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Long-Term Fertilization Effect on Agronomic Yield and Soil Organic Carbon under Semi-Arid Mediterranean Region

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Authors' contributions

This work was carried out in collaboration between all authors. Author Ibrahim Ortas designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author Rattan Lal managed the literature searches and reviewed the text. All authors read and approved the final manuscript. Author Ibrahim Ortas was a visiting scholar at OSU for 6 mounts when the manuscript was prepared.

Original Research Article

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ABSTRACT

Management practices, including use of organic and inorganic fertilizers, significantly affect soil organic carbon (SOC) pool and agronomic yield. Crop yields in semi-arid regions of Turkey are declining because of depletion of SOC pool and the attendant decline in soil quality. Thus, this study was conducted to assess the effects of inorganic and organic fertilizer treatments (control, chemical fertilizer, animal manure, compost and compost + mycorrhizal inoculation) on SOC pool and agronomic yield in a long-term field experiment initiated in 1996 on the Mediterranean coast of Turkey.

The SOC pool under different soil fertilizer management treatments was related to agronomic yield of pepper, wheat and maize. Biomass production increased as the SOC concentration increased with the application of organic and mineral (inorganic) fertilizers compared with the control. Between 1996 and 2010, the SOC concentration in 0-15 cm depth of the unfertilized control decreased from 0.96% to 0.87%. In comparison, SOC concentration increased in treatments amended with organic fertilizers such as manure, compost and compost+mycorrhzae. Agronomic yield was also significantly affected by

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organic and inorganic fertilizer treatments, which declined over time in the control but increased in treatments receiving compost, manure and compost + mycorrhizae. The negative regression was obtained in control treatments between SOC and the wheat yield (Y = -1.18x + 3.84, R^2=0.205) and maize yield (Y = -1.28x + 7.56, R^2=0.016).
Additional research is needed to assess the role of fertilizers on SOC concentration and its effects on agronomic yields under long-term soil and crop management systems especially with mycorrhizal inoculation.

Keywords: Long-term experiments; organic and Inorganic fertilizers; carbon storage; crop yield; relationship between SOC and yield.

1. INTRODUCTION

Soil organic carbon (SOC) levels are low in most soils in the semi-arid regions because of the harsh climate and severe problems of soil degradation. High temperatures prevalent in the semi-arid regions of Mediterranean Turkey; high $CaCO_3$ and clay contents and excessive use of heavy tillage have depleted the SOC pool, and adversely affected agronomic yields. The depletion of SOC pool is also exacerbated by the burning of crop residues and accelerated erosion. Soil and crop management affect many soil properties, including the SOC pool, especially the use of organic and inorganic fertilizers. Enhancing soil quality and agronomic productivity through improvements in the SOC pool have numerous ancillary benefits [1]. The low level of SOC concentration is one of the principal reasons of reduction of the agronomic yield in the Mediterranean region [2,3]. Therefore restoration of SOC pool through adoption of recommended management practices (RMPs) can improve soil quality and enhance agronomic yield. Most agricultural soils under monoculture are heavily tilled, irrigated, and severely depleted of their SOC pool. These soils are also highly degraded by erosion, and are prone to structural collapse, decline in biodiversity and overall deterioration in quality [1]. These conditions reduce crop yields, and increase risks of poverty, food insecurity and malnutrition in developing countries.

Soils of good quality are important to ecosystem services including net primary production (NPP), food security, water storage and quality, and biodiversity. Carbon sequestration in soils can mitigate climate change, increase agronomic productivity and advance global food security through improvements in soil quality [4,5]. Quality and quantity of SOC pool are principal attributes of soil biological, chemical and physical quality [6]. Depletion of SOC pool and the attendant degradation of biological and physical properties adversely affect soil fertility and crop productivity. The impact of SOC pool on agronomic production depends on climate, clay minerals, management, crop species and the antecedent SOC level.

Vegetation and crop species also play a major role in improving physical, chemical, and biological properties of soils through rhizospheric processes [7]. A high biomass production increases the SOC concentration and also affects soil microbial dynamics. Crop yield response to SOC concentration in the root zone depends on numerous factors. Important among these are active or mineralizable fractions, antecedent level of SOC, and the managerial inputs, especially those of nutrients and water, mycorrhizae and other beneficial microorganisms. Arbuscular mycorrhizal fungi (AMF) constitute the largest symbiotic associations between plants and fungi. These associations enhance the uptake of nutrients and biomass production [8,9]. The impact of mycorrhizae on the physical properties of soil and SOC also influence the NPP.

Most agricultural soils contain a lower SOC concentration/pool than those in natural environments because of the higher rates of mineralization accelerated by changes in soil temperature and moisture regimes, lower input of biomass C, and higher losses caused by accelerated erosion and leaching [10]. Long-term (1984-2007) field experiment concluded at the Changwu Ecological Station in China indicated that combined use of organic and inorganic fertilizers increased soil quality and SOC accumulation in the semiarid regions of the Loess Plateau [11]. Under long-term experiment conditions it has been shown that agronomic yield increases often larger on soils with more organic matter compared to those on soils with less organic matter [12]. The trends of several long term experiments of over 100 years show that SOC is directly affected by soil managements [13]. Most of the available data relating crop yields with SOC concentration comprise indirect information from other studies conducted to assess the impact of agronomic practices on soil properties [1,4,14]. Increase in SOC pool contributes to NPP through its effect on nutrient reserves [15], but the magnitude of the impact and the trend depend on crop species [16]. Kanchikerimath and Singh, [17] observed a strong relationship between crop yield and SOC under different fertilizer treatments, and reported that increase in SOC concentration by 1 % in the root zone increased grain + straw yield (biomass production) by 1.6 Mg ha^{-1} for cowpea (*Vigna unguiculata* L.), 7.9 Mg ha^{-1} for maize (*Zea mays* L.), and 12.7 Mg ha^{-1} for wheat (*Triticum aestivum* L.). In Argentina, Díaz-Zorita and Grosso [18] reported that loss of SOC by 1 Mg ha^{-1} decreased yield of wheat by 40 kg/ha, in comparison with the decline of 15.6 kg ha^{-1} reported by Bauer and Black [19] for some soils in the USA. The results of several experiments indicate a strong relationship between crop yields and the SOC pool in the root zone in diverse soils of Argentina, China, India, Nigeria, Russia, Germany, Thailand and the semi-arid areas of West Africa [4].

Furthermore, use of inorganic fertilizers can produce lower than expected crop yields because of degraded soils and low use efficiency of nutrients. Thus, restoring soil quality by enhancing SOC pool above the threshold levels improves the agronomic yields of crops [1,15,20] through several processes such as:

(i) increasing available water capacity [17,21-24], (ii) improving plant nutrient supplies [15,25,26], (iii) restoring soil structure [27-29], and (iv) minimizing risks of soil erosion [6,15].

These and other proven beneficial impacts of the SOC pool on soil quality form the basis of numerous management practices to enhance and sustain high crop yields and soil quality.

Therefore, the objective of this study was to assess the relationship between SOC concentration and agronomic yield under long-term use of organic and inorganic fertilizers (including mycorrhizal inoculation) application under semi-arid Mediterranean climate. The study was based on the hypothesis that a judicious use of organic and inorganic fertilizers improves SOC concentration, and increases agronomic yield.

2. MATERIALS AND METHODS

2.1 Site and Soils Description

A long-term field experiment was conducted between 1996 and 2010 on a range of crops (Table 1) grown on the Menzilat soil series (Typic Xerofluvents Fluvents, Entisols). The Research Farm of the Cukurova University is sited between 37°00′ 54.31″ N longitude, 35° 21′ 21.56″ E latitude and 34 m above mean sea level in eastern part of the Mediterranean region of Adana, Turkey [30]. General soil properties are presented in Table 2. The regional climate is typical Mediterranean with long-term average annual air temperature of 19.1ºC (ranging from 14.2ºC in January-February to 25.5ºC in July – August), and precipitation of 670.8 mm. As much as 80% of the annual precipitation is received between November and April, with a mean annual humidity of 66% [31].

2.2 Description of Field Experiment

The experiment, initiated in 1996, comprised of 5 treatments laid out as a randomized block design with three replications, and plot dimensions of 10 X 20 m. Five treatments were: (1) control, (2) traditional N-P-K fertilizers [160 kg N ha^{-1} as $(NH_4)_2SO_4$, 83 kg K ha^{-1} as K_2SO_4, and 26 kg P ha^{-1} as Ca $(H_2PO_4)_2.H_2O$], (3) compost at 25 Mg ha^{-1}, (4) animal manure at 25 Mg ha^{-1}, and (5) mycorrhiza-inoculated compost at 10 Mg ha^{-1}. The cocktail inoculum (mixture of sand + soil + spores + hyphae) was produced in sorghum (*Sorghum bicolor* L.) host plants. The cocktail mycorrhizal inoculum was mixed with the compost before application. All plots were moldboard ploughed to 15-20 cm depth after each harvest. Annually, the organic fertilizers (animal manure, compost and mycorrhizae) were uniformly spread on the soil surface (moist basis) just before sowing and incorporated into the surface 10-15 cm layer with a disc harrow**.** Similar tillage practices were followed for the control and fertilizer amended plots.

Compost material was produced from a mixture of grass, wheat, maize stubbles and citrus plant leaves and decomposed indoor for 12 months. Animal manure produced from dairy cows was supplied from the Cukurova University research farm.

Plant species were inoculated with the mixture of AMF produced in the Rhizosphere Lab, University of Cukurova, Adana-Turkey. The AMF spores were placed 30-50 mm below the seeds and seedlings at the rate of about 1000 spores per plant for horticultural plants and 500 for crops.

Seedling of eggplant [aubergine] (*Solanum melongena* L.) (CV. Pala), tomato (*Lycopersicon esculentum* Mill), (CV. SC2121) and pepper (*Capsicum annuum* L.), (CV. Kahramanmaras), cucumber (C*ucumis sativus*), (Yayla F1 local variety) watermelon (*Citrullus lanatus* Thunb.), Madera Fı and melon (*Cucumis melo* L.) were transplanted in April and harvested in August. Carrot (*Daucus carota* L.), spinach (*Spinacia oleracea)*, lettuce (*Lactuca sativa*), and radish (*Raphanus sativus*) were sown in October, grown under rain-fed conditions, and harvested in April. Winter wheat was sown in November and harvested at end of the May or beginning of June. Maize was sown as the second crop at end of the June. Second crop of maize grown after the harvest of wheat was irrigated several times depending on climate during the growing periods.

The present experiment was set up in 1996 for pepper, tomato, cucumber, melon, watermelon, carrot, spinach, radish, wheat and maize crops grown in a non-reticule cycle (Table 1). However, wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) were grown since 2005 (Table 1).

2.3 Soil Sampling, Preparation and Soil Organic Carbon Analyzed

Bulk soil samples were obtained from each plot at 0-15 cm and 15-30 cm depths after the harvest every year between 1996 and 2010. Since in many years there was more than one harvest, soil samples were collected after each harvest. Samples were air dried, gently ground, and passed through a 0.5- mm sieve to determine SOC concentrations by the dichromate oxidation method [32].

2.4 Data Analysis

All data were statistically analyzed using the analysis of variance (ANOVA) procedure in the SAS program [33] to assess the effects of different treatments and sampling depths on soil properties. Means were compared using the least significant difference (LSD) test when the ANOVA showed significant fertilizer effects ($P \leq 0.05$). Correlations and regressions were compared between crop yield and SOC concentration for pepper, wheat and maize only. The yield data of melon, watermelon, eggplant, bell pepper, carrot, spinach, salad, and radish were obtained for only 2 years. Thus correlation between agronomic yields of those crops with SOC concentration was not assessed.

3. RESULTS

3.1 Agronomic Yields

Application of organic and mineral fertilizers increased crop yields (Table 3). Maize grain yield (Mg ha^{-1}) in 2002 and 2010, respectively, was 7.65 and 5.41 in control, compared with 10.21 and 12.64 in compost+ mycorrhizae (Table 3). Wheat grain yield (Mg ha^{-1}) in 2000 and 2010, respectively, was 3.00 and 2.87 in control, 4.80 and 5.15 in mineral fertilizer, 4.49 and 5.23 for the compost+ mycorrhizae, and 4.85 and 5.25 for animal manure. Pepper yield (Mg ha^{-1}) in 1996 and 2005, respectively, was 10.08 and 15.33 in control, compared with 17.3 and 21.73 in inorganic fertilizer and 22.08 and 25.53 for the compost. Tomato yield (Mg ha^{-1}) in 1998 and 2005, respectively, was 10.02 and 14.81 in control compared with 13.67 and 16.49 in inorganic fertilizer and 13.65 and 26.24 for the compost (Table 3).

Yield of melon, watermelon, eggplant, bell pepper, carrot, spinach, salad, and radish also increased significantly with the application of organic and inorganic fertilizers compared with the control (Table 3). However yield of melon, watermelon and eggplant decreased over time because of the severe incidence of disease since 2005. Melon yield (Mg ha^{-1}) in 1996 and 2005, respectively, was 53.18 and 15.07 in control, compared with 58.20 and 22.47 in inorganic fertilizer. Yield of watermelon (Mg ha^{-1}) in 1996 and 2005, respectively, was 46.19 and 10.45 in control, compared with 79.37 and 15.51 in compost+ mycorrhizae. Eggplant yield (Mg ha^{-1}) in 1996 and 2005, respectively, was 14.32 and 7.63 for the control, compared with 25.11 and 12.41 in compost+ mycorrhizae.

Table 1. Crop grown in the long term experiment between 1996-2010

Years	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Plants species used during experiment	Pepper	Pepper	Pepper Bell Pepper Eggplant Tomato Cucumber Watermelon Melon	Maize Carrot Spinach	Wheat	Cucumber Lettuce-1 Lettuce-2 Radish Spinach	Maize	Wheat	Maize	Pepper Bell Pepper Eggplant Tomato Cucumber Melon Watermelon Maize	Maize Wheat	Maize Wheat	Maize Wheat	Maize Wheat	Maize Wheat

Table 2. Initial physical chemical and biological characteristics of Menzilat soil series

Properties	Unit	Depth 0-15 cm		Depth 15-30 cm	
Clay		318.8	±30.6	333.4	±21.8
Silt		360.9	±87	379.5	±13.4
Sand		320.3	±23.0	287.2	±16.4
Organic carbon soil	g kg^{-1} soil	0.96	±0.08	0.78	±0.08
Inorganic carbon		3.77	±0.35	3.97	±0.42
Total nitrogen		0.08	±0.01	0.07	±0.01
CEC	$Cmol^{+}$ kg^{-1}	20.50	±2.00	17.90	±1.64
pH	H_2O	7.58	±0.66	7.60	±0.71
Salt	%	0.05	±0.00	0.04	±0.00
P	mg kg^{-1}	22.60	±2.16	20.20	±2.00
Fe		5.43	±0.82	5.66	±0.58
Mn		5.74	±0.32	5.31	±0.59
Zn		0.52	±0.05	0.23	±0.02
Cu		1.86	±0.19	1.56	±0.16
Number of AMF spores	10 g^{-1} soil	64.00	±11.70	44.00	±2.62

Mean of three replicates ± SD

Table 3. Effect of soil fertility management, treatments on crop yield (kg ha^{-1}) from 1996 to 2010

	1996 pepper		**1997 pepper**		**1998 melon**		**1998 cucumber**		**1998 pepper**		**1998 eggplant**		**1998 watermelon**		**1998 Tomato**	
Control	10080	±1008	14000	±1400	53183	±12292	4639	±1682	19990	±1012	14327	±3528	46191	±6413	10019	±14267
Mineral Fertilizer	17280	±1728	15450	±1545	58202	±5749	6257	±1679	18160	±9571	18067	±2695	51277	±25523	13674	±14185
Compost	22080	±2208	24480	±2448	69882	±29843	8006	±2204	32082	±9782	21140	±2754	38661	±14063	13657	±19718
Animal Manure	27720	±2772	25880	±2588	74916	±30305	8416	±6569	26770	±8172	19143	±11040	79260	±69751	21662	±17566
Com. + Mycorrhiza	25392	±2539	26050	±2605	94904	±36416	9351	±1236	39401	±3884	25117	±7302	79370	±37093	15718	±3136
Signifi. of P-values	0.0001		0.0001		0.3675		0.4705		0.0570		0.3806		0.5692		0.9050	
	1999 carrot		1999 spanach		1999 maize		2000 wheat		2001 lettuce		2001spanach		2001 lettuce-2		2001 redish	
Control	19157	±5497	6517	±2224	5009	±1366	3001	±625	9528	±1762	32994	±5860	13727	±1655	15525	±1219
Mineral Fertilizer	26077	±7594	7465	±3099	5436	±2247	4719	±337	15231	±3897	55154	±6102	15241	±725	25223	±4188
Compost	25993	±4228	6105	±1155	8212	±1520	4062	±293	17006	±1920	41636	±5588	15312	±1961	26322	±1476
Animal Manure	32318	±3922	6642	±1237	7943	±2322	4856	±609	19444	±6382	80139	±10272	19142	±2325	31323	±5222
Com. + Mycorrhiza	24145	±3314	6955	±338	5787	±269	4491	±864	24614	±3839	63086	±11392	21909	±877	30343	±1589
Signifi. of P-values	0.1066		0.9205		0.0501		0.0187		0.0103		0.0003		0.0006		0.0009	
	2002 maize		2003 wheat		2004 maize		2005 wheat		2005 maize		2005 tomato		2005 pepper		2005 bel pepper	
Control	7650	±786	3918	±475	8017	±586	2840	±288	7017	±379	14813	±3478	15333	±667	13167	±833
Mineral Fertilizer	11550	±450	5569	±605	11400	±726	570000	±36315	11400	±726	16489	±2895	21730	±730	18970	±997
Compost	10900	±1033	5325	±1089	10883	±666	544167	±33292	10883	±666	26244	±3818	25535	±6065	23868	±648
Animal Manure	10183	±592	5166	±500	10217	±802	510833	±40104	10217	±802	24211	±7770	24540	±8540	24043	±5803
Com. + Mycorrhiza	12467	±660	5953	±1009	13083	±355	654167	±17736	13083	±355	17046	±3555	25500	±2500	20000	±1000
Signifi. of P-values	0.0001		0.0771		0.0001		0.0001		0.0001		0.0449		0.1640		0.0036	
	2005 eggplant		2005 melon		2005 watermelon		2006 maize		2006 wheat		2007 maize		2007 wheat		2008 wheat	
Control	7633	±722	15700	±5145	10444	±694	6967	±177	3129	±278	6982	±140	2544	±127	3095	±320
Mineral Fertilizer	8402	±1999	22478	±8439	12889	±839	12900	±156	5293	±326	10915	±352	4843	±634	5800	±135
Compost	13467	±2454	27333	±5696	14778	±3835	11570	±921	4779	±355	11524	±1429	5219	±412	5167	±218
Animal Manure	12633	±1396	23089	±828	15622	±6249	9802	±953	5033	±807	10422	±1073	4823	±360	6238	±844
Com. + Mycorrhiza	12417	±1218	21789	±14649	15511	±5626	11310	±629	5181	±315	12060	±697	4992	±665	6096	±1469
Signifi. of P-values	0.0042		0.5771		0.5771		0.0001		0.0010		0.0003		0.0003		0.0034	
	2008 maize		2009 wheat		2009 maize		2010 maize		2010 wheat							
Control	5574	±297	2793	±235	6717	±355	5405	±383	2807	±190						
Mineral Fertilizer	10724	±299	5340	±297	10417	±709	11878	±902	5157	±51						
Compost	8782	±1306	4983	±999	10883	±451	11411	±1585	5033	±161						
Animal Manure	10504	±870	6200	±1325	9550	±832	12174	±318	5253	±129						
Com. + Mycorrhiza	9633	±1598	5882	±758	10400	±500	12637	±350	5233	±140						
Signifi. of P-values	0.0006		0.0041		0.0001		0.0001		0.0001							

Table 4. Significance of P-values (probability) from the analysis of variance for different fertilizer treatments on SOC concentration

Treatments	SD	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Depth	1	0.0001	0.0010	0.0013	0.0035	<.0001	<.0001	<.0001	0.0007	0.0073	0.0309	0.3130	0.4790	0.8686	0.2079	<.0001
Fertilizer	4	0.1715	0.2739	0.0066	0.3169	<.0001	0.0002	<.0001	<.0001	<.0001	0.0015	<.0001	<.0001	<.0001	<.0001	<.0001
Dep. X Fer	4	0.6659	0.4980	0.5872	0.1837	0.0929	0.0077	0.0006	0.0316	0.2680	0.4988	0.0410	0.3258	0.0903	0.5365	0.0499

3.2 Soil Organic Carbon Concentration

There were also significant differences in SOC concentration among treatments in 0-15 cm and 15-30 cm depths over 14 year of crop cultivation (Fig. 1). There was a noticeable trend of higher SOC in the plots receiving organic than inorganic fertilizers (Fig. 1). The SOC concentration (%) in 0-15 cm depth in 1996 was 0.96, 0.99, 1.09, 1.05 and 0.96 for control, mineral fertilizer, organic manure, compost, compost +mycorrhiza treatments, respectively. In comparison, SOC concentration in 0-15 cm depth in 2010 was 0.87, 1.17, 1.64, 1.50 and 1.15 for the same treatments (Fig. 1).The SOC concentration (%) in 15-30 cm depth in 1996 was 0.78, 0.76, 0.84, 0.84 and 0.84 for control, mineral fertilizer, organic manure, compost, compost + mycorrhiza treatments, respectively. In comparison, SOC concentration in 2010 was 0.96, 1.10, 1.37, 1.02 and 1.08 for control, mineral fertilizer, organic manure, compost, compost + mycorrhiza treatments, respectively. Significance of P-values from the analysis of variance for different fertilizer treatments on SOC concentration is presented in Table 4.

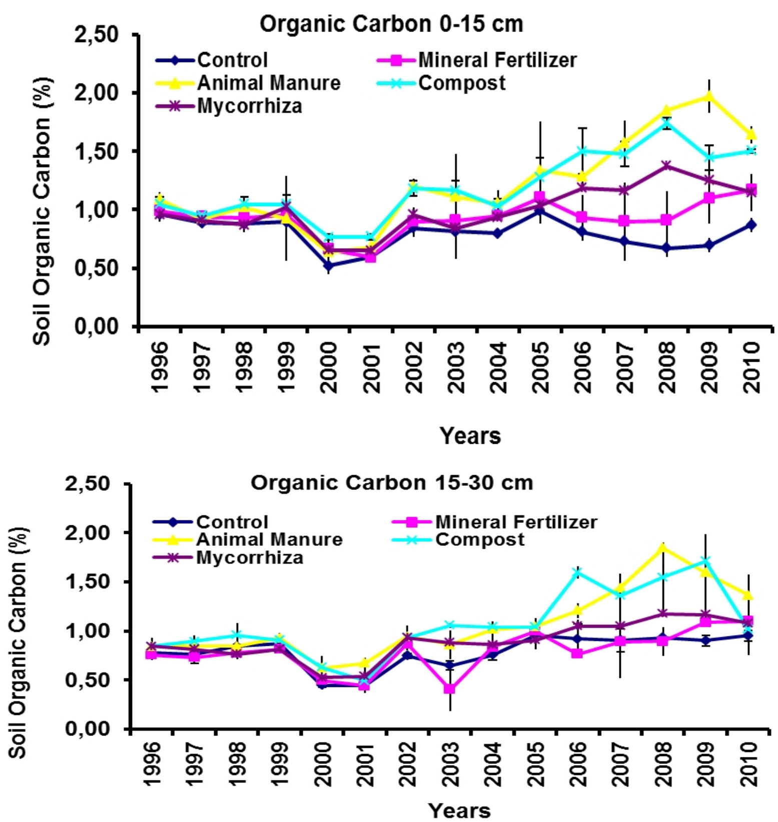

Fig. 1. Effect of several inorganic and organic fertilizers on temporal changes in soil organic carbon concentration

3.3 Relation between Soil Organic Carbon Concentration and Agronomic Yield

The regression and correlation between SOC concentration and agronomic yield of 3 crops (i.e. pepper, wheat, maize) grown under organic and conventional farming methods are shown in (Figs. 2, 3, 4).

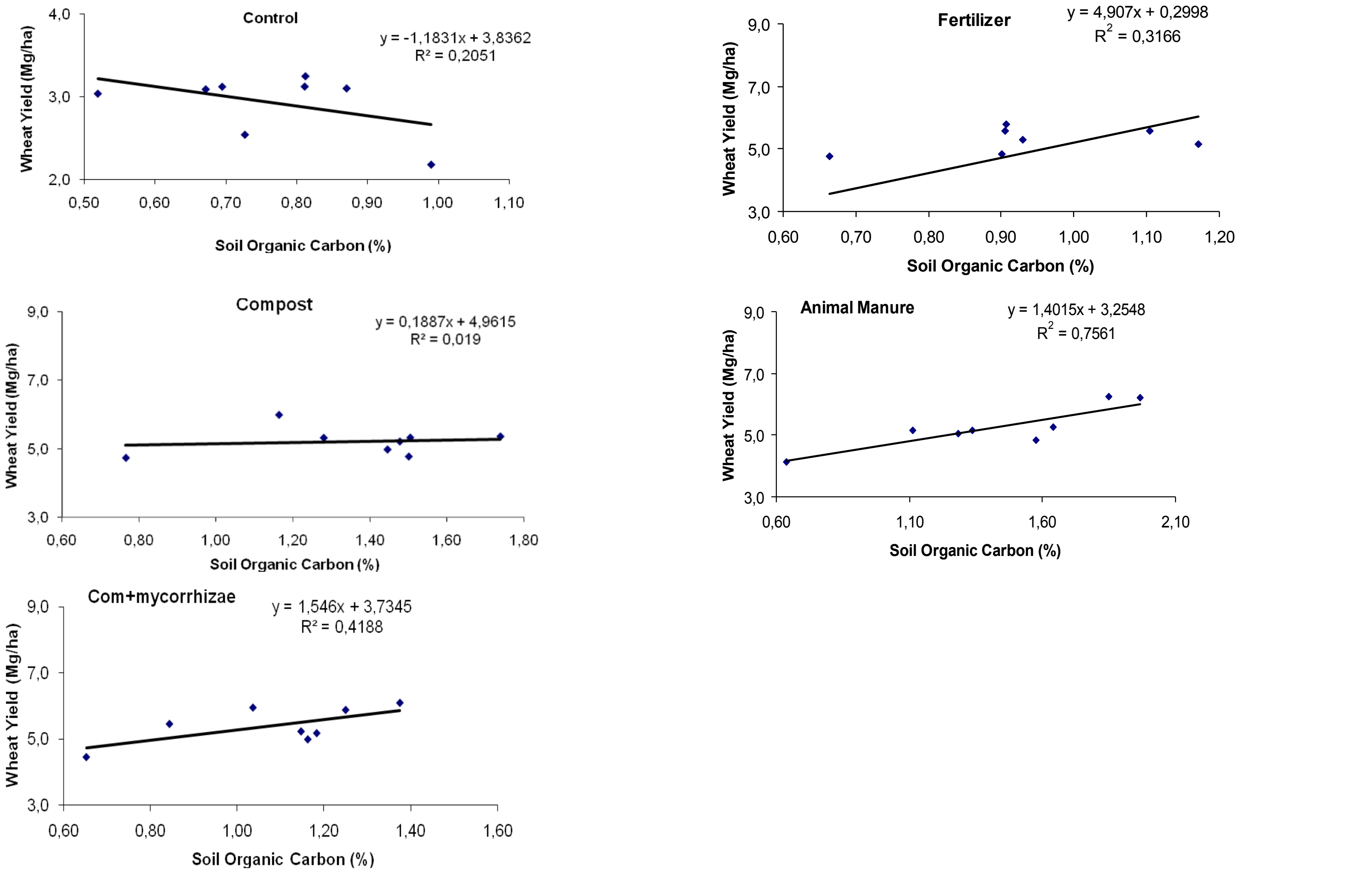

Fig. 2. Relationship between wheat grain yield and SOC concentration in 0-15 cm depth

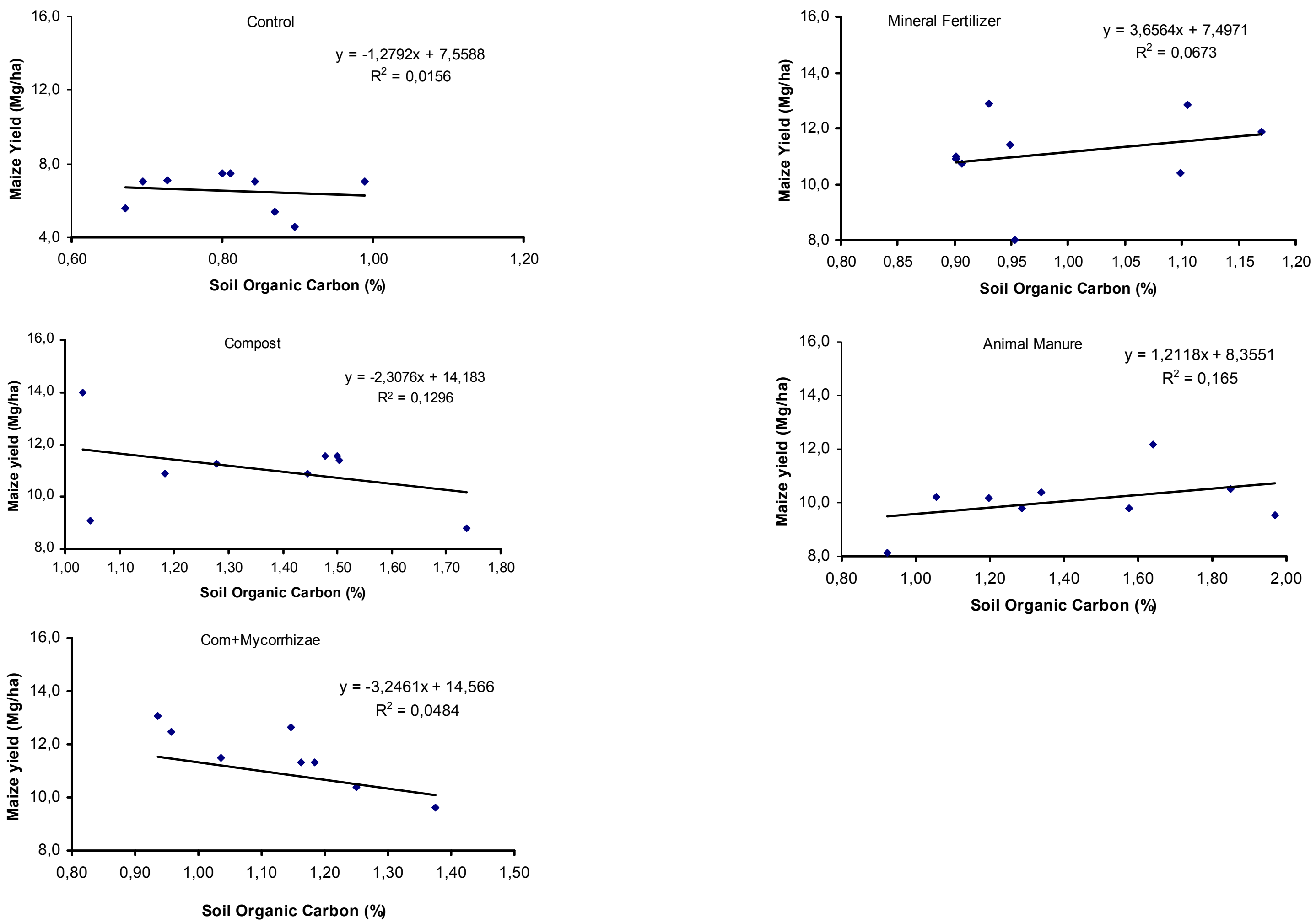

Fig. 3. Relationship between maize grain yield and SOC concentration in 0-15 cm depth

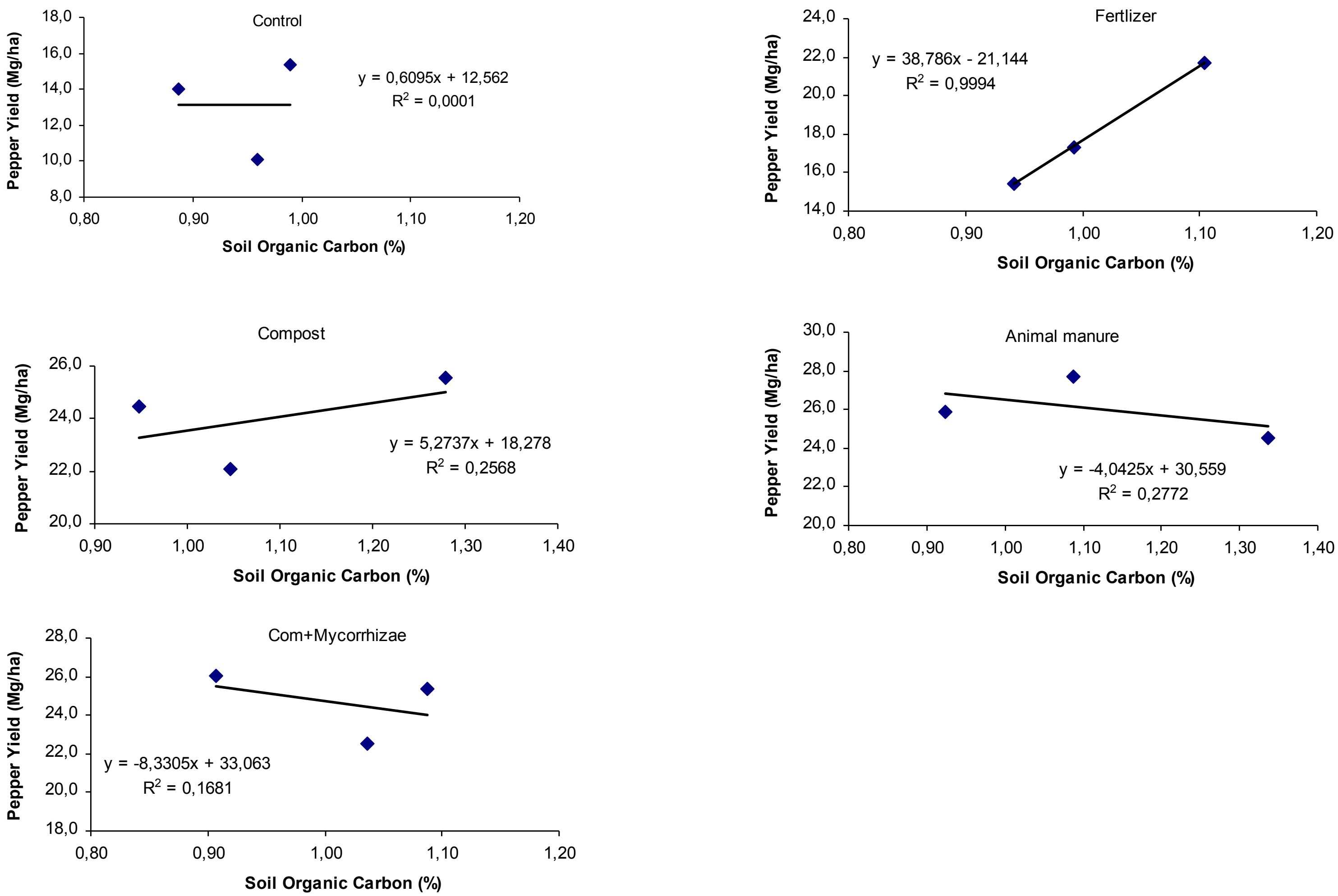

Fig. 4. Relationship between pepper fresh yield and SOC concentration in 0-15 cm depth

The data presented in Fig. 2 show that the increase in SOC concentration in 0-15 cm depth by 1% increased wheat grain yield by 5.21 Mg ha^{-1}, 5.15 Mg ha^{-1}, 4.66 Mg ha^{-1} and 5.28 Mg ha^{-1} for inorganic fertilizer, compost, manure, and compost mycorrhizae, respectively. Similarly increase in SOC concentration by 1% increased maize grain yield by 6.28 Mg ha^{-1}, 11.15 Mg ha^{-1}, 11.88, Mg ha^{-1}, 11.32 Mg ha^{-1} for control, fertilizer, compost and compost+ mycorrhizae respectively (Fig. 3). Increase in SOC concentration by 1% increased yield of pepper by 17.65 Mg ha^{-1}, 26.52 Mg ha^{-1} for mineral fertilizer and manure respectively (Fig. 4).

Agronomic yield was also significantly (P<.0001) affected by the fertilizer treatments. In contrast to wheat and pepper, yield of maize was reduced with compost and compost+mycorrhizae applications, and there were no consistently positive correlation between SOC concentrations and crop yield (Fig. 2). The relationship between SOC concentration and agronomic yield is negative for wheat (Fig. 2). The negative regression was obtained in control treatments between SOC and the grain yield (Y = -1.18x + 3.84, R^2==0.205) for wheat and (Y = -1.28x + 7.56, R^2=0.016) for maize. In general, there is a significantly negative correlation between SOC and yield in control, but positive correlation with inorganic fertilizer for all 3 crops.

4. DISCUSSION

In general, application of organic fertilizers increased crops yield. Also there was a strong and significant effect of fertility management on agronomic yield of different crops (Table 3). Further, yield of all crops decreased overtime in the control except that of pepper. Yet, use of inorganic fertilizer significantly improved crop yields. In comparison with control and inorganic fertilizers, however, impacts of manure and compost application on yields were significantly high, probably due to improvement in soil physical properties [30]. Rasool et al. [34] also reported better yields of rice and wheat with balanced use of organic and inorganic fertilizers, which improved the physical environment of the soil, and enhanced SOC pool.

As is evident from the data in Fig. 1, there exists a large inter-annual variation in SOC concentration. For example, the SOC concentration was lower in 2000 than in 1999 and, 2005, with small differences among treatments. Such a trend may be related to interannual variation in crop growth and the attendant impact on SOC concentration. Furthermore, vegetables were grown in some years (e.g., 1996-1998, 2001, 2005). Subsequently, wheat and maize rotations (Table 1) were followed after 2005, leading to significant differences among treatments. Therefore, differences in crops grown would explain differences in residue returned and on dynamics of the SOC concentration. Assessing the impact of crop species (vegetables vs. grain crops) on SOC dynamics is a researchable priority.

In the present experiment, however, plant response was similar when treated with 25 Mg ha^{-1} of compost with or without mycorrhizae. It seems that inoculation with mycorrhizae alone has more impact on crops than when used in combination with compost. The colonization and the number of spores were also more in compost+mycorrhizae than in other treatments (data not presented). The results indicate that mycorrhizal inoculation strongly affected growth of diverse plant species. Under the same soil conditions, the effects of mycorrhizal inoculation on 12 plant species were tested during 1997-1999 [35].

Liu et al. [36] also observed that rice yields with organic amendments were higher than those in treatments with NPK. Roose and Barthes [29] reported that manure application increased grain yield, and application of organic fertilizers (i.e., mycorrhizae, animal manure and compost) increased pepper yield more significantly than did mineral fertilizer and control.

4.1 SOC influence on yield

The most notable increase in SOC concentration in both depths occurred in plots amended with organic fertilizers. Nevertheless, SOC concentration decreased with increase in soil depth. Further, application of organic fertilizers enhanced SOC concentration, more in 15-30 cm than in the 0-15 cm depth. Similar results have been reported by Eghball et al. [37] and Wang et al. [38]. Kukal et al. [39] also reported that use of balanced fertilization improved SOC concentration under long-term field experiments on rice-wheat and maize-wheat systems in the semi-arid regions of the Indo-Gangetic Plains. Rathod et al. [40] reported that addition of organics (farmyard manure and vermicompost) fertilizer at a high rate increased yield of the wheat-maize system over 2 years.

In general, the relationship between SOC concentration and agronomic yield were positive for organic fertilizer treatments and negative for unfertilized control. However, the relationship was positive for 3 crops even with the use of inorganic fertilizer. Such a trend may be related to climatic factors during the specific year and the attendant changes in soil processes which affect nutrient availability and transformation. Also since we used several wheat and maize genotypes and they have difference production potentials there were differences in yield production between years. Under field condition, depending on soil, crop and climate, there exists a large variability in empirical relationship between SOC concentration and agronomic yield. This confusion of yield differenced between years may be caused by the expression of SOC data in % rather than in Mg/ha. Most literature is in Mg/ha. In present experiment we used % of SOC.

The application of organic amendments such as bio-inoculants (e.g., humic substances, and seaweed extracts) can also stimulate crop growth and development through the actions of plant growth-promoting hormones [41].

The higher SOC concentration measured in 2010 than the antecedent level in 1996 for both depths (Fig. 1) may be attributed to retention of crop residues (straw) which may have created a positive C budget [37]. Larbi et al. [42] also reported that crop residues increased the magnitude of the positive effect of SOC concentration on grain yield. A higher SOC concentration in 15-30 cm depth in 2010 than in 1996 may be due to high root turnover in the subsoil layers.

The relationship between SOC concentration and agronomic yield is positive for the inorganic fertilizer, compost, animal manure, and compost + mycorrhizal treatments. Yield levels of non-legume crops were positively correlated with SOC concentration, but the correlation was significant only for the organic-amended treatments. Application of organic amendments increased SOC concentration and agronomic yield in the absence of inorganic fertilizer. Such a positive response is attributed to an overall improvement in soil quality, due to increase in SOC concentration [4,16]. Yan and Gong [14] reported that under North China Plain conditions, the use of organic fertilizer increased SOC and soil fertility and consequently resulted in a larger yield trend when compared to a balanced chemical fertilizer Since the mineral content of manure and compost is variable from year to year, the effect of organic fertilizer on yield can also be variable. A field experiment conducted at Saria, Burkina Faso also indicated that grain yield was not correlated with total SOC but was positively correlated with total particulate organic matter [26]. Change in SOC and N pools over time is strongly correlated with input of crop residues, and application of farm yard manure and inorganic fertilizers [34]. Data from a long-term experiment in Oregon reported that an increase in the SOC pool by 1 Mg C/ha increased grain yield of wheat by 0.14 Mg/ha between 1942 and 1951, 0.38 Mg/ha between 1952 and 1966, 0.12 Mg/ha between 1967 and 1976, and 0.06 Mg/ha between 1977 and 1986. Corresponding increases in straw yield of wheat was 0.09 Mg/ha, 0.15 Mg/ha, 0.12 Mg/ha and 0.06 Mg/ha, respectively [43]. Synthesizing data from a range of experiments, Lal [1] reported that crop yields can be increased by 20-70 Mg/ha for wheat, 10-50 Mg/ha for rice, and 30-300 kg/ha for maize with every 1 Mg/ha increase in SOC pool in the root zone. In India, Benbi and Chand [25] reported that increase of SOC pool by 1 Mg/ha increased productivity of wheat by 15 to 33 kg/ha across SOC concentration ranging from 3 to 9 g/kg. Field studies conducted in West Africa indicated that 1% increase in SOC concentration in the root zone increased grain yield of upland rice by 0.31 Mg/ha [44]. In USA, Bauer and Black, [19] assessed the effect of SOC on wheat yield and reported that contribution of 1 Mg/ha of SOC increased grain yield by 35.2 kg/ha and straw yield by 15.6 kg/ha. After long term organic and inorganic fertilizers application it seems that organic fertilizers increased SOC content, which had a significant relationship with yield trend of several plants species, suggesting that the use of organic fertilizer would benefit crop yield in the long term.

5. CONCLUSIONS

The data presented support the following conclusions:

1. The yield of crops grown in organic fertilizer treated plots was higher than those receiving inorganic fertilizers. However, yield of crops grown in control decreased over time.
2. The concentration of SOC was significantly increased in treatments receiving organic fertilizers than those receiving inorganic fertilizers and the control. Application of organic and inorganic fertilizers increased SOC concentration because of the increased inputs of organic residues with high biomass production. The SOC concentration was highly variable among years.
3. The relationship between SOC concentration and agronomic yield were negative for unfertilized control, but positive for inorganic fertilizer treatments for 3 crops. In general, the relationship between SOC concentration and agronomic yield were positive for organic fertilizer treatments.

Sustainable agricultural systems are important to SOC sequestration and improvement in soil quality. Accurate measurement of changes in SOC concentrations, in relation to the amount of biomass C applied annually, is a researchable priority for calcareous soils of the Mediterranean regions.

There is a strong need to establish threshold level of SOC pool, and of the relation between SOC pool and agronomic yield, especially with reference to the projected climate change. Use of inorganic fertilizers and organic amendments must be encouraged to alleviate nutrient imbalance, increase crop yield, and enhance SOC pool. The effect of mycorrhizae and other organic fertilizers on the SOC pool and the relationship to yield increase must be assessed for a range of soils and ecosystems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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