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Short-Term Effects of Tillage Intensity and Fertilization on Sunflower Yield, Achene Quality, and Soil Physicochemical Properties under Semi-Arid Conditions

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Abstract: Inappropriate soil management practices and specific climatic conditions in semi-arid region cause loss of soil organic matter (SOM), decline soil fertility, and trigger soil erosion processes and desertification. A two-year field study was carried out to investigate the effects of tillage intensity and fertilizer regime treatments on the productivity of sunflower (*Helianthus annus* L.) and soil physicochemical properties in the semi-arid highland region in northwest Iran (37°31′ north (N), 46°53′ east (E)). Five fertilizer treatments were included under conventional (CT) or reduced tillage systems (RT): F1, no fertilizer application; F2, 20 t·ha^{-1} farmyard manure (FYM); F3, 40 t·ha^{-1} FYM; F4: 20 t·ha^{-1} FYM + 50% of the recommended dose of nitrogen–phosphorus–potassium (NPK) chemical fertilizer; F5: full dose of the recommended chemical NPK fertilizer. Results showed that utilization of FYM decreased bulk density (BD); its effects were more evident under the highest SOM content for the F2 and F3 treatments, whereas application of mineral fertilizer had no significant effect upon SOM content, and elevated levels of FYM preserved higher organic carbon contents in topsoil. The highest N, P, and K contents of the soil were obtained with FYM plus inorganic fertilizer application in the RT system. Hydraulic conductivity and soil moisture content were significantly improved by RT and FYM application. The highest root growth was observed for F3 and F4 under the RT system. The effect of fertilizer and tillage treatments was more pronounced during the second year. Traits related to growth and seed quality such as achene oil content, leaf area, and harvest index were enhanced by chemical fertilization in the CT system. The highest achene yield and oil percentage were recorded for plants grown with F3 and F4. The best option for enhancing sunflower productivity and quality in semi-arid, high-altitude environments is the application of organic fertilizers amended with reduced amounts of chemical fertilizers.

Keywords: conservation tillage; organic–inorganic fertilizers; reduced tillage; semi-arid environment; soil physicochemical properties; sunflower

1. Introduction

About one-third of the land surface in the world is arid or semi-arid. Growing population, increasing food demand, and technological advances may soon lead to intensifying land use in semi-arid regions [1,2]. The semi-arid land represents regions of the world where the precipitation is low, irregular, and unpredictable, which is rarely sufficient for crop production and negatively affects the physical, chemical, and biological properties of soil [1–4]. Due to the mentioned climatic problems and lack of proper agricultural and soil management practices, soil organic matter (SOM) and mineral nutrient contents are very low.

Most semi-arid regions are classified as winter-dominant rainfall areas. Wheat is extremely well adapted to endure in such an environment, where its productivity and stability of production are exceeded only by barley [4]. Therefore, the dominant cultivation of semi-arid regions is often based on winter cereals with a "wheat or barley/fallow rotation". However, it was shown that crop biodiversity has a noticeable effect on soil fertility [5]. This is a main problem in the semi-arid highlands in northwest Iran, where successive wheat or barley farming ended up reducing infiltration rates and SOM. Furthermore, inadequate vegetation and imbalanced precipitation contributed to the creation of runoffs which tend to erode the soil even more extensively [6–8]. Lack of interest, smallholdings, frequent dry spells, drought, low profitability, unsustainable management practices, low research commitment, and problems of complexity resulted in a shortage of low-tillage technologies for improving soil properties across semi-arid regions [9]; Poor soil and water conservation measures lead to land degradation.

Arable soils are under significant threat due to unsustainable cultivation practices. Cautious soil management is essential to obtain sustainable agricultural production especially in drought-prone areas [10]. Tilling and turning the soil layer is common practice for the preparation of seedbeds. However, the tillage intensity can greatly affect the properties of soils and the plant yield. This is especially important in soils with low organic matter, such as semi-arid regions. Conventional tillage or plowing turns over the soil completely, bringing soil materials from under the plow layer to the surface and burying materials from fertile topsoil to a lower depth. However, continuous and frequent conventional tillage can lead to degradation of soil structure, due to the gradual loss of stable aggregates, leading to soil erosion and compaction, which then result in low moisture availability for plants [11]. On the contrary, conservation tillage or reduced tillage (RT) is an agricultural management approach that aims to minimize the frequency or intensity of tillage operations. RT potentially produces benefits that result from soil C accumulation in the surface soil, such as improved infiltration, water-holding capacity, erosion reduction, nutrient cycling, and soil biodiversity. Continuous and frequent conventional tillage can significantly change the soil physical properties within a growing season [12,13].

Inorganic fertilizers play a critical role in the world's food security; however, they do not add to or maintain soil organic matter, and their inappropriate continued use can damage the soil and endanger sustainability of production in the long term [14]. Furthermore, some studies emphasized associated problems with the inappropriate application and improper management of inorganic fertilizers, including increased consumption of fossil fuels, leach out of soil, pollution of water basins, destruction of micro-organisms and advantageous insects, increased sensitivity of the crop to diseases, and reduced soil fertility, all of which tend to impose irreparable damage to the overall system. On the other end of the spectrum, organic fertilizers seem to be capable of addressing these problems [15,16].

Apparently, a major concern in semi-arid regions is the further loss of SOM and, hence, deteriorated fertility. A number of factors contribute to reduced crop residue mulch and, hence, loss of SOM; these include overgrazing, burning the residues, termites, sparse vegetation, limited moisture, and over-ploughing [16,17].

It was revealed that surface SOM concentration is, in general, negatively correlated with aridity and positively correlated with mean annual precipitation and altitude [18]. In semi-arid regions, there are slow-cycling SOM pools, and, due to unsuitable climatic conditions, the turnover rate is low.

Tillage systems and fertilizer managements were proven to impose significant impacts on soil productivity [19–22]. Inoperative farming management decreases soil productivity to the point where many previously cultivated soils are faced with serious nutrient deficiency and can no longer naturally sustain crop productivity [23]. A combination of reducing soil tillage, mulching with crop residues, application of organic fertilizers, and crop rotation exhibit large capabilities for reversing chemical, physical, and biological processes degrading the soil [22].

However, in most semi-arid areas, reduced-tillage systems are constrained by soil densification, which decreases rainfall infiltration, thereby limiting root access to water [21,24]. Therefore, implementing low-tillage methods should be combined with other soil management options to achieve the desired result. A primary approach to preserve soil productivity is to increase SOM by simply adding OM to the soil.

As a potential supply of OM, farmyard manure (FYM, which is largely produced by the growing livestock industry in northwestern Iran) can be used to improve physical, chemical, and biological characteristics of the soil. The general aim of this study was to investigate the effects of various combinations of FYM, inorganic fertilizers, and tillage systems on selected physical and chemical properties of soil.

2. Materials and Methods

2.1. Site Characteristics

The experiments were conducted in Kharajoo District, between Maragheh and Hashtroud, northwestern Iran (longitude: 46°53′ east (E), latitude: 37°31′ north (N), altitude: 1780 m) during the 2015–2016 growing seasons (two years). The site was covered by a fine mixed, mesic, typical cacixerepts soil, exhibiting a xeric moisture regime [25]. This regime is the typical moisture regime of Mediterranean climates, where winters are moist and cool, and summers are warm and dry. Annual average precipitation is 310 mm with a maximum in April, and one-third of the precipitation falls as snow, and about 78% of the precipitation occurs during the growing seasons [26].

Before the initiation of the experiments a wheat–fallow rotation was applied as a common rotation system in the region. Being adjacent to Sahand Mountains, the area is known to experience long cold winters. The average slope across the study site was measured at 5%–6%. Table 1 shows the monthly average evaporation, relative humidity, temperature, and precipitation across the study area during the growing seasons experienced in this research.

Table 1. Monthly average evaporation, relative humidity, temperature, and precipitation of Kharajoo region during growing seasons of sunflower.

	Temperature (°C)		Evaporation (mm)		Relative Humidity (%)		Precipitation (mm)	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
March	3.6	3.4	53.62	42.36	56.32	61.32	19.62	35.62
April	7.4	6.4	71.40	61.35	45.30	50.57	24.32	24.36
May	10.8	9.8	90.35	84.35	42.68	46.35	15.35	17.65
June	17.1	16.5	113.62	117.89	41.28	36.32	8.65	16.32
July	19.2	18.1	120.36	132.57	37.36	29.64	6.62	8.65
August	25.6	24.3	154.40	160.32	30.17	31.64	0	1.3

2.2. Experimental Design and Farm Management

The soil was clay/loam texture and contained 3.82 g·kg^{-1} organic matter, 0.64 g·kg^{-1} total N, 11.75 mg·kg^{-1} available phosphorus (P), and 182.31 mg·kg^{-1} available potassium (K) in the 0–20-cm soil layer [27–29]. Organic matter content of the soil was low (<0.5%) at the initiation of the experiment [30]. The study site was left uncultivated for three years prior the experiments. A randomized complete blocked design with four replications was adopted based on a split plot arrangement. Main plot size

was set to 40 m × 6 m and sub-plot size was set to 6 m × 6 m. Sunflower (cv. Azargol) was cultivated in a particular site during the wet season (April–August) for two successive years.

Two tillage systems, namely, (a) moldboard ploughing (into an average depth of 30 cm) + two shallow disc harrowing (herein referred to as conventional tillage: CT), and (b) chisel ploughing + disc (herein referred to as reduced tillage: RT), were implemented onto the main plots. The subplots were allocated to five fertilizer treatments including F1: control (no fertilizer application), F2: FYM (20 Mg·ha^{-1}), F3: FYM (40 Mg·ha^{-1}), F4: FYM (20 Mg·ha^{-1}) + 50% of the recommended dose of chemical 100 kg·ha^{-1} N + 50 kg·ha^{-1} P + 50 kg·ha^{-1} K, and F5: full recommended dose of chemical fertilizers (100:50:50, that is, 200 kg·ha^{-1} N + 100·kg ha^{-1} P + 100 kg·ha^{-1} K).

Farmyard manure was applied annually, and tillage operations were performed every March. Planting dates were 10 April 2015 and 15 April 2016. Sunflower seeds were sown manually in rows 0.75 m apart with a plant-to-plant distance in the row of 0.20 m. This resulted in a plant density of approximately 5–7 m^{-2}. Dates of harvesting were 21 August 2015 and 14 August 2016. Chemical fertilizers were added after layout preparation in the form of urea (CH_4N_2O, N 46%), triple superphosphate ($Ca(H_2PO_4)_2 \cdot H_2O$), and potassium sulfate (K_2SO_4).

Each year, farmyard manure was applied, and a tillage operation was performed in March. Then, the planting phase was undertaken a month after the tillage manure application by planting sunflower seeds manually along rows of 75-cm row spacing, at a plant-to-plant distance of 20 cm.

Chemical fertilizers were used in three splits including 1/3 N + full P + full K as basal, 1/3 N as top dressing at the vegetative stage (V4), and 1/3 N as top dressing at the reproductive stage (R2). Each year, following tillage operation, the surface layer of the soil was provided with decayed farmyard manure and mixed to a depth of 15 cm by spade to achieve a uniform mix. In order to arrange the experimental plots into ridges and furrows, soil was piled on either side of rows, so that inter-row areas defined the furrows. The furrow was used to irrigate or drain the plot. In the course of this preparation process, large amounts of FYM and soil were piled along the ridges.

The used farmyard manure was dominantly composed of wheat straw and cow dung—what is normally used for bedding in cowsheds. Containing C at 16.9%, N at 0.52%, P at 0.19%, and K at 0.43%, the FYM was applied on the basis of dry weight. Six rounds of irrigation via furrows were performed during the growing season to provide the plants with water. Composite samples of soil were collected from the top 10–20 cm of the soil layer across each subplot.

2.3. Evaluation of Soil Properties and Plant Growth

Soil samples were collected in mid-June of each year to assess physical and chemical properties. Accordingly, mean emergence time (MET) was evaluated as follows: MET = (Σn × g)/N, where n is the number of seedlings emerging per day, g is the required number of days for emergence, and N is total number of emerged seeds [31].

Bulk densities (BDs) were evaluated from oven-dried (at 105 °C for 24 h) soil sample weights and the soil corer volume, and they were further used to determine total porosity by assuming a particle density of 2.65 cm^{-3}. BD of the soil was calculated for a depth interval of 0–15 cm using the core method [32]. A gravimetric method was devised to record soil moisture at 55 DAS at a depth of 20 cm between sunflower rows across each plot. The moisture content of soil was recorded five days after each round of irrigation. BD multiplied by the gravimetric moisture content gave volumetric soil moisture. The Blanco-Canqui method [33] was followed to obtain saturated hydraulic conductivity (K_{sat}). Core samples were taken from a depth of 0–15 cm along rows and across inter-row areas. Root depth was evaluated according to Shirani et al. [20].

Chlorophyll was evaluated with the Minolta SPAD-502 hand-held device in fully expanded upper leaves at the flowering stage. Leaf area measurements were performed upon termination of the flowering stage. Observations on 10 plants selected at random were recorded to check for the impacts of different tillage systems and fertilizer treatments on phenological development of plants until maturity. Physiological maturity stage was targeted for harvesting the plants, as indicated by the color

alteration of the back of the head (from green to yellow) and bracts (to brown). As far as harvesting was concerned, 10 plants were sampled at random from each replicate for each treatment before being quantified in terms of yield and yield components. Oil contents of the samples were extracted by a small expeller press and were further extracted by the Soxhlet extraction method where hexane served as the solvent [34]. Crop and soil properties were subjected to analysis of variance as described by Gomez and Gomez [35]. The procedure was implemented utilizing SAS Software (SAS Institute, Cary, NC, USA). The F-test was devised to indicate whether or not effects of the treatments were significant, while significance of the difference between means of the two treatments was evaluated by least significant difference (LSD) at 5% probability. We assessed the factor year and found no significant tillage × year × fertilizer type interactions.

3. Results

3.1. Physical Properties

Results of one-way ANOVA were indicative of significance of effects of tillage system, fertilizer treatment, and their interaction on K_{sat} (Table 2), which represents soil infiltration. The comparison between mean values showed an increase in the value of K_{sat} upon applying FYM, particularly in the second year, while different FYM levels exhibited the same effect. By comparison of mean values of K_{sat} over each year, a decrease in K_{sat} was noted in the CT system during the second year, even upon applying FYM.
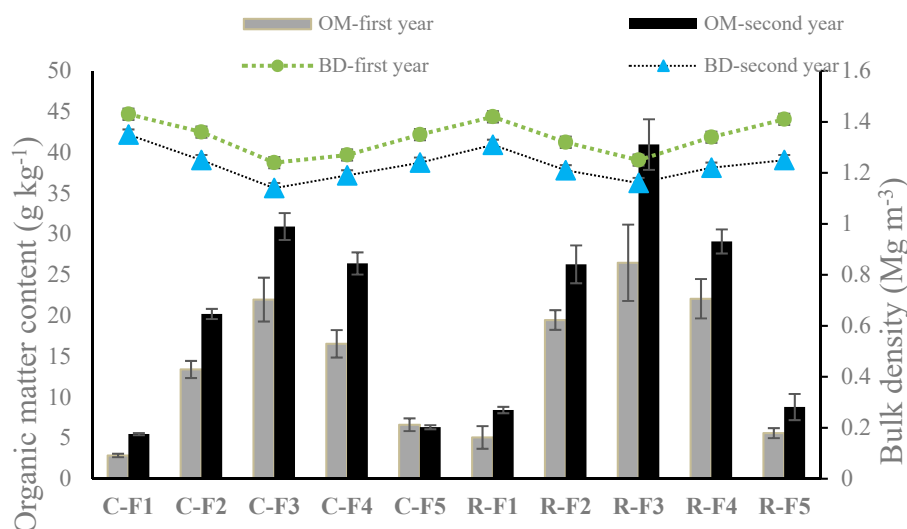
Based on bulk density (BD) evaluations, BD was found to be significantly influenced by both fertilizer treatment and tillage system. On the other hand, FYM was seen to lower BD, such that maximum and minimum BDs were observed in the control plot (the one with no fertilization) and that onto which FYM was applied at the maximum level, respectively. In the meantime, a further decrease in BD in response to the application of FYM was observed in the first and second years in the CT and RT systems, respectively (Figure 1).

Table 2. Analysis of variance (ANOVA) on the effects of tillage (T), fertilizer type (F), and their interaction on soil physicochemical properties and sunflower root depth for two years.

Tillage	Fertilizer	K_{sat} 2015	K_{sat} 2016	VM 2015	VM 2016	N 2015	N 2016	K 2015	K 2016	P 2015	P 2016	RD 2015	RD 2016
CT	F_1	7.13e	5.93f	19.69bc	19.62c	0.046d	0.057e	180.60de	182.50e	10.92d	11.58d	35.00c	36.80e
	F_2	11.05c	10.90d	21.79b	23.57ab	0.072b	0.080c	236.60c	257.50c	13.78c	12.65d	39.75b	53.10bc
	F_3	14.53a	13.59c	26.53a	23.41ab	0.070b	0.082c	258.40b	273.75bc	16.89b	16.95c	45.75a	68.70a
	F_4	11.50bc	9.57de	23.36ab	22.89b	0.077a	0.075c	250.94b	288.00b	16.11b	21.02a	42.25a	54.60b
	F_5	7.84e	6.99f	17.90c	20.40c	0.073ab	0.075c	223.32c	214.00d	20.98a	21.49a	31.75d	47.70c
RT	F_1	7.89e	8.71e	18.34cd	21.56bc	0.054c	0.072cd	186.06de	195.25d	11.71d	14.19cd	33.25cd	40.81d
	F_2	14.00a	16.99a	24.06ab	27.41a	0.082a	0.092ab	227.14c	287.00b	16.43b	16.37c	36.50bc	45.60cd
	F_3	13.86ab	16.72ab	27.42a	27.55a	0.072b	0.082c	248.40b	317.75a	16.77b	18.69bc	42.75a	48.60c
	F_4	14.66a	17.96a	21.92b	26.18a	0.082a	0.101a	287.97a	319.00a	19.99a	22.15a	38.75b	54.00b
	F_5	9.06d	9.57de	17.90cd	20.27c	0.074ab	0.077c	216.33d	241.00c	15.49bc	19.29b	35.25c	45.30cd
Statistical Significance													
Tillage (T)		**		**		*		**		NS		**	
Fertilizer (F)		**		**		**		**		**		**	
T × F		**		NS		NS		NS		**		**	

CT: conventional tillage, RT: reduced tillage, F_1: control, F_2: farmyard manure (FYM) at 20 Mg·ha^{-1}, F_3: FYM at 40 Mg·ha^{-1}, F_4: 50% of the recommended dose of chemical nitrogen–phosphorus–potassium (NPK) + FYM at 20 Mg·ha^{-1}, F_5: full recommended dose NPK fertilizer. K_{sat}: saturated hydraulic conductivity (cm·h^{-1}), VM: volumetric moisture (%), N: nitrogen concentration (%), P: phosphorus concentration (ppm), K: potassium concentration (ppm), RD: root depth (cm). The columns sharing the same letter are not significantly different from each other (least significant difference (LSD), $p < 0.05$). NS: $p > 0.05$, * $p \leq 0.05$, ** $p \leq 0.01$.

Figure 1. Effect of nutrient management practices and tillage systems on soil organic matter content (OM: columns) and bulk density (BD: dashed line) during the years 2015 and 2016. The error bars indicate standard deviation. C: conventional tillage, R: reduced tillage, F_1: control, F_2: farmyard manure (FYM) at 20 Mg·ha^{-1}, F_3: FYM at 40 Mg·ha^{-1}, F_4: 50% of the recommended dose of chemical nitrogen–phosphorus–potassium (NPK) + FYM at 20 Mg·ha^{-1}, F_5: full recommended dose NPK fertilizer.

However, the effect of FYM was more prominent in second year. These findings indicate the gentle trend through which FYM may work in RT systems, such that it may take a long time for positive effects of the application of FYM on physical characteristics of soil to emerge. Results were indicative of a negative correlation between BD and OM ($r = -0.87$ and -0.84; Table 3).

Evaluation of soil moisture during the first year showed that, upon applying FYM, soil moisture enhanced significantly, with the enhancement being more evident in the RT system rather than the CT system (Table 2). Here, 50% and 33% increases in soil moisture (over control) were obtained upon applying FYM at 20 and 40 t·ha^{-1}, respectively. Different levels of FYM resulted in significant differences by the first year, while the same result was obtained with different FYM application rates during the second year.

Table 3. Correlation coefficients among some physicochemical properties of soil and morphological traits of sunflower.

	OM	BD	K_{sat}	MET	VM	N	K	P	RD	LA	CHL	AY	BY	DM	OIL	HI
OM		−0.87	0.96	−0.84	0.91	0.64	0.83	0.47	0.78	0.16	0.54	0.75	0.38	0.90	0.59	−0.03
BD	−0.84		−0.79	0.80	−0.87	−0.57	−0.72	−0.50	−0.86	−0.09	−0.71	−0.77	−0.27	−0.99	−0.37	−0.09
K_{sat}	0.84	−0.67		−0.83	0.85	0.69	0.84	0.46	0.73	0.17	0.52	0.73	0.48	0.82	0.56	−0.12
MET	−0.91	0.87	−0.77		−0.77	−0.73	−0.85	−0.51	−0.77	−0.27	−0.66	−0.92	−0.23	−0.81	−0.34	−0.25
VM	0.88	−0.64	0.95	−0.78		0.36	0.59	0.16	0.87	0.14	0.41	0.57	0.35	0.88	0.27	−0.15
N	0.66	−0.67	0.87	−0.76	0.76		0.79	0.77	0.31	0.20	0.56	0.79	0.48	0.61	0.57	0.13
K	0.92	−0.83	0.86	−0.95	0.84	0.82		0.72	0.67	0.23	0.79	0.93	0.12	0.75	0.69	0.32
P	0.31	−0.57	0.32	−0.49	0.23	0.55	0.57		0.16	−0.09	0.66	0.71	0.16	0.52	0.71	0.35
RD	0.61	−0.80	0.41	−0.75	0.33	0.58	0.59	0.37		0.25	0.67	0.71	−0.02	0.82	0.13	0.19
LA	0.91	−0.81	0.81	−0.94	0.85	0.79	0.94	0.58	0.62		−0.07	0.21	−0.09	0.17	0.02	0.37
CHL	0.81	−0.75	0.58	−0.83	0.60	0.53	0.87	0.65	0.52	0.84		0.85	−0.15	0.65	0.35	0.44
AY	0.75	−0.73	0.81	−0.80	0.70	0.87	0.90	0.73	0.57	0.86	0.81		0.01	0.76	0.45	0.49
BY	0.57	−0.45	0.48	−0.62	0.52	0.43	0.75	0.68	0.09	0.68	0.84	0.69		0.32	0.25	−0.75
DM	0.81	−0.98	0.62	−0.82	0.62	0.61	0.75	0.54	0.77	0.78	0.70	0.66	0.38		0.46	0.06
OIL	0.60	−0.63	0.67	−0.66	0.68	0.78	0.66	0.62	0.50	0.81	0.55	0.75	0.41	0.68		0.01
HI	0.29	−0.49	0.18	−0.28	0.05	0.23	0.12	−0.06	0.76	0.14	0.01	0.15	−0.46	0.52	0.18	

Critical values of correlation $p < 0.05$ and $p < 0.01$ are 0.65 and 0.85, respectively. The coefficients above the diagonal line are related to the first year and the numbers below the diagonal line are related to the second year. K_{sat}: saturated hydraulic conductivity, VM: volumetric moisture, N: nitrogen concentration, P: phosphorus concentration, K: potassium concentration, RD: root depth, CHL: chlorophyll content, LA: leaf area, DM: day to maturity, BY: biological yield, OIL: achene oil percentage, HI: harvest index.
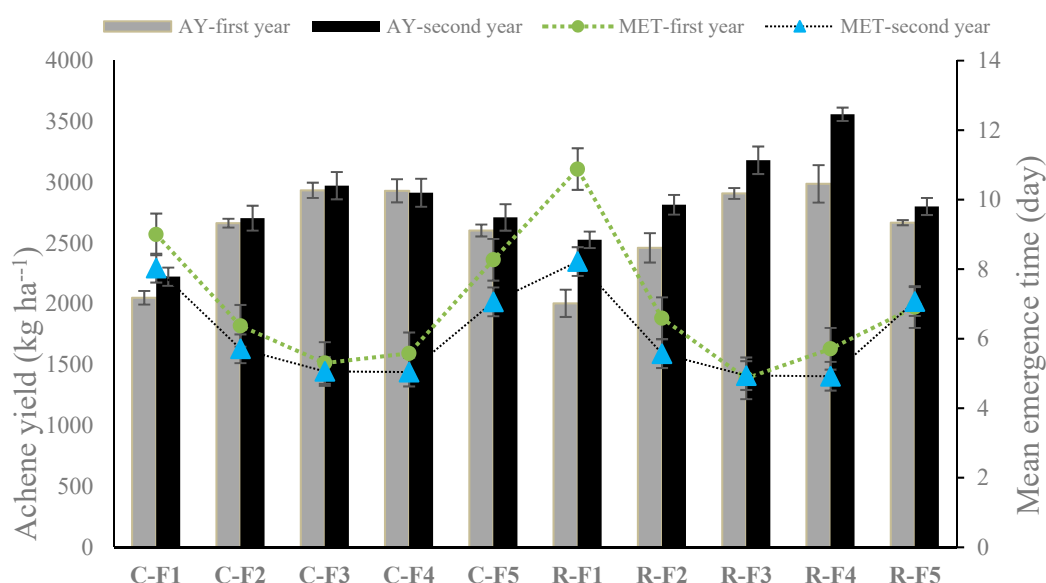
3.2. Chemical Properties

Based upon OM measurement results, application of FYM was observed to enhance SOM under both tillage systems (Figure 1). A comparison of mean values among different fertilizer treatments showed significantly different organic matter content ($p < 0.05$) with different rates of FYM application. In the meantime, FYM exhibited more remarkable impacts under the RT system than the CT system. Maximum SOM was obtained when FYM was applied at 40 t·ha^{-1} in the RT system (27 and 41 g·kg^{-1} in the first and second years, respectively). A small increase in SOM was observed with chemical fertilization, as compared to control.

Nitrogen content measurements indicated that, irrespective of NPK fertilizer dose, application of NPK fertilizer enhanced the nitrogen content of the soil. Generally speaking, higher nitrogen contents were obtained with the RT system than the CT system. The highest nitrogen content was achieved in the second year when 50% of the recommended dose of chemical fertilizer was applied in combination with FYM in the RT system (Table 2). Commonly, the nutrient content of plots subjected to CT was more perceptible, partly because of the deficit in substantial soil displacement and mixing. Maximum K and P contents were observed when FYM was applied in combination with chemical fertilizer in the RT system (Table 2). Maximum K content in the RT system was 13% higher than that in the CT system. Applying FYM in combination with chemical fertilizer in the CT and RT systems enhanced K content by 48% and 59% over the control, respectively. Although the soils of semi-arid areas are known to contain relatively high K contents, the use of FYM and an RT system can improve the content of K available to the plant, thereby increasing its resistance to abiotic stresses.

P content measurements made it clear that maximum P contents in the CT and RT systems were achieved with chemical fertilization and combined FYM/chemical fertilizer application, respectively. The results indicated that further organic P was available in the RT system than the CT system.

3.3. Plant Growth Properties

According to root depth measurements, the deepest root was recorded in the CT system where FYM was applied at a high level. Based on the obtained values of mean emergence time (MET), the application of FYM lowered the MET significantly in both tillage systems, such that minimum MET was recoded for plots receiving 40 t·ha^{-1} FYM (Figure 2). Comparing mean values of MET between the two tillage systems revealed that there were similar MET values in both systems. A further comparison of MET between FMY-treated and fertilized subplots indicated that F2, F3, F4, and F5 had MET values of 32%, 44%, 41%, and 19%, respectively. The effects of fertilizers on MET were much more prominent in RT systems than in CT systems. Given the soil compaction in RT systems, the application of FYM could largely address this problem and enhance the seedling emergence rate, thereby improving seedling establishment even further. Further confirming this fact, a positive association was identified between BD and MET (Table 3). Moreover, MET was found to be inversely related to OM, as well as nutrient concentration (Table 3). According to the results, a further improvement in soil physical properties can raise seedling emergence rate. Table 4 reports the impacts of the two tillage systems and fertilized treatments on growth parameters and achene yield. The results showed that chlorophyll index was originally not affected by the tillage system; however, an increase by 43% was observed in the chlorophyll index upon the combined application of FYM and 50% of the recommended dose of chemical fertilizer.

Figure 2. Effect of nutrient management practices and tillage systems on sunflower (*Helianthus annuus* L.) achene yield (AY: columns) and on the mean emergence time of seedling (MET: dashed line) during the years 2015 and 2016. The error bars indicate standard deviation. C: conventional tillage, R: reduced tillage, F1: control, F2: FYM at 20 Mg·ha^{-1}, F3: FYM at 40 Mg·ha^{-1}, F4: 50% of the recommended dose of chemical NPK + FYM at 20 Mg·ha^{-1}, F5: full recommended dose NPK fertilizer.

The largest leaf area was recorded with F3 and F4 in the RT systems. A positive relationship was observed between leaf area and OM, moisture content, root depth, and P, K, and N contents (Table 3). An investigation on the obtained values of achene yield indicated that, although the two tillage systems had no significant difference in the first year, the highest achene yield in the second year occurred in the RT system (Figure 2). Maximum yield in either year was obtained across F3 and F4 subplots. Surprisingly, a positive significant correlation was detected between achene yield as K_{sat}, OM content, soil moisture, and nutrient concentration (Table 3).

4. Discussion

The increased K_{sat} upon adding FYM to inorganic fertilizer might be related to the enhanced structural stability of soil, increased OM, and improved surface soil biological activity. Farmyard manure and a balanced chemical fertilizer seem to contribute to better aggregation, thereby increasing effective pore volume. Given the dependence of soil permeability on effective pore volume, one may suggest a direct impact in terms of improved pore volume upon applying FYM on the K_{sat} of soil [34]. According to the results, the RT system with combined FYM + 50% of the recommended dose chemical NPK fertilizer application could increase K_{sat} significantly, possibly because of decreased density. Hydraulic conductivity is significantly affected by soil pore volume, and our findings showed that the application of FYM and choosing a suitable tillage (RT) can affect flow and transport through the soil matrix by improving the pores. These factors are very important in semi-arid regions, and they can determine the effective rain ratio for plants. the application of RT without the application of organic fertilizers will lead to failure in the short term.

Table 4. Effect of FYM and chemical fertilizers on plant growth parameters under different tillage systems for two years.

Tillage	Fertilizer	CHL		LA		DM		BY		OIL		HI	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
CT	F_1	36.75^d	40.50^d	4245.31^e	4101.00^e	109.25^e	113.00^e	7734.81^d	8053.00^d	37.71^{cd}	37.73^e	26.53^c	27.68^c
	F_2	42.25^{cd}	47.50^{cd}	4883.00^{cd}	5951.62^c	117.50^c	120.75^{cd}	8606.00^c	8670.35^{cd}	39.09^{bc}	41.26^c	31.03^a	31.23^b
	F_3	57.50^a	49.25^c	6240.00^{ab}	6531.6^b	124.50^a	134.00^a	10,096.00^a	9871.80^b	38.22^c	43.04^b	29.12^{ab}	30.15^b
	F_4	57.25^a	55.50^b	5658.85^b	7144.25^{ab}	122.70^b	127.00^b	10,345.50^a	10,857.52^a	39.38^{bc}	42.00^{bc}	28.32^b	26.85^{cd}
	F_5	49.25^b	46.25^{cd}	5507.80^b	4569.00d	116.75^{cd}	125.25^c	8315.00^c	8820.36^{cd}	40.95^b	44.34^a	31.36^a	30.75^b
RT	F_1	38.50^d	39.00^d	5151.35^c	4897.59^d	110.25^e	116.50^e	7573.30^d	7391.50^e	38.77^c	40.76^c	26.48^c	34.17^a
	F_2	40.00^c	43.75^d	5765.85^b	6676.25^b	120.50^{bc}	126.50^b	8456.50^c	9098.34^b	40.63^b	43.69^b	29.15^{ab}	30.99^b
	F_3	46.75^{bc}	60.25^a	6576.32^a	7321.82^a	125.25^a	132.00^a	9776.00^b	11,031.00^a	40.67^b	43.45^b	29.81^{ab}	28.84^c
	F_4	53.25^a	55.50^b	6232.35^{ab}	7554.00^a	118.25^c	124.25^c	10,205.52^a	10,717.00^a	44.04^a	45.89^a	29.28^{ab}	33.27^a
	F_5	45.25^{bc}	45.75^{cd}	5382.51^c	4724.00^d	109.75^e	120.25^d	8758.30^c	9348.80^c	36.78^{de}	38.33^d	30.45^a	30.75^b
Statistical significance													
Tillage (T)		NS		**		NS		NS		*		*	
Fertilizer (F)		**		**		**		**		**		*	
T × F		NS		**		**		**		**		NS	

CT: conventional tillage, RT: reduced tillage, F1: control, F2: FYM at 20 Mg·ha^{-1}, F3: FYM at 40 Mg·ha^{-1}, F4: 50% of the recommended dose of chemical NPK + FYM at 20 Mg·ha^{-1}, F5: full recommended dose NPK fertilizer. CHL: chlorophyll content (SPAD unit), LA: leaf area (cm^2), DM: day to maturity, BY: biological yield (kg·ha^{-1}), OIL: achene oil percentage, HI: harvest index (%). The columns sharing the same letter are not significantly different from each other (LSD, $p < 0.05$). NS: $p > 0.05$, * $p \leq 0.05$, ** $p \leq 0.01$.

Our results showed that there was a significant negative correlation between BD and OM. Given that potential factors determining soil density are mostly mineral and chemical, the organic contents of FYM can affect these factors, mainly by influencing the charges on colloid surfaces [35]. Furthermore, differences in tillage systems could be responsible for more extensive soil structure degradation and structure changes in the CT system. Following the same approach explained for soil tillage, machine traffic tends to deteriorate soil porosity, thereby increasing BD. A difference observed between the years can be related to the accumulated effects of fertilizer and aridity of the first year. The significant correlation of FYM and tillage effects with BD showed that the soil organic matter and carbon levels are now below their critical level in the studied site, and this status was noticeable under the RT system. Our findings demonstrate that the combined effects of tillage and fertilizer should be considered in soil management; however, the effect of FYM was more prominent than other treatments.

These results demonstrate that, in RT systems, it is necessary to apply significant amounts FYM or adopt proper crop residue management. The resultant increase in SOM can be attributed to the increased macro-aggregate stability of clay soils, possibly because of promoted microbial populations and the aggregation of clay- and silt-sized particles to form macro-aggregates using the microbe-produced mucilage [36–38]. Studies showed that the distribution of dominant populations of microorganisms is affected by tillage system, thereby highlighting differences among various tillage systems. However, generally, microbial activities follow slower trends in RT systems than in CT systems where OM is supplied to the soil. Likewise, incorporating farmyard manure into the soil and RT reportedly increased the OM content of the soil, protected the soil against erosion, and resulted in enhanced porosity and aggregation of the soil, which enhanced the water retention and infiltration characteristics of the soil while reducing its mechanical impedance.

Soil moisture was considerably increased by FYM application under RT in the second year. The soil had very low SOM before the application of farmyard manure. Under the mentioned conditions, due to the unsuitable physical conditions, water retention capacity in the soil was very low, and a small part of the provided water from rainfall or irrigation could penetrate into the effective depth of the soil, and most of the water was either runoff from the plant surface or temporarily stored in the surface layers and evaporated from the soil immediately. The application of FYM by reducing bulk density, and increasing porosity, water infiltration rate, saturated hydraulic conductivity, and other factors improved the capillary water holding capacity. The improvement of permeability, increased water holding capacity in the soil, and reduced evaporation were among the factors contributing to the improvement of water content in these conditions. The volume of moisture stored in the soil is a function of total precipitation, which was, as a matter of fact, higher in the second year than in the first year. The observed outcome was possibly a result of the cumulative effect of FYM. Moreover, a comparison between the two tillage systems showed significant differences, with the RT system exhibiting the maximum moisture content. These results further confirmed those of Zibilske and Bradford [39]. The subplot subjected to chemical fertilization showed the minimum soil moisture, possibly due to promoted foliage growth and accelerated moisture depletion through transpiration. As another observation, CT was often seen to increase soil temperature. The relatively high soil moisture–OM content correlation coefficient could be explained by these factors ($r = 0.91$ and 0.88; Table 3). Also, an increase in soil moisture was recorded for the second year. In this regard, some previous studies also suggested that inorganic fertilization can indirectly increase SOM by improving the root biomass compared to control plots [34,35].

Irrespective of the applied tillage system, the minimum OM contents were observed either without using any fertilizer or upon using chemical fertilization. Indeed, despite the original presumption that chemical fertilizers can contribute to increased soil OM by promoting root development by extending the population of microorganisms, our results showed the non-sustainability and insignificance of this mentioned assumption in the studied semi-arid region. Hence, taking into account the specific set of dominant conditions across semi-arid areas, such as high temperature, low rainfall, and inadequate straw return, chemical fertilizers may fail to enhance SOM appropriately.

For most part, the soil surface exhibits the highest nutrient content, with the content degrading upon moving to further depths. This is because nutrients are commonly applied at the surface where crop residues also decay. Rainfall is thought to accelerate the loss of residual N. However, the gradual release of elements from FYM largely inhibits the losses, such that high levels of N can be preserved by applying FYM. The higher amount of N in plots receiving NPK was due to faster N release from urea, which enabled maximum N availability only up to 30 days, coinciding with the stem elongation stage. In addition to NPK, FYM also supplied appropriate quantities of N, P, K, Mn, Zn, and Fe, thus conferring a distinctive advantage in terms of the continued balanced supply of major and micro-nutrients for a prolonged period, thereby mitigating the chance of nutrient stress. An adequate supply of N and other nutrients through FYM was the main reason for their better performance. The difference in P content between the tillage systems could be attributed to corresponding differences in the physicochemical properties and moisture content of soil. It is advantageous to compare this figure to that presented by Rotta et al. [40], who suggested a reduction in P content with soil disturbance in CT.

The highest root depth was recorded for CT. It should be, however, noted that over-compaction in the reduced tillage system imposes adverse impacts on soil water, soil nutrient pools, and root growth, thereby limiting the explored volume of soil by roots. This can then degrade the plant's ability to provide itself with nutrients and water. These outcomes are in agreement with those of other researchers who pointed out that the compaction of deeper soil layers in an RT system inhibits the proper development of roots [19]. However, long-term application of FYM was found to significantly reduce soil compaction and density.

The highest chlorophyll content and leaf area were recorded for plants grown with an integrated application of FYM and NPK fertilizer. Given the key roles played by nitrogen and magnesium in the synthesis of chlorophyll, this improved index could partly be attributed to increased availability of these elements. Leaf area and chlorophyll index are determinant factors for photosynthesis rate and source strength in a plant, and they take key part in determining the supply of photo assimilates. The results indicate that crop yield can be enhanced through improving soil conditions by adjusting sink–source relationships and by increasing the strength and size of the source. Biological yield and achene oil content also followed similar trends. The improvements in photosynthetic vegetative organs strengthen the source capacity in plants and ultimately result in higher achene yield and improved oil yield.

The statistically significant correlation coefficient between growth characteristics and soil properties showed that even a small improvement in physical and chemical properties of soil through proper management can end up increasing the yield. The maximum harvest index in the first and second years was seen with chemically fertilized and combined FYM/chemically fertilized subplots in the RT system, respectively. The superior effect of FYM in the second year was largely due to cumulative effects of OM and the gradual release of nutrients. Our findings emphasized that, in semi-arid regions such as the studied location, the successive application of FYM and chemical fertilizer under reduced tillage (RT) can achieve sustainable conditions where the effects of chemical fertilizer will be more realistic.

5. Conclusions

Our findings revealed that best sunflower performance was obtained with the integrated application of FYM and chemical fertilizer. The application of FYM improved soil organic matter, soil moisture, and nutrient concentration while decreasing bulk density. Also, the choice of tillage system strongly affected particular soil characteristics (e.g., the CT system caused a dramatic drop in soil quality). Integrating soil fertility management with RT resulted in larger root growth and maximized nutrient use efficiency, as well as enhanced access of the plant to soil nutrients and stored moisture. After two years of applying FYM across this region, the soil exhibited higher productivity, particularly in the RT system. The advantages of FYM were more evident in the second year. The results reflected that, to achieve an acceptable result in the short term, both organic and inorganic fertilizers should be considered. It was further shown that achene oil content significantly responded to soil management and nutrition supply, especially under the RT system. To sum up, soil preservation practices including

RT and combined FYM/chemical fertilizer application can help enhance the efficiency of crop production systems and soil structure in the long run.

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