil moisture and moisture stress are prominent factors affecting the crop growth in rainfed areas. Due to high evaporation rate in semi-arid environment, it is very difficult to maintain soil moisture (improved nutrient uptake) that is largely proportional to crop yield. It is well established that soil erosion by runoff water is induced by detachment and transport of soil particles. This process of erosion depends on factors such as climate, topography, plant cover and soil management (Toy et al., 2002). Many approaches were prevalent for soil moisture conservation for wheat production including gypsum ($CaSO_4.2H_2O$) cheapest source that improve water infiltration rate and does not interfere to crop growth even applied in excess. It also holds moisture and nutrients for crop (Sajid et al., 2013). Gypsum as an amendment can improve water infiltration into the soil and water redistribution within the soil (Hamza and Anderson, 2004). With improved infiltration, a given amount of water will enter the soil in less time. With improved redistribution, downward movement of water within the soil would be faster; "using gypsum as a soil amendment is the most economical way to cut the non-point runoff-pollution of phosphorus and other soil nutrients. Gypsum, in addition to prevention and correction of sodicity, include greater stability of soil organic matter, more stable soil aggregates, improved water penetration into the soil, and more rapid seed emergence (Rashid et al., 2008). It improves water infiltration rates into soils and also the hydraulic conductivity of the soil and improves the permeability of the soil (Korcak, 2001). Similarly, green manure can provide nutrition for soil organisms, thus protecting and enhancing the soil's biological activity (Tejada et al., 2008). The frequent use of green manures resulted in more organic matter in soil which improves both soil physical and chemical properties that may be due to improved soil structure and drainage; it may stimulate microbial activities with mineralization (Fanish, 2017). Addition of crop residue to the soil enhanced soil organic matter. The increase in soil organic matter will lead to an increase in nutrient availability and improves the physical qualities of soil such as water infiltration, moisture storage capacity, aggregate stability, and resistance erosion. The poor management of organic matter and unavailability of bio-organic fertilizers results in the many soil related constraints, that is, depletion of soil organic matter and crop yields (Jahiruddin and Sattar, 2010; Martius et al., 2002). This study was carried out to evaluate the impact of gypsum and green manuring on soil moisture conservation and wheat yield under rainfed conditions.

MATERIALS AND METHODS

Experimental setup

The experiment was planned at Soil and Water Conservation Research Station (SAWCRS), Fateh Jang (latitude 33.55° N, longitude 72.58° E and 402 m high from the sea level), Pakistan, during 2013/2014 to 2015/2016 in Rabi season each year. The experiment was laid out in Randomized Complete Block Design (RCBD) in split plot arrangement at six sites including Kharala Kalan (S1), Kharala Kalan (S2), Kharala Khurd (S3), Kharala Khurd (S4), BARS (S5) and BARS (S6) under varied soil conditions to confirm the sustainability of techniques. In this study, an effort was being made to develop the technology to conserve rain water received during monsoon for succeeding wheat crop by means of green manure and gypsum by using treatments Control (T_1), Farmer Practice (FP) (T_2), Gypsum (T_3), Guar (T_4), and Guar+Gypsum (T_5). In June, the ploughing of the field was done with cultivator and gypsum was incorporated at 1 t ha^{-1} into the soil with cultivator before the onset of monsoon once in three years. The sowing of guar was done using seed rate of 20 kg ha^{-1}. The biomass of guar was incorporated into the soil with moldboard plough in mid of August in each year of the xperiment and the sowing of wheat (Chakwal-97) was carried out in October after addition of recommended rates of fertilizers NPK at 120, 80, 60 kg ha^{-1} in all the treatments including control except FP whereas the yield of FP (inputs of farmer's choice and availability) practice was noted for comparison. Crop was harvested manually and three samples each from 1 m^2 area of wheat were collected to record yield data.

Soil sampling and analysis

A composite soil sample from each plot, before the sowing of wheat was collected from the depth of 0 to 12 cm for soil moisture contents and nutrients analysis every year. To assess the change in soil due to gypsum and green manuring application these samples were analyzed for moisture contents determination and soil physico-chemical estimations. Soil moisture contents were measured by gravimetric method (Shukla et al., 2014). Soil organic matter (Chatterjee et al., 2009), available phosphorous (Turner et al., 2005), extractable K (Darunsontaya et al., 2010) while soil pH and Ec_e was measured by the methods described by Mclean (1982) and Khorsandi and Yazdi (2007), respectively.

Soil and climate

The basic soil analysis before conducting experiment indicated that all sites were found free from salinity/sodicity hazard (1.09 dSm^{-1}), moisture contents (7.2%), alkaline in reaction (8.2), poor in organic matter (0.73%), low in available phosphorus (18 kg ha^{-1}) and medium in extractable-potassium (240 kg ha^{-1}) (Table 1). The textural class ranged from sandy loam to loamy. The climate of the study location was semi-arid with average mean monthly temperature ranging from 2.54 to 34.13°C, 3.22 to 35.16°C and 3.93 to 33.86°C during 2013/2014 to 2015/2016, respectively. The mean monthly temperature data showed that temperature decreased gradually from September to January and further increased each year (Table 2). The maximum annual precipitation recorded was 807 mm during 2014/2015 at the study sites from September to April and mostly more rainfall occurred in the month of September, October and March during crop growing period (Table 3).

Statistical analysis

The data collected was statistically analyzed using the methods described by Steel et al. (1997). Statistix 10.0 software was used for data analysis.

Table 1. Antecedent soil properties of the experimental sites .

Location	Moisture contents (%)	pH	Ece (dSm^{-1})	OM (%)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
S1	5.6	8.0	1.06	0.44	15	140
S2	6.3	7.8	0.98	0.58	17	204
S3	6.8	7.7	0.92	0.61	17	215
S4	7.2	7.6	0.83	0.73	18	240
S5	6.0	7.9	1.03	0.54	15	189
S6	5.1	8.2	1.09	0.39	13	123

Source: Soil and Water Conservation Research Station, Fateh Jang.

Table 2. Mean monthly minimum and maximum temperature during the crop growing season.

Month	2013/2014		2014/2015		2015/2016	
	Temperature (°C)		Temperature (°C)		Temperature (°C)	
	Min.	Max.	Min.	Max.	Min.	Max.
September	10.20	34.13	18.53	35.16	20.60	33.86
October	12.36	33.54	16.64	28.80	16.41	29.00
November	9.23	31.66	10.16	26.26	9.70	21.36
December	5.06	20.41	4.03	15.32	5.03	13.77
January	2.54	18.38	3.22	16.09	3.93	15.61
February	4.35	17.71	5.60	16.10	5.86	18.00
March	6.93	18.83	8.90	20.87	9.25	24.32
April	12.40	25.50	15.00	25.76	13.76	29.90

Source: Soil and Water Conservation Research Station, Fateh Jang.

Table 3. Mean monthly rainfall and humidity during the crop growing season.

Month	2013-14		2014-15		2015-16	
	Rainfall (mm)	Humidity (%)	Rainfall (mm)	Humidity (%)	Rainfall (mm)	Humidity (%)
September	40	73.90	106	83.96	57	86.13
October	59	71.61	138	85.19	78	81.46
November	15	73.98	14	78.51	11	84.73
December	3	70.96	0	75.64	0	79.25
January	3	71.56	63	71.12	12	85.09
February	67	73.73	80	76.05	115	75.58
March	137	80.24	261	79.30	193	82.90
April	35	67.10	145	70.96	14	77.46
Total	359	-	807	-	480	-

Source: Soil and Water Conservation Research Station, Fateh Jang.

RESULTS

Moisture contents (%)

The availability of moisture is key factor that limits growth and development of crop. Data regarding soil moisture contents showed a significant ($p \leq 0.05$) increase in availability of soil moisture contents by the addition of gypsum and green manuring alone and in combination as compared to control and farmer practice. Results revealed that the maximum soil moisture contents (15.94%) at site 4 in 3rd year were recorded where combination of gypsum and green manuring applied and almost similar results were observed at all the experimental sites while the lowest moisture contents (5.00%) was recorded at site 1 in 1st year of experiment (Table 4). The results

Table 4. Integrated effect of gypsum and green manure on moisture contents (%)

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	5.90	5.00	8.10	6.50	9.00
	S2	6.50	6.00	8.60	7.50	9.70
	S3	7.10	6.30	9.20	7.60	10.10
	S4	7.80	7.20	9.90	7.70	11.10
	S5	6.10	5.70	8.30	7.00	9.40
	S6	5.50	4.70	6.70	6.40	7.70
2014/2015	S1	6.66	5.76	9.08	9.44	11.34
	S2	7.23	6.72	9.58	9.94	12.04
	S3	7.86	7.06	10.18	10.54	12.41
	S4	8.56	7.96	10.88	11.24	13.35
	S5	6.86	6.44	9.28	9.64	11.74
	S6	6.26	5.46	7.68	8.04	10.04
2015/2016	S1	7.12	6.13	10.27	10.67	13.88
	S2	7.72	7.22	11.27	11.15	14.58
	S3	8.32	7.45	11.37	11.73	14.92
	S4	9.02	8.42	11.47	12.47	15.94
	S5	7.32	6.94	10.73	10.88	14.28
	S6	6.72	5.89	10.17	9.27	12.49

Source: Soil and Water Conservation Research Station, Fateh Jang.

showed that moisture contents gradually increased (34-65%) after the application of gypsum and green manure alone and in combination. The increase in the moisture contents due to application of gypsum and green manure alone and in combination resulted in the availability of nutrients required by crop and ultimately increased crop yield. In order to maintain moisture contents for longer period, gypsum and green manure were added in soil to increase the organic matter and ultimately crop yield. These results correlated with Pawar et al. (2018) who reported that incorporation of plant litter improves the water relationship and better aeration. The higher crop yield and more photosynthetic rates were reported due to the application of gypsum in soil because it improved the soil structure and crops with deeper roots system able to absorb more water even under drought and water deficit conditions (Zhang and Norton, 2002). The increase in soil moisture is closely related to crop yield (Dutra et al., 2012).

Organic matter

The results regarding organic matter showed that soil organic matter significantly ($p \leq 0.05$) increased by the application of gypsum and green manures alone and in combination compared to farmer practice and control. Improvement in soil properties directly linked to grain yield of wheat as the increase in organic matter improved soil structure that affected the crop yield. The maximum organic matter (1.17%) was found at site 4 in 3rd year of experiment while the lowest organic matter (0.30%) was recorded at site 6 in 1st year of experiment (Table 5). The gradual increase in organic matter was recorded with the application of gypsum + green manure compared to previous years as with the increase in organic matter microbial activity increased which ultimately increased availability of nutrients that resulted in increased yield of wheat. These results are in confirmation with Pawar et al. (2018) who reported that organic matter increased with the application of crop residues and green manures.

Available phosphorous (kg ha^{-1})

The data regarding available phosphorous presented in Table 6 showed the significant ($p \leq 0.05$) increase in the available phosphorous of the soil with the application of green manure and gypsum alone and in combination. The indicated data showed that maximum available phosphorous (43.84 kg ha^{-1}) was found in gypsum + green manure at site 4 in 3rd year of experiment while the lowest available phosphorus was recorded in control at site 6 in the 1st year of experiment (Table 6). This showed that the application of green manure and combination of gypsum + green manure resulted in the

Table 5. Integrated effect of gypsum and green manure on organic matter (%).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	0.37	0.32	0.45	0.40	0.47
	S2	0.65	0.46	0.68	0.65	0.77
	S3	0.74	0.56	0.83	0.78	0.84
	S4	0.78	0.67	0.90	0.87	0.87
	S5	0.40	0.38	0.54	0.47	0.58
	S6	0.32	0.30	0.27	0.22	0.42
2014/2015	S1	0.45	0.45	0.65	0.76	0.76
	S2	0.66	0.68	0.73	0.81	0.84
	S3	0.69	0.75	0.80	0.84	0.87
	S4	0.75	0.82	0.82	0.91	0.90
	S5	0.50	0.59	0.69	0.78	0.80
	S6	0.39	0.36	0.59	0.68	0.74
2015/2016	S1	0.62	0.59	0.79	0.78	0.83
	S2	0.67	0.62	0.87	0.89	1.01
	S3	0.71	0.67	0.93	0.98	1.08
	S4	0.76	0.81	1.08	1.11	1.17
	S5	0.65	0.63	0.83	0.82	0.90
	S6	0.56	0.52	0.75	0.70	0.80

Source: Soil and Water Conservation Research Station, Fateh Jang.

Table 6. Integrated effect of gypsum and green manure on available Phosphorous (kg ha^{-1}).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	18.43	17.20	20.00	21.45	23.00
	S2	20.12	19.00	23.22	22.00	28.10
	S3	22.00	21.04	25.00	23.00	31.00
	S4	23.11	21.33	27.32	24.00	33.65
	S5	22.50	19.50	24.00	23.09	26.00
	S6	15.00	15.76	17.11	18.50	21.92
2014/2015	S1	19.88	18.65	26.54	27.99	29.54
	S2	21.57	20.45	28.54	29.76	34.64
	S3	23.45	22.49	29.54	31.54	37.54
	S4	24.56	22.78	30.54	33.86	40.19
	S5	23.95	20.95	29.63	30.54	32.54
	S6	16.45	17.21	23.65	25.04	28.46
2015/2016	S1	22.33	21.10	30.19	31.64	33.19
	S2	24.02	22.90	32.19	33.41	38.29
	S3	25.90	24.94	33.19	35.19	41.19
	S4	27.01	25.23	34.19	37.51	43.84
	S5	26.40	23.40	34.19	33.28	36.19
	S6	18.90	19.66	27.30	28.69	32.11

Source: Soil and Water Conservation Research Station, Fateh Jang.

increase of available phosphorous that may be due to the increased activity of microbes acidifying the soil pH. The

Table 7. Integrated effect of gypsum and green manuring on Extractable Potassium (kg ha^{-1}).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	201	189	218	219	228
	S2	212	195	229	232	265
	S3	217	201	235	245	279
	S4	218	203	248	262	287
	S5	206	193	223	226	240
	S6	179	164	215	219	223
2014/2015	S1	236	214	272	281	306
	S2	247	223	283	294	343
	S3	252	228	289	307	357
	S4	253	234	302	324	365
	S5	241	218	277	288	318
	S6	214	192	269	281	301
2015/2016	S1	260	231	299	319	351
	S2	271	241	310	332	388
	S3	276	248	316	345	402
	S4	277	253	329	362	410
	S5	265	236	304	326	363
	S6	238	208	296	319	346

Source: Soil and Water Conservation Research Station, Fateh Jang.

continuous application of green manures in the soil resulted in increased crop yield which confirmed the benefit of gypsum + green manure. The results are in line with Yaspal et al. (1993) who reported the influence of organic manures with the application of crop residues in soil build-up available phosphorous through the activity of cations like Ca^{2+} and Mg^{2+} responsible for fixation of phosphorous in soil.

Extractable potassium (kg ha^{-1})

The extractable potassium significantly ($p \leq 0.05$) increased with the application of green manure and gypsum+green manure alone and in combination. The results indicated that maximum extractable potassium (410 kg ha^{-1}) found in gypsum+green manure at site 4 in 3rd year of experimentation while the lowest extractable potassium (164 kg ha^{-1}) was recorded at site 6 in farmer practice in 1st year (Table 7). The availability of potassium in soil improves the quality and yield of crop. The indicated results showed that the application of green manure and combination of gypsum + green manure increased the availability of potassium and thus crop yield gradually. The results are in confirmation with other scientists. Yadav and Chhipa (2007) reported that application of crop residue and green manure significantly increased the extractable potassium over control.

Electrical conductivity (Ece)

The data presented in Table 8 regarding Ece ($p \leq 0.05$) showed that with the application of green manure and gypsum + green manure Ece decreased gradually. The maximum Ece (1.59 dSm^{-1}) was recorded at site 1 in 1st year of experiment while the lowest Ece (0.11 dSm^{-1}) at site 4 in 3rd year of experiment (Table 8). This indicated that with the application of green manure and combination of gypsum + green manure help in reducing soil salinity and resulted in increasing crop yield. These results are in correlation with Aragues et al. (2014) who reported that the application of organic straw mulch on soil surface reduces evaporation that resulted in reducing soil sodicity in the root zone. The same results reported by Pawar et al. (2018) who stated that Ece of soil decreased with an increase in organic matter in soil.

pH

The data regarding pH ($p \leq 0.05$) presented in Table 9 showed that pH slightly vary due to gypsum and combination gypsum + green manure. The results showed that maximum soil pH (8.1) was obtained at site4 in the 1st year of experiment in control while the lowest soil pH (7.2) close to neutral was obtained at site 4 in the 3rd year of experiment (Table 9). This showed that the

Table 8. Integrated effect of gypsum and green manure on Ece (dSm^{-1}).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	1.59	1.5	1.02	0.84	0.44
	S2	0.48	0.69	0.42	0.65	0.39
	S3	0.63	0.59	0.58	0.41	0.39
	S4	1.07	1.28	0.52	0.29	0.32
	S5	0.76	0.88	0.47	0.43	0.41
	S6	1.39	1.2	1.37	1.15	0.85
2014/2015	S1	1.46	1.41	0.78	0.56	0.27
	S2	0.35	0.60	0.38	0.37	0.24
	S3	0.50	0.50	0.34	0.13	0.22
	S4	0.94	1.19	0.28	0.22	0.15
	S5	0.63	0.79	0.23	0.15	0.24
	S6	1.26	1.11	1.13	0.87	0.68
2015/2016	S1	1.38	1.39	0.63	0.50	0.19
	S2	0.27	0.58	0.29	0.31	0.15
	S3	0.42	0.48	0.19	0.12	0.12
	S4	0.86	1.17	0.13	0.16	0.11
	S5	0.55	0.77	0.21	0.09	0.21
	S6	1.18	1.09	0.98	0.81	0.57

Source: Soil and Water Conservation Research Station, Fateh Jang.

increase of plant litter in soil organic matter resulted in increase of acidifying the soil pH. These results confirmed by Pawar et al. (2018) who reported that soil pH markedly decreased by the application of green manures in soil due to enhancing microbial activities and improving soil chemical and physical properties. Improvement in microbial activities observed by the application of green manures and crop residues due to the production of organic acids in soil as Ca^{+2} replaced with Na^{+} resulted in decreased soil ESP and pH (Rao and Pathak, 1996).

Grain yield of wheat (kg ha^{-1})

Data pertaining to grain yield revealed a significant ($p \leq 0.05$) increase in grain yield by the application of gypsum and green manuring alone and in combination compared with FP and control. The data recorded showed that maximum grain yield (3533 kg ha^{-1}) attained at site 4 in the 3rd year of experimentation while minimum grain yield (2000 kg ha^{-1}) obtained at site 6 in the 1st year of experiment (Table 10). The results indicated that the increase in organic matter and moisture contents in the increased soil microbial activities which resulted to an optimum supply of nutrients to crop and ultimately crop yield increased. The improvement in the grain yield of wheat ranges from 38 to 76% due to the application of combination of gypsum + green manures. These results suggested that incorporation of green manures and gypsum significantly increased the grain yield of wheat. The green manuring technique (*Sesbania rostrata*) saves up to 50 to 60% N and significantly improved soil physico-chemical properties that resulted in improved yield of the second crop sown after the green manuring (Mann et al., 2000).

Straw yield of wheat (kg ha^{-1})

Data regarding straw yield showed a significant ($p \leq 0.05$) increase in straw yield by the application of gypsum and green manuring alone and in combination compared with FP and control. The indicated data showed that maximum straw yield (4002 kg ha^{-1}) was attained at site 4 in the 3rd year of experimentation while minimum straw yield (2450 kg ha^{-1}) was obtained at site 6 in the 2nd year of experiment at farmer practice (Table 11). The results indicated that the same trend was observed in the straw yield as in grain yield noted. The improvement in the straw yield of wheat ranged from 20 to 41% due to the application of combination of gypsum + green manures. These results suggested that incorporation of green manures and gypsum significantly increased the grain yield of wheat. The rice straw yield increased significantly with the application of green manures (Zahir et al., 2011).

Table 9. Integrated effect of gypsum and green manure on pH.

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	7.7	7.8	7.7	7.6	7.7
	S2	7.7	7.7	7.7	7.6	7.7
	S3	7.7	7.9	7.9	7.8	7.9
	S4	8.1	7.8	7.8	7.8	7.9
	S5	7.6	7.6	7.6	7.5	7.7
	S6	7.6	7.8	7.6	7.4	7.6
2014/2015	S1	7.5	7.8	7.6	7.6	7.8
	S2	7.5	7.7	7.7	7.5	7.7
	S3	7.8	7.7	7.8	7.7	7.8
	S4	7.8	7.7	7.7	7.6	7.5
	S5	7.5	7.5	7.6	7.4	7.3
	S6	7.9	7.7	7.5	7.9	7.8
2015/2016	S1	7.3	7.4	7.4	7.5	7.6
	S2	7.3	7.3	7.5	7.4	7.7
	S3	7.3	7.4	7.5	7.5	7.6
	S4	7.4	7.5	7.6	7.4	7.2
	S5	7.1	7.5	7.4	7.6	7.6
	S6	7.6	7.3	7.5	7.3	7.5

Source: Soil and Water Conservation Research Station, Fateh Jang.

Table 10. Integrated effect of gypsum and green manure on Grain Yield (kg ha^{-1}).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	2211	2020	2475	2417	2659
	S2	2223	2118	2515	2436	2778
	S3	2311	2290	2646	2491	2807
	S4	2370	2218	2797	2582	2934
	S5	2219	2123	2509	2423	2771
	S6	2181	2000	2366	2387	2590
Mean		2252	2129	2551	2456	2757
2014/2015	S1	2190	2035	2507	2421	2625
	S2	2287	2080	2518	2494	2690
	S3	2290	2165	2703	2456	2809
	S4	2292	2190	2713	2517	2880
	S5	2305	2256	2445	2372	2490
	S6	2188	2148	2340	2257	2370
Mean		2259	2146	2538	2419	2644
2015/2016	S1	2800	2085	3266	2995	3404
	S2	2262	2733	3301	3018	3400
	S3	2808	2705	3204	2992	3307
	S4	3169	2633	3433	3448	3533
	S5	2659	2601	3007	2789	3504
	S6	2270	2097	2635	2536	2781
Mean		2661	2476	3141	2963	3322

Source: Soil and Water Conservation Research Station, Fateh Jang.

Table 11. Integrated effect of gypsum and green manure on Straw Yield (kg ha^{-1}).

Season	Location	Control	FP	Gypsum	Green Manure	Gypsum+Green Manure
2013/2014	S1	2640	2485	2957	2871	3075
	S2	2737	2530	2968	2944	3140
	S3	2740	2615	3153	2906	3259
	S4	2742	2635	3163	2967	3330
	S5	2755	2706	2895	2822	2940
	S6	2638	2598	2790	2707	2820
Mean		2709	2596	2988	2870	3094
2014/2015	S1	2661	2470	2867	2925	3109
	S2	2673	2568	2886	2965	3228
	S3	2761	2740	2941	3096	3257
	S4	2820	2668	3032	3247	3384
	S5	2669	2573	2873	2959	3221
	S6	2631	2450	2837	2816	3040
Mean		2703	2578	2906	3001	3207
2015/2016	S1	3269	2554	3464	3735	3873
	S2	2731	3207	3487	3770	3869
	S3	3277	3174	3461	3673	3776
	S4	3638	3106	3917	3905	4002
	S5	3128	3070	3258	3476	3973
	S6	2739	2566	3005	3104	3250
Mean		3130	2945	3432	3610	3791

Source: Soil and Water Conservation Research Station, Fateh Jang.

DISCUSSION

The results of this study showed that the maximum grain and straw yield was recorded where gypsum and guar were applied in combination. These results were similar with Ramzan (2001) who observed that use of gypsum with FYM was significantly better in improving soil physical and chemical properties and crop yield, gypsum alone was ranked second then guar which attributes the maximum benefit could be due to enhanced soil moisture retention and addition of organic matter. Since, gypsum improves hydraulic conductivity of soil which leads to better soil structure and physical conditions (Naseem, 2006). Gypsum decreased runoff and improved soil aggregate stability (Peterson et al., 2002; Yu et al., 2003), while the guar green manure positively affects the organic matter and nutrients availability in soil and improved soil structure (Shah et al., 2011) and the use of green manure influences soil physical properties to maintain functional capacity of soil for crop growth by decreasing bulk density and increasing total porosity by organic matter deposition (Lampurlanes and Cantero, 2003). The effect of these additives was directly proportional to the rainfall but the gypsum seems to produce better economic results in lower rainfall year results similar with Farina et al. (2000). The minimum yield in FP showed that farmers of the study area are not applying the appropriate fertilizer inputs which may be the bottom line of lower wheat yields in this part of the country. In control since the recommended fertilizer inputs were applied, the potential yield targets are yet to be obtained. Green manure and gypsum reserved more moisture and nutrients resulted in higher crop yield. As far as the effect of green manuring and gypsum on soil moisture contents is concerned a similar trend was noticed like grain and straw yield since the combination of gypsum with organic amendments helps in preventing the soil compaction and promoting water infiltration rates into soils and also the hydraulic conductivity of the soil which ultimately enhance the water use efficiency. These results are also in line with Sultani et al. (2004) who observed that the incorporation of peas and green manure crop and residues, after harvesting grains significantly increased wheat grain yield. The organic matter, available phosphorous, and extractable potassium increased with the application of gypsum + green manures gradually compared to control and farmers practice in subsequent years at different sites and electrical conductivity. The slightly decreased pH in soil resulted in increased activity of microbes with the benefit of enhanced available

nutrients and crop yield. Shah et al. (2002) also reported that addition of organic matter in soil promotes microbial activities and encourage the immobilization of nutrients particularly N and P.

CONCLUSION AND RECOMMENDATIONS

One of the challenges facing Pakistan today is the production of adequate food to feed the rapidly growing population. Bringing more agricultural land into cultivation is not possible in the densely populated areas. Increased agricultural productivity requires higher yields per unit land area, which increases the demand of the soil to provide adequate nutrients. Improving soil fertility is one of the major factors to develop soil productivity. However, most agricultural soils of the tropics, in which Pakistan is not an exception, are deficient with the required nutrients. Application of gypsum and green manuring has improved the wheat grain and straw yield significantly since the soil organic matter level and soil fertility may be improved by green manure (sesbania, guar, etc.) and gypsum application once in three years. They also ensured the sufficient moisture supply for rainfed wheat production. Farmer of the area should apply the appropriate rates of fertilizer (NPK at 120: 80: 60 kg ha^{-1}) inputs along with these practices for maximum crop production in these areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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