Comparative effects of organic and inorganic fertilizers on soil organic carbon and wheat productivity under arid region

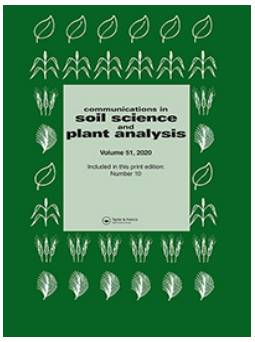
Article *in* Communications in Soil Science and Plant Analysis · April 2020

Hafiz Mohkum Hammad
Muhammad Nawaz Shareef University of Agriculture
151 PUBLICATIONS 7,048 CITATIONS

Abdul Khaliq
University of Agriculture Faisalabad
215 PUBLICATIONS 9,827 CITATIONS

Farhat Abbas
University of Prince Edward Island
184 PUBLICATIONS 10,335 CITATIONS

F. Sh
Abdul Wali Khan University Mardan
908 PUBLICATIONS 43,314 CITATIONS



Communications in Soil Science and Plant Analysis

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

Comparative Effects of Organic and Inorganic Fertilizers on Soil Organic Carbon and Wheat Productivity under Arid Region

Hafiz Mohkum Hammad , Abdul Khaliq , Farhat Abbas , Wajid Farhad , Shah Fahad , Muhammad Aslam , Ghulam Mustafa Shah , Wajid Nasim , Muhammad Mubeen & Hafiz Faiq Bakhat

To cite this article: Hafiz Mohkum Hammad , Abdul Khaliq , Farhat Abbas , Wajid Farhad , Shah Fahad , Muhammad Aslam , Ghulam Mustafa Shah , Wajid Nasim , Muhammad Mubeen & Hafiz Faiq Bakhat (2020) Comparative Effects of Organic and Inorganic Fertilizers on Soil Organic Carbon and Wheat Productivity under Arid Region, Communications in Soil Science and Plant Analysis, 51:10, 1406-1422, DOI: 10.1080/00103624.2020.1763385

To link to this article: https://doi.org/10.1080/00103624.2020.1763385

Published online: 22 Jun 2020.

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2020, VOL. 51, NO. 10, 1406–1422
https://doi.org/10.1080/00103624.2020.1763385

Taylor & Francis
Taylor & Francis Group

Comparative Effects of Organic and Inorganic Fertilizers on Soil Organic Carbon and Wheat Productivity under Arid Region

Hafiz Mohkum Hammad[a], Abdul Khaliq[b], Farhat Abbas[c], Wajid Farhad[d], Shah Fahad[e], Muhammad Aslam[f], Ghulam Mustafa Shah[a], Wajid Nasim[g], Muhammad Mubeen[a], and Hafiz Faiq Bakhat[a]

[a]Department of Environmental Sciences, COMSATS University Islamabad, Vehari, Pakistan; [b]Department of Agronomy, University of Agriculture Faisalabad, Faisalabad, Pakistan; [c]Faculty of Sustainable Design Engineering, University of Prince Edward Island, Charlottetown, Canada; [d]Department of Agronomy, University College of Dera Murad Jamali Naseerabad, Sub-Campus Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Pakistan; [e]Department of Agronomy and Stress Physiology, The University of Swabi, Pakistan; [f]Layyah Campus, Government College University Faisalabad–38000, Pakistan; [g]Department of Agronomy, University College of Agriculture & Environmental Sciences, Islamia University of Bahawalpur, Bahawalpur, Pakistan

ABSTRACT
Organic amendments in the soil perform better than synthetic fertilizers in regards to soil fertility and sustainable crop productivity. Experiments were conducted to compare the effects of organic and synthetic fertilizers on soil fertility and wheat (*Triticum aestivum* L.) productivity. Soil fertility and protein contents of wheat grains (13.2% and 13.3% during 2005–06 and 2006–07, respectively) were improved by organic amendments. However, synthetic fertilizer (at the rate of 150, 100, and 60 kg ha^{-1} N, P_2O_5, and K_2O, respectively) applications resulted in the maximum grain yield (4.05 and 4.46 t ha^{-1} during 2005–06 and 2006–07, respectively). The observed and simulated soil organic carbon (SOC) reasonably agreed during RothC model validation (R^2 = 0.99). Economic analysis showed the maximum net profit and relative increase in income ($729 US ha^{-1} and 309%, respectively) from inorganic treatment. Application of synthetic fertilizers increased grain yield and farm profit while organic manure enhanced grain quality. The RothC model had potential for determining the SOC in organic farming under arid environment.

ARTICLE HISTORY
Received 19 April 2019
Accepted 24 April 2020

KEYWORDS
Economic analysis; soil organic carbon; soil fertility; plant nutrition; rothamsted carbon turnover model

Introduction

Wheat is the most important cereal crop worldwide and meets about two-third of the protein-energy needs of the world population (Cakmak 2009). It is grown organically as well as inorganically. The demand of organically grown wheat is increasing in the world due to its high nutritional value (Hai et al. 2010; White and Broadley 2009) since organically produced foods are usually considered to have a better taste, better balanced vitamins and minerals than those conventionally grown (Fuertes-Mendizabal et al. 2010). Protein contents in wheat grains grown by organic fertilizers are higher than in those grown by chemical fertilizers (Bahrman et al. 2004; Shivay, Prasad, and Rahal 2010).

Organic farming has received attention during the last two decades due to its high-quality products (Farhad et al. 2018; Rodrigues et al. 2006), high price, and low market availability of inorganic fertilizers, especially in developing countries like Pakistan. Certified organic grains have higher values than inorganic products (Delate and Camberdella 2004). Similarly, organic cropping system has higher nutrient use efficiency than conventional system (Hildermann et al. 2010). In contrast to

CONTACT Hafiz Mohkum Hammad hafizmohkum@gmail.com Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus-61100, Multan Road Pakistan

mineral fertilizers, the organic manures add organic matter to soil improving its fertility, microbial activity, and water infiltration moisture holding capacity (Abbas et al. 2012; Meagy et al. 2016).

In most countries, agricultural systems are often incapable of supplying adequate micronutrients to efficiently attain the requirements of their populations (Welch 2002). It is partially due to increasing grain yield demand from agricultural systems over the past 50 years. Therefore, to fill the gap between demand and supply, cropping intensity and fertilizer application have increased resulting in reduction of soil fertility (Khoshgoftarmanesh et al. 2010). Moreover, excessive chemical fertilizers applications in an agricultural system may negatively affect surface water, groundwater, and atmosphere through leaching, runoff, and volatilization of nitrogen (N), respectively (Galloway et al. 2008).

Organic manures are keys to enhance soil quality and crop yield since they perform numerous functions in agroecosystems (Jones et al. 2007). Their inputs are in general beneficial for the overall health of the agroenvironment (Jedidi et al. 2004). Organic sources of nutrients include farmyard manure (FM) generated from sheep, poultry litter (PL), green manures, sewage sludge, and press mud (Farhad et al. 2011; Iqbal et al. 2014). Municipal solid-waste compost, FM and chemical fertilizers have been tested previously for their beneficial role for wheat growth and soil bacterial characteristics under arid climatic condition (Azeez and Van Averbeke 2010; Cherifa et al. 2009; Murtaza et al. 2019). Integrated use of PM and urea was reported to be favorable for crop production (Ojo et al. 2016; Sharma et al. 2002). Integration of organic manures and synthetic fertilizers supply essential nutrients to the crops leading to increased crop yields and reduced environmental threats (Yadvinder-Singh et al. 2009). The use of organic fertilizers and residues management enhances microbiological properties of soil (Naeem, Khan, and Ahmad 2009). However, in arid environment, the soil microbiological activities are generally low due to high temperature and less use of organic manures. Resultantly, less than 1% organic matter is present in arid region of Pakistan (Azad and Yousaf 1982).

Soil organic carbon enhances soil quality by improving the input use efficiency results in optimum sustainable crop productivity and environmental safety (Kushwah et al. 2016: Lal 2013). Researchers are using crop model as a tool for studying crop response to nutrients (Ahmed, Ijaz, and Ahmad 2018). Similarly, emission of soil organic carbon and CO_2 from arable soils can be predicted by using several C turnover models including carbon-nitrogen dynamics (CANDY) (Franko 1996), Dynamically Architected Instruction Set from Yorktown (DAISY) (Hansen et al. 1991) and among these models the RothC-23.6 model has a user-friendly interface with simpler structure, and can be run with easily available input data. The model can be used in all region of the world with calibration of the model (Abbas and Fares 2009). Worldwide the RothC model has been used in contrast with the other C models (Abbas et al. 2012). Similarly, Wu et al. (1998) tested the model in the soils of Northeast Thailand and they concluded that it simulated SOC well under these experimental situations. Moreover, scientists also used this model for simulation of SOC dynamics in the tropics environment; Shirato et al. (2005) simulated RothC model for arable soils in Japan while simulation and validation of the model on irrigated soils in China were done by Guo et al. (2007). No such in-depth experiment has been conducted on testing of RothC model under arid environments.

The extensive literature review did not reveal any in-depth study on the economic evaluation and agronomic performance of integrated use of organic manures, inorganic fertilizers, and their combinations on soil quality, wheat growth, and yield under arid climate of Pakistan for sustainable agriculture. Similarly, no study was found on calibration and use of RothC model on Pakistani soils and environmental conditions. Therefore, this study was carried out to fill this knowledge gap. The objective of this study was: (i) to evaluate the effects different organic and inorganic amendments on soil, wheat growth, and productivity, (ii) to compare the economic feasibility of organic versus inorganic sources, and (iii) to simulate soil organic-carbon-based soil fertility for its tilth to cultivate wheat by using RothC model under arid environmental conditions.

Materials and methods

Experimental setup and treatments

The experimental location was arid in nature having < 250 mm rainfall per annum with the maximum temperature of 48 °C in a summer and the maximum winter temperature of 19 °C, (Abbas 2013; Abbas et al. 2014). The weather detail of experimental location is given in Figure 1. A field experiment of wheat was conducted during two consecutive growing seasons from 2005 to 2007 at Adaptive Research Farm Karor, Pakistan. For this purpose, experimental plots each measured 1.5 m × 5 m were prepared and seeded with wheat cultivar Bukhar-2002 at a seed rate of 120 kg ha^{-1} in rows with 20 cm apart from each other. Crop was sown on November 16, 2005 and November 16, 2006. In the arid region of Pakistan, farmer added organic manures in bulk density to overcome the nutrient and water stress therefore, for the determining best management practices for the farmer of the rejoin. The treatments were: unfertilized control (T_1), recommended N, P_2O_5, and K_2O at the rate of 150, 100, and 60 kg ha^{-1}, respectively (T_2), FM + PL (T_3), FM + poultry manure (PM) (T_4), FM + Sewage Sludge (T_5), PL + PM (T_6), and PL + SS (T_7). Each type of organic manure was applied at the rate of 10 t ha^{-1} during both

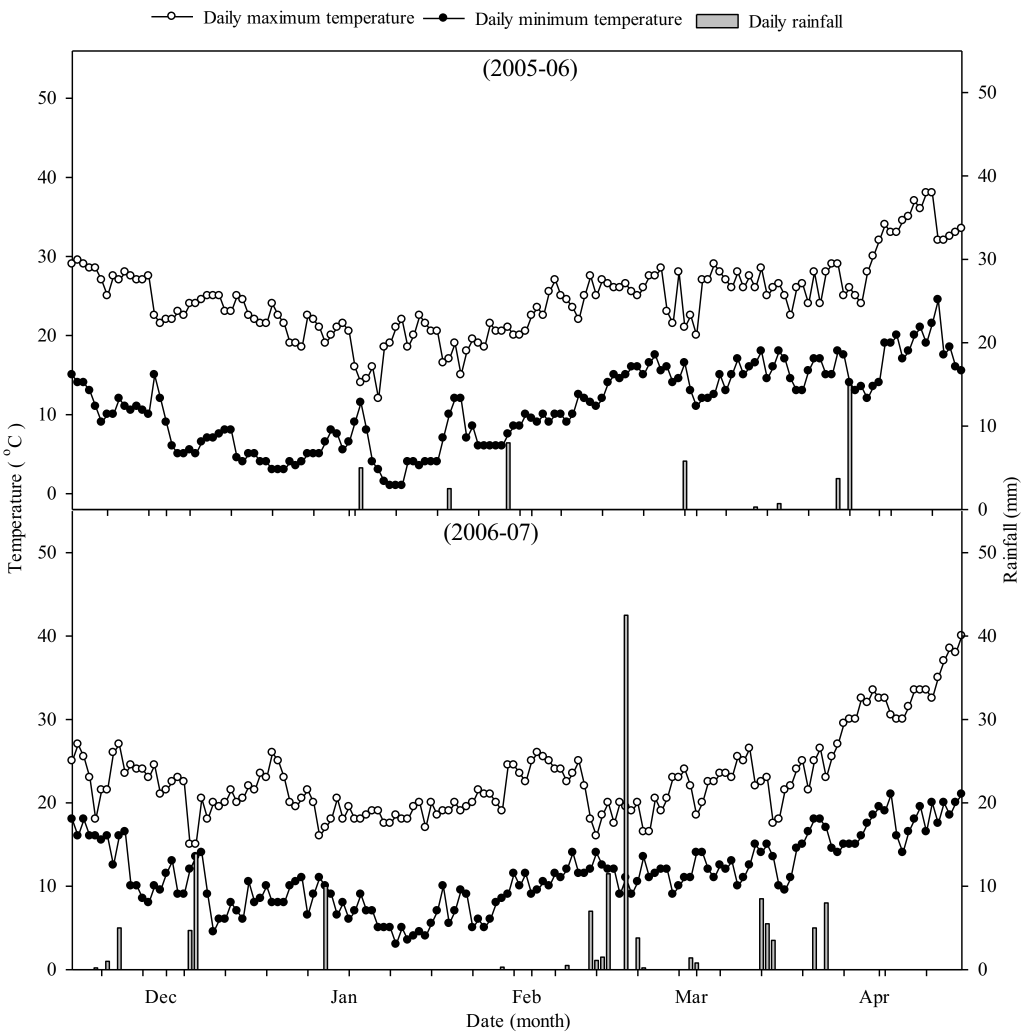


Figure 1. Daily meteorological data of experimental site during the growing season.

growing season. The mentioned rates of organic and inorganic fertilizer were based on the farmers' fertilizer management practices in the study area. All the treatments were arranged in a randomized complete block design with four replicates. In treatment T_2 recommended dose of P_2O_5, K_2O, and one-third N was applied at the time of sowing; the remaining N dose was applied in two equal splits at tillering and anthesis stages. The organic manures were incorporated in the soil a week before sowing. Six irrigations were applied to the crop during each growing seasons.

Soil sampling and analysis

The properties of experimental soil including field capacity, permanent wilting point, soil pH, and EC were given in Table 1. Soil of the experimental site was sandy loam in nature having 0.48% soil organic manure. Soil samples were collected from each plot at depth of 0–30 cm three times during the two growing seasons: prior to growing season I (S-I), before growing season II (S-II), and at the end of growing season II (S-III). Four soil cores were collected with the help of an auger from each plot and then mixed to a composite sample. The soil samples were secured in cold room prior to analyzes. Organic matter of the soil samples was determined by dichromate oxidation method (Walkley and Black, 1943). Electrical conductivity (EC) and soil pH were determined in a 1:5 soil/water extract. Plant available-N content was determined by the method defined by Hesse (1971). The soil available-P determined using the method as described by Olsen (1954). Available soil potassium (K) was determined by method described by Junsomboon and Jakmunee (2011). Soil bulk density was determined by core method, using the process of the Spanish Ministry of Agriculture (APA 1986).

Values of SOC (%) were converted to t C ha^{-1}, as the amount of SOC found in a soil layer of the depth, d (cm) and bulk density, ρ_b (g cm^{-3}), using the following relationship (Baldock 2008).

$$SOC\ (t\ C\ ha^{-1}) = d \times \rho_b \times\ SOC\ (\%) \tag{1}$$

Plant sampling and calculations

From each experimental plot, one-third of the total area was used for growth sampling and the remaining for the final harvest/yield data. To see the availability of soil nutrients to plant the plant growth was periodically measured five times during each growing season by harvesting 0.5-m-long strip to the ground level at every 25 day after planting. After harvesting, fresh biomass of the plants was measured and the representative samples were oven dried at 70 °C up to constant weight to estimate dry matter. Area of fresh leaves of the sampled plants was measured, by multiplying their measured length and width with a correction factor, k, which is 0.50 for wheat (Thorne et al. 1988). Similarly, leaf area index (LAI) was calculated by using the following formula given by Watson (1952).

Table 1. Soil physicochemical analysis of experimental site.

Characteristics of soil	Values
Sand (%)	71
Silt (%)	13
Clay (%)	16
Texture	Sandy clay loam
Field capacity (%)	20.52
Wilting point (%)	6.41
Soil pH	7.56
EC (dS m^{-1})	1.53
Soil organic matter (%)	0.48

$$\mathrm{LAI} = \frac{\mathrm{Leaf\ area}}{\mathrm{Ground\ area}} \tag{2}$$

At maturity, from each experimental plot, numbers of productive tillers were counted from randomly selected three sites. Thereafter, crop from an area of 0.90 m × 3 m was harvested from each plot. Harvested biomass was air dried for few days to record biological yield. Thereafter, 1000 grains were counted by Seed Counter (Model-108 Count-A-Pak) and weighed. Harvest index (HI) was determined using the following equation as suggested by Kemanian et al. (2007).

$$\mathrm{HI} = \left(\frac{\mathrm{Grain\ yield}}{\mathrm{Biological\ yield}}\right) \times 100 \tag{3}$$

Nitrogen contents were determined using the micro-Kjeldhal method (Helrich 1990). Subsequently, plant N uptake was determined by multiplying the plant total dry matter (TDM) with its N concentration (Hammad et al. 2016).

Crude protein contents were measured with the following formula:

$$\mathrm{Crude\ protein} = (\mathrm{Nitrogen\ contents}) \times 6.25 \tag{4}$$

Input preparation, calibrating, and validation of RothC model

RothC model input files and calibration need inert organic matter measured from the long-term soil organic carbon values of the study site. It also needs land management, weather and scenario files as input data. Therefore, the model was validated by independent data of the experiment. The input data for the weather file included monthly mean air temperature (°C), rainfall (mm); and they were taken from Pakistan Metrological Department. The model was calibrated by using the field data of 2006–07 and the initial soil carbon and IOM from equilibrium run.

The other input data for the model included soil organic matter (Table 2) in the land management file, that were calculated based on amounts of organic matter amendments applied in field. Thus, RothC model was run at equilibrium mode (for 10,000 years) by iteratively fitting plant carbon inputs in the land management file (Shirato et al. 2005). Increments in plant carbon input were used until the simulated soil organic carbon closely matched the observed soil organic carbon. The RMSE of simulated data was calculated as follows (van Wesemael et al. 2004):

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} (\mathrm{P_i} - \mathrm{O_i})^{2}/n} \tag{5}$$

Economic analysis

For economic analysis, cost of variable inputs and income from wheat yields were taken into consideration. The following formulae (CIMMYT 1988) were used for calculation of value cost ratio (VCR) and relative increase in income (RII).

Table 2. Major chemical components (NPK) in the organic manures used during the study.

Source	Nitrogen (%)	Nitrogen applied (kg ha^{-1})	Phosphorus (%)	Phosphorus applied (kg ha^{-1})	Potassium (%)	Potassium applied (kg ha^{-1})
Farm yard manure	0.86	43	0.82	90	0.62	31
Sewage sludge	3.53	177	2.04	102	0.36	18
Press mud	0.75	38	1.25	63	0.74	37
Poultry litter	2.03	102	2.07	104	1.85	93

$$\text{VCR} = \left(\frac{\text{Value of increased yield obtained}}{\text{Cost of fertilizer or organic matter}}\right) \quad (6)$$

$$\text{RII} = \left(\frac{\text{Net income}}{\text{Income at control}}\right) \times 100 \quad (7)$$

Statistical analysis

The effects of various sources of nutrients on the studied variables were analyzed by constructing analysis of variance using SAS, 2004. The difference in treatment means was considered significant at $P < 0.05$. Similarly, correlations among the studied variables were drawn by using sigma plot.

Results

Soil physicochemical properties

The results revealed that the addition of the organic manures significantly increased ($P < 0.05$) soil NPK and organic matter content as compared to the unfertilized control and inorganic fertilizers (Figure 2). In our study, soil organic matter and NPK content significantly decreased with the season in the control and traditionally inorganic treatments. Contrary, at the end of each growing seasons the treatments which were comprised of organic farming significantly increased soil organic matter percent and plant macronutrients (NPK) in the soil (Figure 2). EC of the soil samples collected from organic treatments increased at the end of each growing season. Soil bulk density decreased with

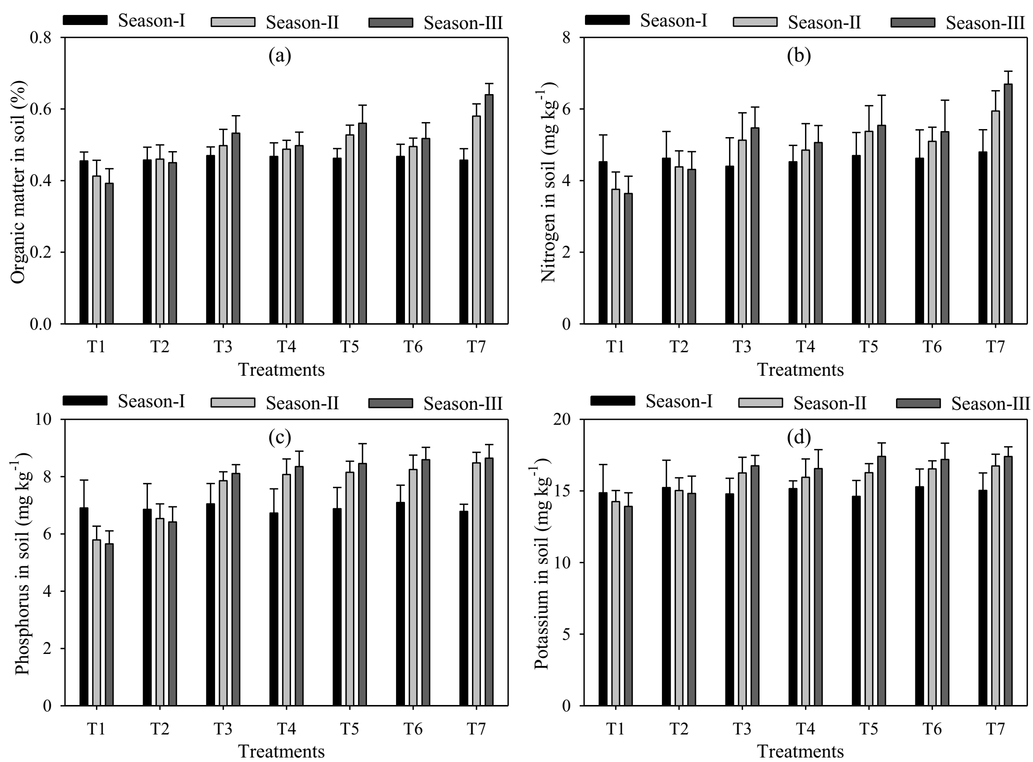


Figure 2. Effect of organic matter application on soil physicochemical properties including organic matter percent (a), nitrogen (b), phosphorus (c), and potassium (d) during growing seasons.

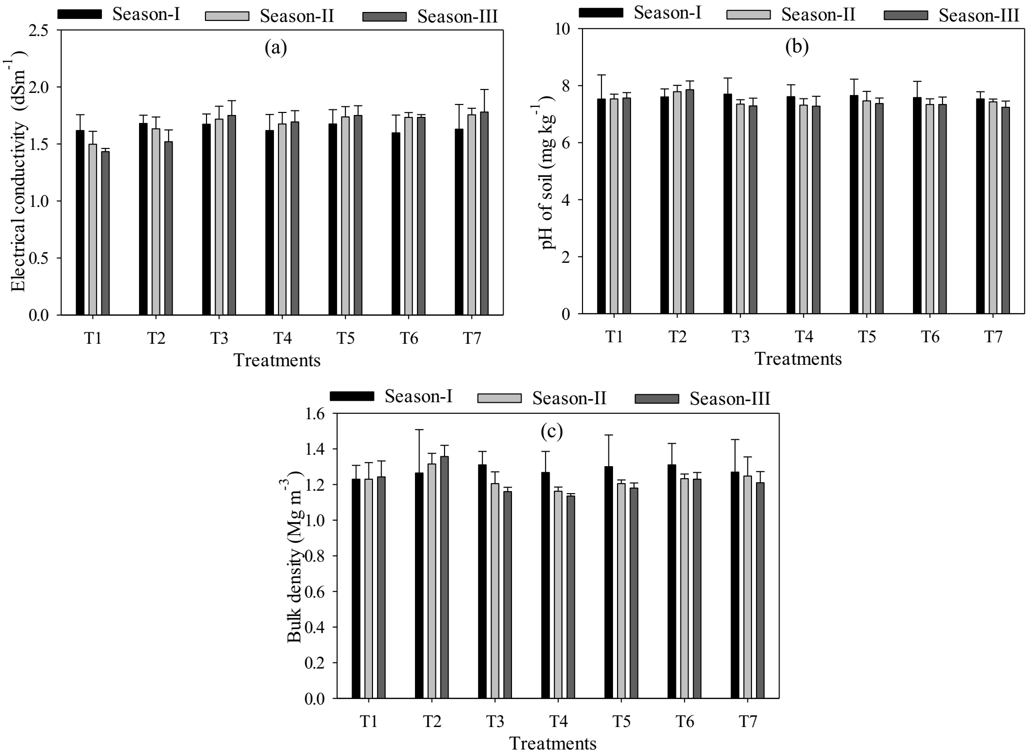


Figure 3. Effect of organic matter application on soil electrical conductivity (a), pH, (b), and bulk density (c) during growing seasons.

organic matter application. Our results showed that organic matter application significantly decreased soil pH while an increase in soil pH was observed in control and inorganic treatments (Figure 3b). The application of different organic manure increased soil carbon but showed a little change in soil chemical properties as compared to plant growth and yields.

Crop growth

Various sources of organic matter showed significant effect on the LAI during 2005–06 and 2006–07. The LAI of crop gradually increased days after sowing (DAS) in all treatments. The maximum LAI of crop was recorded at 75 DAS in all treatments (Figure 4). Inorganic fertilizers treatment significantly resulted in the maximum LAI this might be because of quick availability of the nutrients (NPK) in the treatment. Among combination of organic manures, the maximum LAI was achieved in treatment T_7 during both years. Table 2 showed maximum NPK present in SS and PL that is why, the maximum growth was achieved by the combination of both. In all fractions, minimum LAI was observed in control treatment in both years. Application of different source of organic manure was significantly affected the TDM production at each crop growth stages (Figure 5). The maximum TDM production at all stages was achieved where the recommended NPK were applied through in organic source. Among the organic sources, the maximum TDM was recorded in plots where T_7 was used in both years. In both growing season, minimum TDM during whole growing season was recorded in control treatment.

Grain yield and the yield components

The results indicated that during both years productive tillers (m^{-2}) were significantly affected by various sources of nutrients (Table 3). The application of recommended NPK (T_2) produced the

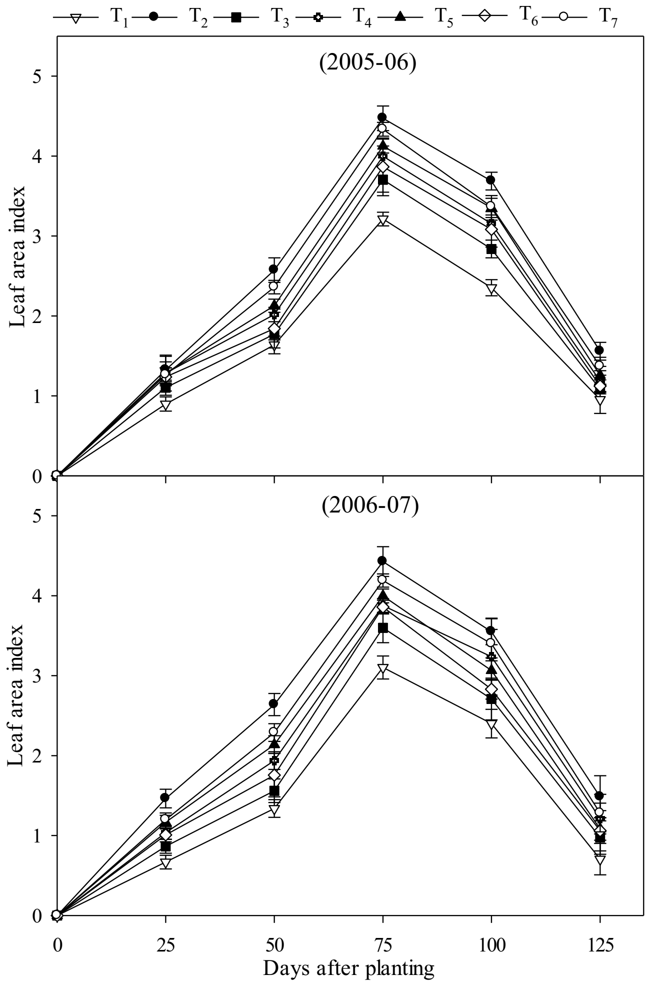


Figure 4. Change in leaf area index by application of various sources of nutrients during 2005–06 and 2006–07.

maximum number of productive tillers (286 and 294 during 2005–06 and 2006–07, respectively) per unit area. Application of different source organic manures also significantly influenced the number of productive tillers (Table 3). Among the organic manures, the maximum productive tillers (253 and 269 m^{-2} during 2005–06 and 2006–07, respectively) were recorded where the crop was subjected to FM + SS each at the rate of 10 t ha^{-1} (T_5) and both year this treatment followed to the treatments T_7 and T_4, respectively. The minimum number of productive tillers (192 and 200 m^{-2} during 2005–06 and 2006–07, respectively) were obtained from the control treatment (T_1) where nutrient was not applied.

Thousand grain weights play significant role in grain yield. In the study, sources of nutrients significantly affected 1000-grain weight (Table 3). The results revealed that the maximum 1000-grain weight (39.1 and 48.8 g during 2005–06 and 2006–07, respectively) was attained by the application of treatment T_7 and both year this treatment followed by the recommended NPK (T_2). The PL and SS restrained maximum percentage of P_2O_5 and K_2O (Table 2). Moreover, high 1000-grain weight during second season might be due to high soil fertility during the growing season. The control treatment was resulted the minimum 1000-grain weight (24.8 g) during 2005–06; however, this treatment was statistically at par with the treatments T_6 and T_3.

The crop attained maximum grain yield (4.05 and 4.46 t ha^{-1} during 2005–06 and 2006–07, respectively) by the application of recommended rate of NPK (T_2) and both years this treatment

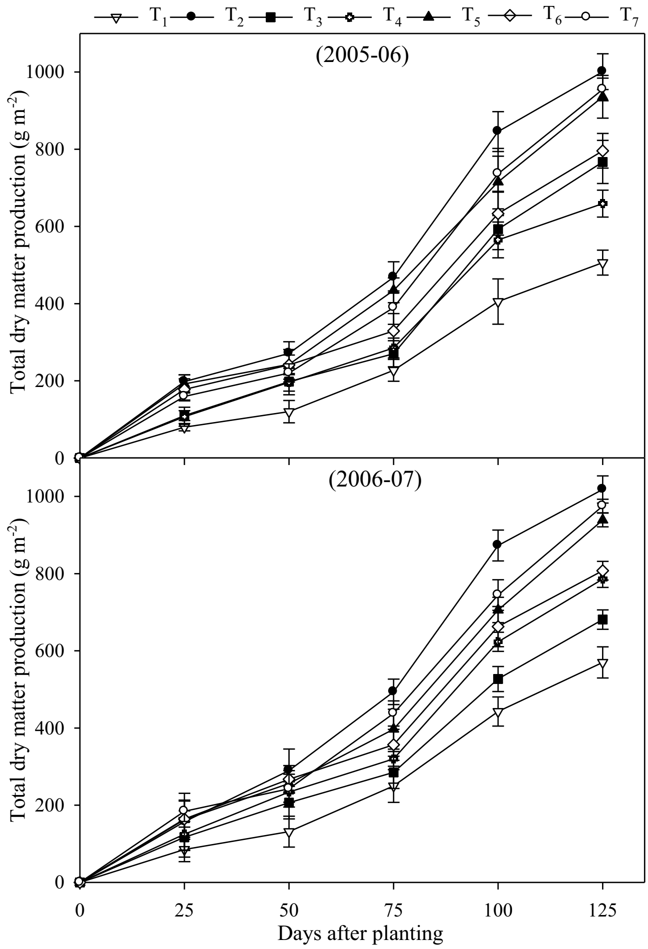


Figure 5. Change in dry matter production by application of various sources of nutrients during 2005–06 and 2006–07.

followed to the treatment T_7 (Table 3). Among different source of manure, the maximum yield was recorded by the application of treatment T_7 and this grain yield increased was 208% as compared to the control treatment (T_1). The minimum grain yield (1.31 and 1.45 t ha^{-1} during 2005–06 and 2006–07, respectively) was obtained from control treatment.

Data regarding the HI in both years showed the significant differences among the treatments (Table 3). Maximum HI (40.5% and 41.7% during 2005–06 and 2006–07, respectively) was examined where recommended NPK was applied and during the study this treatment performed better in all other yield components as compared to all other treatments. Among the organic manures, the maximum HI was achieved from application of PL + SS which followed to the treatment T_5 and T_4 but both years these both treatments was statistically similar with each other. While the minimum HI (26.0% and 27.1% during 2005–06 and 2006–07, respectively) was recorded in control treatment where any source of nutrient did not apply.

Nitrogen uptake

The application of different organic manure significantly affected total N uptake of plant. The plant accumulated significantly higher N (33.18 and 38.38 kg ha^{-1} during 2005–06 and 2006–07,

Table 3. Various sources of nutrients influence wheat grain yield and yield components and nitrogen uptake.

	Productive tillers (m^{-2})		1000-grain weight (g)		Grain yield ($t\ ha^{-1}$)		Harvest index (%)		Protein contents (%)		Nitrogen uptake ($kg\ ha^{-1}$)	
Treatment	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
T_1	192 g	200e	24.6 g	26.3e	1.31 g	1.48f	26.0f	27.1c	7.90f	7.96f	11.00f	12.29f
T_2	286a	295a	37.9b	45.8 ab	4.05a	4.46a	40.5a	41.7a	12.96b	13.02b	33.73b	35.89b
T_3	208f	204e	30.5f	33.8cde	1.91f	2.00e	29.0e	28.6c	9.50e	9.738e	17.52e	19.34e
T_4	237d	244cd	34.1d	38.8bcd	2.72d	2.90d	35.5c	36.1b	12.68c	12.69c	27.37c	29.16c
T_5	253b	269b	36.1c	41.0 bc	3.31c	3.57c	35.4c	36.5b	12.70c	12.81c	34.26b	36.34b
T_6	228e	234d	33.1e	30.5 de	2.49e	2.76d	33.9d	36.4b	11.68d	11.75d	24.48d	25.42d
T_7	245c	253c	39.1a	48.8a	3.64b	4.00b	38.2b	40.0a	13.20a	13.29a	36.18a	38.38a
LSD (5%)	4.98	15.72	0.674	8.68	0.015	0.18	1.027	2.52	0.05	0.21	1.55	1.62
Rep.	*	NS	*	NS	*	NS	NS	NS	NS	NS	*	NS
T	**	**	**	**	**	**	**	**	**	**	**	**
Year	*	*	*	*	*	*	*	NS	*	*	*	*
Year × T	*	NS	*	NS	NS	*	*	NS	NS	*	*	*

Means not sharing the same letters in a column differ significantly at 5% probability.
*, ** = Significant at 5% and 1%, respectively, NS = Nonsignificant.
T_1 = (Control), T_2 = (Recommended NPK at the rate of 150, 100, and 60 kg ha^{-1}, respectively),
T_3 = (FM + PL), T_4 = (FM + PM), T_5 = (FM + SS), T_6 = (PL + PM), and T_7 = (PL + SS).
Each organic manure was applied at the rate of 10 t ha^{-1} during both growing seasons.

respectively) by application of PL + SS, each at the rate of 10 t ha^{-1} (Table 3). The both sources of organic manures (PL and SS) have higher concentration of N as compared to others sources used in the study.

Seed protein content

Seed protein content (SPC) of wheat was significantly affected by sources and quantity of applied nutrients (Table 3). Maximum SPC (13.2% and 13.3% during 2005–06 and 2006–07, respectively) was observed by application of treatment T_7 and it was 67% higher from control treatment followed by recommended NPK treatment. Whereas, the minimum values of SPC (7.9% and 8.0% during 2005–06 and 2006–07, respectively) was obtained from the control treatment.

Simulated and observed SOC and performance of RothC

In the field, there were significant ($P < 0.001$) effects of organic manures was observed on the SOC. This was due to variation of carbon contents in the manure applied during the study in the field. The observed SOC was increased by 43% in field with the application of PL and SS manure as compared to control treatment.

The RothC simulated well SOC for the experimental conditions during this study. The model showed minimum RMSE and MPD between simulated and observed values (Table 4). There was an overall good agreement between simulated and observed values of the SOC for each individual treatment and the combination of FM and SS showed minimum RMSE and MPD as compared to other organic manure combination. Figure 6 showed simulated values of the SOC was in the range of the observed SOC. For control, synthetic and organic manure treatments, the model overpredicted the SOC except for the treatment in which SS was applied. The simulated value of the SOC for SS manure treatments was lower than the observed values of the SOC. Overall, the observed and the simulated values of the SOC were highly significant ($P > 0.001$) with a positive linear correlation ($R^2 = 0.99$) as shown in Figure 7.

Economic analysis

Application of recommended NPK gave the maximum net income (729 \$ ha^{-1}). Similarly, application of PL and SS together increased the net income but comparatively less than inorganic fertilizers (Table 5). VCR was the highest (9.6) by application of FM + SS each at the rate of 10 t ha^{-1}. RII was the maximum

Table 4. Model errors and mean percentage difference among the different organic manures application.

Treatment	RMSE (t ha^{-1})	MPD† (t ha^{-1})
T_1	**1.69**	**4.67**
T_2	**1.59**	**2.98**
T_3	**1.70**	**2.83**
T_4	**1.42**	**1.89**
T_5	**2.05**	**3.51**
T_6	**1.53**	**2.05**
T_7	**1.85**	**2.59**
Mean	**1.69**	**2.93**

†**Mean percentage difference between the means of simulated and observed values.**
T_1 = (Control), T_2 = (Recommended NPK at the rate of 150, 100, and 60 kg ha^{-1}, respectively),
T_3 = (FM + PL), T_4 = (FM + PM), T_5 = (FM + SS), T_6 = (PL + PM), and T_7 = (PL + SS).
Each organic manure was applied at the rate of 10 t ha^{-1} during both growing seasons.

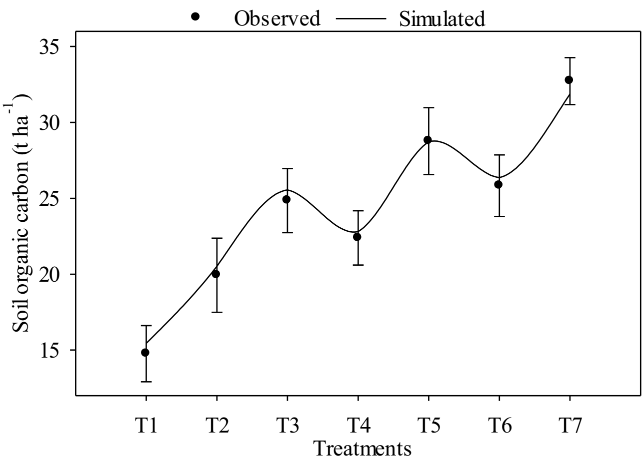


Figure 6. Observed (•) and simulated (—) changes in soil organic carbon (SOC) values.

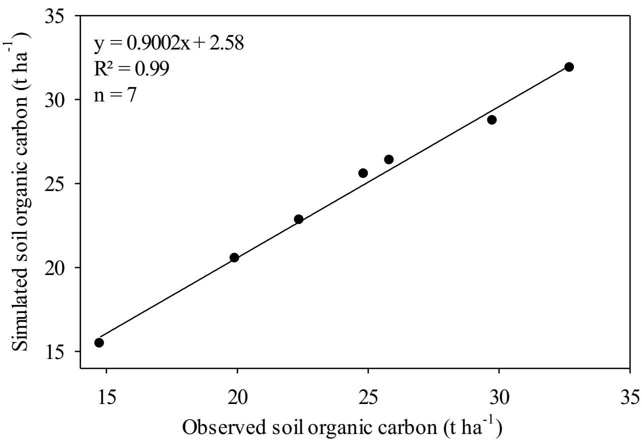


Figure 7. Relationship between observed and simulated soil organic carbon values.

Table 5. Economics analysis of inorganic and organic nutrient sources use for wheat production.

Treatments	Gross income ($ ha^{-1})	Variable input cost ($ ha^{-1})	Net income ($ ha^{-1})	Value cost ratio	Relative increase in income %
T_1	262	–	236	–	–
T_2	810	120	729	4.1	309
T_3	382	31	344	3.5	146
T_4	544	50	490	5.1	208
T_5	662	38	596	9.6	227
T_6	498	44	448	4.9	190
T_7	728	56	655	7.5	278

T_1 = (Control), T_2 = (Recommended NPK at the rate of 150, 100, and 60 kg ha^{-1}, respectively), T_3 = (FM + PL), T_4 = (FM + PM), T_5 = (FM + SS), T_6 = (PL + PM), and T_7 = (PL + SS).
Each organic manure was applied at the rate of 10 t ha^{-1} during both growing seasons.

(309%) under recommended NPK treatment but it had little difference with the application of PL and SS together. The RII was the lowest where the FM and PL applied together. In the study, VCR did not match with crop yield for the consideration of economic benefits. The RII looked to be more appropriate for economic analysis and it coincided with crop yield.

Discussion

The organic manures application such as PL and SS enhanced soil fertility. It might be due to inherited higher nutrient contents in these organic amendments (Table 2). In addition, application of organic matter improves soil health by increasing various soil physicochemical characteristics, i.e. cation exchange capacity, saturation percentage, soil porosity, and soil nutrient turnover rate. Improved nutrient availability to plant has been reported with the application of organic matter to the soil (Braschi et al. 2003). The fact may be correlated with the increased soil EC with organic amendment at the end of each growing season during the study probably due to release of nutrients as result of decomposition of organic matter from the applied manures (Zhao et al. 2009). Further, the decreased soil bulk density during the study due to addition of organic matter was also evident as the same also has reported by Bhattacharyya (2004) due to low-density fibers from the organic manures in soil (Abbas and Fares 2009).

The organic matter application significantly decreased soil pH. The decrease in soil pH may be due to a higher soil microbial activity caused by increased N content in soil. Since the dominant source on N taken up by the plant is ammonium, then the plant releases hydrogen ions and results in decrease soil pH in the rhizosphere (Bezdicek, Fauci, and Schwab 2002). Organic matter increases soil enzymes activity while the soil enzymes significantly affect soil pH (Zhao et al. 2009). Moreover, SOC significantly affects the soil pH (Liao, Wu, and Zhu 2016). There was an increase in soil pH in control and inorganic treatments (Figure 3b) possibly might be due to presence of hydroxyl ions in soils of these treatments (Bezdicek, Fauci, and Schwab 2002).

Organic matter application significantly improved plant growth which was evident with the higher LAI of the plants. Rehman et al. (2010) applied the different source of organic manure along with synthetic fertilizers and they concluded that LAI significantly increased by increasing rate of organic manure. At initial crop growth stages curves of TDM crossed and overlap to each other might be variation in microbial activity under the soil (Zhao et al. 2009). However, at maturity significant difference was observed in TDM production among the treatments which might be due to well difference of nutrients percentage among the source of organic manures as reflected in Table 2.

However, during the study synthetic fertilizer was resulted higher TDM then organic manures application. This might be due to quick availability of nutrients from inorganic sources (Hammad et al. 2011). Furthermore, the different chemical composition of the organic manures might have different effect on the soil and plant growth. Grain yield of the wheat crop is the result of collective contribution of different yield components, which are significantly affected by availability of crop inputs. The different sources of nutrient in both years showed significant effect on grain yield of the crop might be various concentration of NPK in the applied organic manure (Table 2).

Channabasanagowda et al. (2008) obtained the maximum grain yield (3.00 t ha^{-1}) by application of FM and PM together. They concluded that higher grain yield observed might be due to the increased N availability through organic sources. The addition of fertilizer especially in the form of organic manure into the soil may have stimulated microbial activity that improved soil fertility and eventually crop yield (Reddy et al. 2005). Application of organic manure improves the soil quality and health by increasing soil carbon and microorganism which are beneficial for wheat crop (Gaind and Singh 2016). Moreover, best management practices might guarantee the good yield (Hammad et al. 2015).

The N uptake linearly increased by increasing the N from different sources (Hammad et al. 2016). Similarly, SPCs were directly proportional to the application of N (Strecter et al. 1972), same is clear from Table 2. The organic farming increases grain quality by enhancing protein contents in the grain. This might be due to continuous and smooth availability of the N to plant throughout the growing season under organic farming (Shah et al. 2009). This corroborates with the finding of Channabasanagowda et al. (2008) and Shivay, Prasad, and Rahal (2010) who found grain protein contents of 11.1% and 13.20%, respectively, by application of NPK through synthetic fertilizers.

The statistical modal might be helpful for researchers to predict SOC that may be helpful for managing soil fertility to enhance crop productivity under arid conditions. Since RothC model predict SOC from soil organic matter, the value of soil organic matter was higher from the plots amended with higher manure applications compared to control treatments. Our results concur with the findings of Abbas and Fares (2009) who observed higher SOC in a field where poultry and goat manure, respectively, had been applied. They also concluded that SOC significantly increased with the application of organic manure into the soil. Moreover, organic farming results higher farm profit as compare to synthetic fertilizer. This may be due to two reasons: firstly, because of lower price of FM and SS as compared to inorganic and organic fertilizers; secondly, due high percentage of NKP in the SS (Table 2). Furthermore, organic matter application enhances physical and biological properties of the soil and provides sustainable practice for the farmers to increase their farm profit as compare to synthetic fertilizer.

Conclusion

The results indicated that organic matter application had positive effects on numerous soil properties, i.e. field capacity, EC, pH, and bulk density. However, inorganic fertilizers performed well with respect to economic yield of wheat. The inorganic fertilizers gave maximum total biomass as compared to organic manures. Among the organic manures, the maximum grain yield was achieved by application of the manure PL and SS each at the rate of 10 t ha^{-1}. This combination also improved quality of grain. It seems that organic matter application helps to enhance some of physical and biological properties of the soil and provide sustainable environments for the farmers to increase the quality of the produce. We also evaluated the performance of RothC model for arid region by simulating SOC in an organically modified arid soil. The results of the study support the potential of using of RothC model for determining of SOC under the arid region.

ORCID

Hafiz Mohkum Hammad http://orcid.org/0000-0002-1725-3069
Ghulam Mustafa Shah http://orcid.org/0000-0003-1230-7029
Wajid Nasim http://orcid.org/0000-0001-6221-7318

References

Abbas, F. 2013. Analysis of a historical (1981-2010) record of temperature of semi-arid Punjab, Pakistan. *Earth Interaction* 17:1–23.

Abbas, F., A. Ahmad, M. Safee, A. Ali, F. Saleem, H. M. Hammad, and W. Farhad. 2014. Changes in precipitation extremes over arid to semi-arid and sub-humid Punjab, Pakistan. *Theoretical Applied Climatology* 116:671–80.

Abbas, F., and A. Fares. 2009. Soil organic carbon and carbon dioxide emission from an organically amended Hawaiian Tropical. *Soil Science Society of America Journal* 73:1–9.

Abbas, F., A. Fares, H. R. Valenzuela, and S. Fares. 2012. Carbon dioxide emissions from an organically amended tropical soil. *Journal of Sustainable Agriculture* 36:3–17.

Ahmed, M., W. Ijaz, and S. Ahmad. 2018. Adapting and evaluating APSIM-SoilP-wheat model for response to phosphorus under rainfed conditions of Pakistan. *Journal of Plant Nutrition* 1–16. doi:10.1080/01904167.2018.1485933.

APA. 1986. Meˇitodos oficiales de anaˇilisis. Ministerio de Agricultura, Pesca y Alimentacioˇin. 1: 221–85.

Azad, M. I., and M. V. Yousaf. 1982. Recycling of organic matter to improve soil productivity. *Pakistan Journal of Agriculture Research* 22:15–18.

Azeez, J. O., and W. Van Averbeke. 2010. Nitrogen mineralization potential of three animal manures applied on a sandy clay loam soil. *Bioresource Technology* 101:5645–51.

Bahrman, N., J. Le Gouis, L. Negroni, L. Amilhat, P. Leroy, A. L. Laine, and O. Jaminon. 2004. Differential protein expression assessed by two-dimensional gel electrophoresis for two wheat varieties grown at four nitrogen levels. *Proteomics* 4:709–19.

Baldock, J. 2008. Nitrogen and carbon in soil organic matter. Grains Research and Development Corporation Project Update. www.grdc.com.au (Accessed January 14, 2018).

Bezdicek, D., M. Fauci, and G. Schwab. 2002. Impacts and management of soil acidity under direct seed systems - Effects of beneficial soil microbes and soil fauna. *Direct Seed Conference Report WSU*, *Pullman* WA pp 1–2.

Bhattacharyya, R., P. S. Ved, A. K. S. Kundu, and H. S. Gupta. 2004. Effect of long term manuring on soil organic carbon, bulk density and water retention characteristics under soybean-wheat cropping sequence in NW Himalayas. *Journal of the Indian Society of Soil Science* 52:238–42.

Braschi, I., C. Ciavatta, C. Giovannini, and C. Gessa. 2003. Combined effect of water and organic matter on phosphorus availability in calcareous soils. *Nutrient Cycling in Agroecosystems* 67:67–74.

Cakmak, I. 2009. Enrichment of fertilizers with zinc: An excellent investment for humanity and crop production in India. *Journal of Trace Elements Medical and Biological* 23:281–89.

Channabasanagowda, N. K., P. Biradar, B. N. Patil, J. S. Awaknavar, B. T. Ninganur, and R. Hunje. 2008. Effect of organic manures on growth, seed yield and quality of wheat. *Karnataka Journal of Agricultural Sciences* 21:366–68.

Cherifa, H., F. Ayaria, H. Ouzaria, M. Marzoratib, L. Brusettib, N. Jedidia, A. Hassena, and D. Daffonchiob. 2009. Effects of municipal solid waste compost, farmyard manure and chemical fertilizers on wheat growth, soil composition and soil bacterial characteristics under Tunisian arid climate. *European Journal of Soil Biology* 45:138–45.

CIMMYT. 1988. *An Economic Training Manual: From Agronomic Data to Farmer Recommendations*, 1–25. Mexico: D.F. CIMMYT.

Delate, K., and C. A. Camberdella. 2004. Agro-ecosystem performance during transition to certified organic grain production. *Agronomy Journal* 96:1288–98.

Farhad, W., M. A. Cheema, H. M. Hammad, M. F. Saleem, S. Fahad, F. Abbas, I. Khosa, and H. F. Bakhat. 2018. Influence of composted poultry manure and irrigation regimes on some morpho-physiology parameters of maize under semiarid environments. *Environmental Science and Pollution Research* 25:19918–31. doi:10.1007/s11356-018-2125-9.

Farhad, W., M. A. Cheema, M. F. Saleem, H. M. Hammad, and M. F. Bilal. 2011. Response of maize hybrids to composted and non-composted poultry manure under different irrigation regimes. *International Journal of Agriculture and Biological* 6:923–28.

Franko, U. 1996. Modeling approaches of soil organic carbon turnover within the CANDY system. In *Evaluation of soil organic matter models using existing long-term datasets*, ed. D. Powlson, P. Smith, and J. U. Smith, Vol. 38, NATO ASI Series I 247–54. Heidelberg: Springer-Verlag.

Fuertes-Mendizabal, T., A. Aizpurua, M. B. Gonzalez-Moro, and J. M. Estavillo. 2010. Improving wheat bread making quality by splitting the N fertilizer rate. *European Journal of Agronomy* 33:52–61.

Gaind, S., and Y. V. Singh. 2016. Short-term impact of organic fertilization and seasonal variations on enzymes and microbial indices under rice–wheat rotation. *Clean-Soil, Air, Water* 44:1396–404. doi:10.1002/clen.201500946.

Galloway, J. N., A. R. Townsend, J. W. Erisman, M. Bekunda, Z. Cai, J. R. Freney, L. A. Martinelli, S. P. Seitzinger, and M. A. Sutton. 2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. *Science* 320:889–92.

Guo, L. P., F. K. Coleman, B. Zhou, Y. Li, E. Lin, and F. Zhang. 2007. Application of the RothC model to the results of long-term experiments on typical upland soils in northern China. *Soil Use Management* 23:63–70.

Hai, L., X. G. Li, F. M. Li, D. R. Suo, and G. Guggenberger. 2010. Long-term fertilization and manuring effects on physically-separated soil organic matter pools under a wheat maize cropping system in an arid region of China. *Soil Biology and Biochemistry* 42:253–59.

Hammad, H. A., F. Ahmad, A. W. Farhad, B. C. Cordoba, and G. Hoogenboom. 2015. Water and nitrogen productivity of maize under semi-arid environments. *Crop Science* 55:877–88.

Hammad, H. M., W. Farhad, F. Abbas, S. Fahad, S. Saeed, W. Nasim, and H. F. Bakhat. 2016. Maize plant nitrogen uptake dynamics at limited irrigation water and nitrogen. *Environmental Science and Pollution Research* 24 (3):2549–57. doi:10.1007/s11356-016-8031-0.

Hammad, H. M., A. Khaliq, A. Ahmad, M. Aslam, A. H. Malik, W. Farhad, and K. Q. Laghari. 2011. Influence of different organic manures on wheat productivity. *International Journal of Agriculture and Biology* 13:137–40.

Hansen, S., H. E. Jensen, N. E. Nielsen, and H. Svendsen. 1991. Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model DAISY. *Fertilizer Research* 27:245–59.

Helrich, K. 1990. *Official methods of analysis*, volume 1 and 2, 15th education Published by Association of Official Analytical Chemists, Suit-400 2200 Walson Boulevard Arlington, Virginia.

Hesse, P. R. 1971. *Textbook of Soil Chemical Analysis*. London: John Murray.

Hildermann, I., M. Messmer, D. Dubois, T. Boller, A. Wiemken, and P. Mader. 2010. Nutrient use efficiency and arbuscular mycorrhizal root colonisation of winter wheat cultivars in different farming systems of the DOK long-term trial. *Journal of the Science of Food and Agriculture* 90:2027–38.

Iqbal, Z., M. Khalid, N. Soleman, and D. L. Jones. 2014. Differential utilization of dissolved organic and inorganic nitrogen by wheat (*Triticum aestivum* L.). *Journal of Plant Nutrition* 37:2094–107.

Jedidi, N., A. Hassen, O. V. Cleemput, and M. A. Hiri. 2004. Microbial biomass in a soil amended with different types of organic wastes. *Waste Management Research* 22:93–99.

Jones, S. K., R. M. Rees, U. M. Skiba, and B. C. Ball. 2007. Influence of organic and mineral N fertilizer on N_2O fluxes from temperate grassland. *Agriculture Ecosystem and Environment* 121:74–83.

Junsomboon, J., and J. Jakmunee. 2011. Determination of potassium, sodium, and total alkalies in Portland cement, fly ash, admixtures, and water of concrete by a simple flow injection flame photometric system. *Journal of Automated Methods and Management in Chemistry* 1–9. doi:10.1155/2011/742656.

Kemanian, A. R., C. O. Stockle, D. R. Huggins, and L. M. Viega. 2007. A simple method to estimate harvest index in grain crops. *Field Crops Research* 103:208–16.

Khoshgoftarmanesh, A., R. Schulin, R. Chaney, B. Daneshbakhsh, and M. Afyuni. 2010. Micronutrient-efficient genotypes for crop yield and nutritional quality in sustainable agriculture. A review. *Agronomy for Sustainable Development* 30:83–107.

Kushwah, S. S., D. Damodar Reddy, J. Somasundaram, S. Srivastava, and R. S. Khamparia. 2016. Crop residue retention and nutrient management practices on stratification of phosphorus and soil organic carbon in the soybean–wheat system in Vertisols of Central India. *Communications in Soil Science and Plant Analysis* 47 (21):2387–95. doi:10.1080/00103624.2016.1243703.

Lal, R. 2013. Intensive agriculture and the soil carbon pool. *Journal of Crop Improvement* 27:735–51.

Liao, K., S. Wu, and Q. Zhu. 2016. Can soil pH be used to help explain soil organic carbon stocks? *Clean-Soil, Air, Water* 44:1685–89. doi:10.1002/clen.201600229.

Meagy, M. J., T. E. Eaton, A. V. Barker, and G. M. Bryson. 2016. Assessment of organic and conventional soil fertility practices and cultivar selection on mineral nutrient accumulation in field-grown lettuce. *Journal of Plant Nutrition* 39:1936–49. doi:10.1080/01904167.2016.1201490.

Murtaza, B., G. Zaman, M. Imran, G. M. Shah, M. Amjad, N. Ahmad, M. A. Naeem, A. Zakir, A. Farooq, S. Ahmad, et al. 2019. Municipal solid waste compost improves crop productivity in saline-sodic soil: A multivariate analysis of soil chemical properties and yield response. *Communications in Soil Science and Plant Analysis*. doi:10.1080/00103624.2019.1603305.

Naeem, M., F. Khan, and W. Ahmad. 2009. Effect of farmyard manure, mineral fertilizers and mung bean residues on some microbiological properties of eroded soil in district Swat. *Soil and Environment* 28:162–68.

Ojo, A. O., M. T. Adetunji, K. A. Okeleye, C. O. Adejuyigbe, and R. Odeyinde. 2016. Effect of poultry manure and P fertilizer on some phosphorus fractions in some soils of Southwestern Nigeria – An incubation study. *Communications in Soil Science and Plant Analysis* 47:2365–77. doi:10.1080/00103624.2016.1216559.

Olsen, S. R., C. W. Cole, F. S. Watanabe, and L. A. Dean. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. Washington, D.C U.S. Department of Agriculture, circular, 939.

Reddy, S. S., B. Shivaraj, V. C. Reddy, and M. G. Ananda. 2005. Direct effect of fertilizer and residual effect of organic manure on yield and nutrient uptake of maize (*Zea may* L.) in groundnut-maize cropping system. *Crop Research* 29:390–95.

Rehman, S., S. K. Khalil, F. Muhammad, A. Rehman, A. Z. Khan, A. A. Rehman, S. M. Zubair, and I. H. Khalil. 2010. Phenology, leaf area index and grain yield of rainfed wheat influenced by organic and inorganic fertilizer. *Pakistan Journal Botany* 42:3671–85.

Rodrigues, M. A., A. Pereira, J. E. Cabanas, L. Dias, J. Pires, and M. Arrobas. 2006. Crops use-efficiency of nitrogen from manures permitted in organic farming. *European Journal of Agronomy* 25:328–35.

SAS Institute. 2004. *SAS/STAT 9.1 User's Guide*. SAS Inst., Cary, NC.

Shah, S. A., S. M. Shah, W. Mohammad, M. Shafi, and H. Nawaz. 2009. N uptake and yield of wheat as influenced by integrated use of organic and mineral nitrogen. *International Journal of Plant Production* 3:45–56.

Sharma, B. L., S. Singh, S. Sharma, V. Prakash, and R. R. Singh. 2002. Integrated response of Press mud cake and urea on sugarcane in calcareous soil. *Cooperative Sugar* 33:1001–04.

Shirato, Y., K. Paisancharoen, P. Sangtong, C. Nakviro, M. Yokozawa, and N. Matsumoto. 2005. Testing the rothamsted carbon model against data from long-term experiments on upland soils in Thailand. *European Journal of Soil Science* 56:179–88.

Shivay, Y. S., R. Prasad, and A. Rahal. 2010. Studies on some nutritional quality parameters of organically or conventionally grown wheat. *Cereal Research Communications* 38:345–52.

Strecter, J. G. 1972. Nitrogen nutrition of field grown plants. I. Seasonal varieties in nitrate reductase, glutamate, dehydrogenase and nitrogen constituents of plant parts. *Agronomy Journal* 64:315–19.

Thorne, G. N., I. Pearman, W. Day, and A. D. Todd. 1988. Estimation of radiation interception by winter wheat from measurements of leaf area. *Journal of Agriculture Science* 110:101–08.

van Wesemael, B., S. Lettens, C. Roelandt, and J. van Orshoven. 2004. Changes in soil carbon stocks from 1960 to 2000 in the main Belgian cropland areas. *Biotechnology, Agronomy, Society and Environment* 8:133–39.

Walkley, A. J., and C. A. Black. 1934. An estimation of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid tritration method. *Soil Science* 37:29–38.

Watson, D. J. 1952. The physiological basis of variation in yield. *Advances in Agronomy* 4:101–45. doi:10.1016/S0065-2113(08)60307-7.

Welch, R. 2002. The impact of mineral nutrients in food crops on global human health. *Plant Soil* 247:83–90.

White, P., and M. Broadley. 2009. Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist* 182:49–84.

Wu, J., A. G. O'Donnell, J. K. Syers, M. A. Adey, and P. Vityakon. 1998. Modelling soil organic matter changes in ley–arable rotations in sandy soils of Northeast Thailand. *European Journal of Soil Science* 49:463–70.

Yadvinder-Singh, R. K., H. S. T. Gupta, Bijay-Singh, Varinderpal-Singh, Gurpreet- Singh, Jagmohan-Singh, and J. K. Ladha. 2009. Poultry litter as a nitrogen and phosphorous source for the rice–wheat cropping system. *Biology and Fertility of Soils* 45:701–10.

Zhao, Y., P. Wang, J. Li, Y. Chen, X. Ying, and S. Liu. 2009. The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat–maize cropping system. *European Journal of Agronomy* 31:36–42.