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Tillage intensity by organic fertilization interaction on sunflower performance and some soil properties

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Abstract: A field trail was performed to study the impacts of soil tillage system and some organic and inorganic fertilizers treatments on sunflower performance and soil characteristics in the semi-arid region across 2015–2016 growing season. The tillage systems were (T1) conventional tillage, and (T2) reduced tillage while the fertilizer treatments were (F1) control, (F2) 20 t ha^{-1} farmyard manure, (F3) 40 t ha^{-1} farmyard manure, (F4) 20 t ha^{-1} farmyard manure plus 50:25:25 kg ha^{-1} NPK, (F5) 100:50:50 kg ha^{-1} NPK. The two-way entry (treatment) by tester (trait) biplot tool, described 84 % of the observed variability (68 % and 16 % by the first two principal components, respectively). The which-wins-where pattern, showed six vertex treatment (tillage system × fertilizer type) as: T1-F1 which had the highest values for bulk density; T1-F3 which had the highest values for days to maturity, organic matter and root depth; T1-F5 which had the highest values for soil phosphorus and harvest index; T2-F1 which had the highest values for mean emergence time; T2-F3 which had the highest values for soil potassium and achene yield; and T2-F4 which had the highest values for soil nitrogen. The ideal treatment pattern indicated that T2-F4 was the best treatment combination. We found that the best performance for sunflower achene yield was obtained with using reduced tillage system plus F3 or F4 fertilizer treatments. Finally, application no fertilizer or using only chemical fertilizers could not improve sunflower performance in both tillage systems.

Keywords: chemical fertilizers; conservation tillage; farmyard manure; reduced tillage.

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1 Introduction

Human population growth puts pressure on natural resources, and increases the demand for food while in most areas producers are faced to risk of environmental stresses. Regarding the arid and semi-arid areas in world and recent technology advancements, it may cause to strengthening land use in such regions (Naorem et al. 2023). In these areas, a little precipitation is irregular as well as unpredictable, which is inadequate for many crops' production. Such circumstances restrict organic matter maintenance in soil and influence adversely different properties of soil including physical, chemical, and biological indices (Zhao et al. 2023). The Iran's north-west semi-arid areas have winter-dominant rainfall and winter cereals are well adapted to such conditions while from crop biodiversity viewpoint and sustainability aspect, winter cereals-fallow rotation impacts negatively soil fertility (Nouraein et al. 2019b).

Insufficient vegetation, drought stress, unsustainable management practices like conventional tillage caused to more problems while using low-tillage can improve soil properties under semi-arid circumstances. Conventional tillage system is routine operation for the seedbed preparation in Iran's north-west semi-arid areas. Although, conventional tillage system can influence the soil properties positively and improve the crop performance, especially in soils with low organic matter, but also it transposes the positive fertile factors from topsoil to a lower depth. Also, applying frequently conventional tillage system can degrade of soil structure and cause to soil erosion, and moisture shortage for planted crops due to soil compaction (Ordoñez-Morales et al. 2019). Conservation tillage system wants to decrease the tillage times which generates some benefits like increasing carbon accumulation in the soil surface, decreasing erosion reduction, and improving soil biodiversity.

Inorganic fertilizers have not capacity to serve sufficient organic matter content in soil, and their continuous application can destroy the soil properties and eliminate the yield stability in several years. Some investigations demonstrated that the main problems occur in semi-arid regions are high costs of fuels, water and soil pollution, eliminations of soil microorganisms, increasing diseases, and soil fertility reduction which were generated by weak management of fertilizers' usage (Zhou et al. 2022). In contrast, organic fertilizers can solve these problems especially in semi-arid areas where a major concern is the huge loss of soil organic matter. Some problems responsible for field residue reduction and, hence, loss of soil organic matter; which include overgrazing, residues elimination, restricted moisture, and conventional tillage system. Surface soil organic matter is negatively associated with limited humidity and positively associated with some climatic factors like magnitudes of rainfall and altitude. In semi-arid areas, the soil organic matter cycle is slow due to harsh weather circumstances, the turnover rate is very low and regarding tillage types and applied fertilizer intensified such cycle impacts on soil fertility (Hag-Husein et al. 2021).

Combining of reduced tillage, system with large scale of crop residues as well as using organic fertilizers and proper rotation system indicated huge potential for maintaining chemical, physical, and biological properties of soil (Zhang et al. 2022). However, in most of semi-arid regions, using reducing soil tillage is caused to soil densification and so restricts rainfall infiltration in soil, thus the availability of water to palnts is decreased remarkably. Therefore, reduced tillage application should be incorporated with the other soil managements to get the most favorable results such as increase soil organic matter by adding or maintaining organic matter to the soil (Yankov and Drumeva 2021). One of the main sources of organic matter is farmyard manure which is produced in large scale by the livestock growing in Iran and applying organic matter to the soil can reclaim some soil characteristics like physical or chemical properties of field soil. The main target of this research was to study the impacts of farmyard manure application and tillage systems on some characteristics of sunflower as well as some soil characteristics under semi-arid condition.

2 Materials and methods

The trial was performed in Maragheh region, northwestern Iran (46°53′ E, 37°31′N) during the 2015–2016 season. The region has the Mediterranean climate moisture regime with cold and humid winters as well as warm and dry summers with 310 mm annual precipitation and altitude 1780 m. The pervious cultivation system of field experiment was a wheat–fallow rotation. The field soil was clay/loam with contained 0.4 % organic matter. A randomized complete block design with four replicates was used in a split plot layout whereas large plot was tillage systems and small plot was fertilizer treatments. Sunflower (cultivar Azargol) was planted in experimental plots manually in 75 cm × 20 cm plant distances. The tillage systems were (T1) conventional tillage system consist on moldboard ploughing and two shallow disc harrowing, and (T2) reduced tillage consist on chisel ploughing and disc. The fertilizer treatments were (F1) control, (F2) 20 tons per hectare farmyard manure, (F3) 40 tons per hectare farmyard manure, (F4) 20 tons per hectare farmyard manure plus 50:25:25 kg ha^{-1} NPK, (F5) 100:50:50 kg ha^{-1} NPK as the full local recommended of chemical fertilizers in Maragheh region. For treatment application, farmyard manure distributed and then tillage operation was done on March and planting was done in 10 April and harvesting was done on 21 August. Six times irrigation were done based on local recommendation for sunflower production.

The top surface (10–20 cm) composite samples were collected for measuring some soil characteristics. Mean emergence time (MET) was computed based on Nouraein et al. (2019b). Bulk density (BD) was measured from dried samples (at oven with 105 °C for 24 h) of soil weight and the soil corer volume, and then nitrogen, phosphorus and potassium concentrations as well as organic matter (OM) were measured in soil samples. Root depth (RD) was measured from ten random plants of each plot. Days to physiological maturity (DM) was recorded at plant harvesting time, achene yield (AY) and biological yield were measured in each plot and used to computation of harvest index (HI). The entry by tester or treatment-trait (T × T) biplot figures were generated by plotting the symmetric scaled scores of the treatment combinations and traits, thus each entry (treatment combination) or tester (trait) is indicated by a sign in the figure which were drawn by GGEbiplot software (Yan 2001).

3 Results

The T × T biplot model for sunflower dataset, explained 84 % of the observed variability of the standardized dataset, and such high description amount indicates the good capability of T × T biplot model for interpretation the relationships among the sunflower traits as well as treatment combinations. The PC1 and PC2 described 68 % and 16 %, respectively, whereas reveals the most importance of the first principal component. Acceding to Yan and Frégeau-Reid (2018), if the first two PCs explain more than 60 % of the observed variability, the proper and acceptable goodness of fit for the TT biplot model is achieved. The T × T biplot Figure 1, as which-wins-where pattern, shows six vertex treatment combinations (tillage system × fertilizer type) in this study as: T1-F1 (conventional tillage system – control) which had the highest values for bulk density (BD); T1-F3 (conventional tillage system – 40 t ha^{-1} farmyard

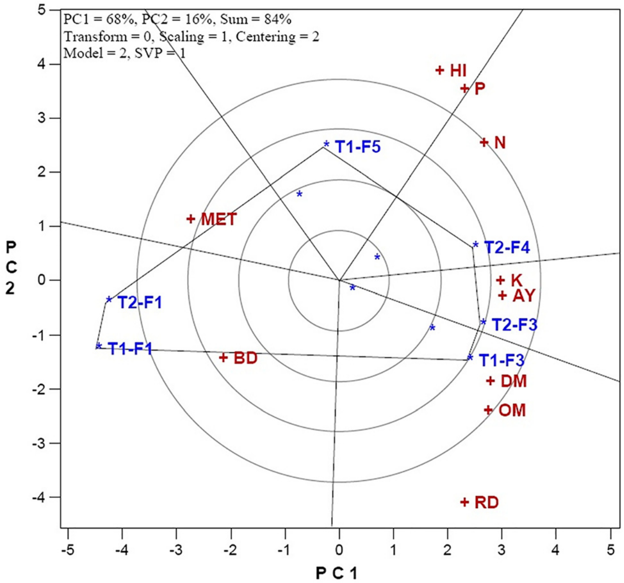

Figure 1: Which-wins-where pattern of treatment by trait (TT) biplot showing which treatment had the highest values for which traits. Traits are nitrogen (N), potassium (K), phosphorus (P), root depth (RD), days to maturity (DM), harvest index (HI), achene yield (AY), mean emergence time (MET), organic matter (OM) and bulk density (BD).

manure) which had the highest values for days to maturity (DM), organic matter (OM) and root depth (RD); T1-F5 (conventional tillage system – 100:50:50 kg ha^{-1} NPK) which had the highest values for soil phosphorus (P) and harvest index (HI); T2-F1 (reduced tillage system – control) which had the highest magnitudes for mean emergence time (MET); T2-F3 (reduced tillage system – 20 t ha^{-1} farmyard manure) which had the highest values for soil potassium (K) and achene yield (AY); and T2-F4 (reduced tillage system – 40 t ha^{-1} farmyard manure plus 50:25:25 kg ha^{-1} NPK) which had the highest values for soil nitrogen (N). These treatment combinations have the highest or the lowest performance in some of the recorded traits of sunflower because their distance from the plot origin were high. Thus, it can be concluding that most of the treatment combinations had the highest values for some of the sunflower traits. However, from economical aspect, T2-F3 (reduced tillage system – 20 t ha^{-1} farmyard manure) could produce the high magnitudes of achene yield (AY). This treatment combination has standards of conversional tillage system and organic agriculture and due to not using the chemical fertilizers can reach to high sustainable cultivation targets.

In the T × T biplot, a vector is generated from the graph origin to each sign of the treatment combinations to show imagination of the association between and among the treatment combinations. In the Figure 2, the association coefficients between any

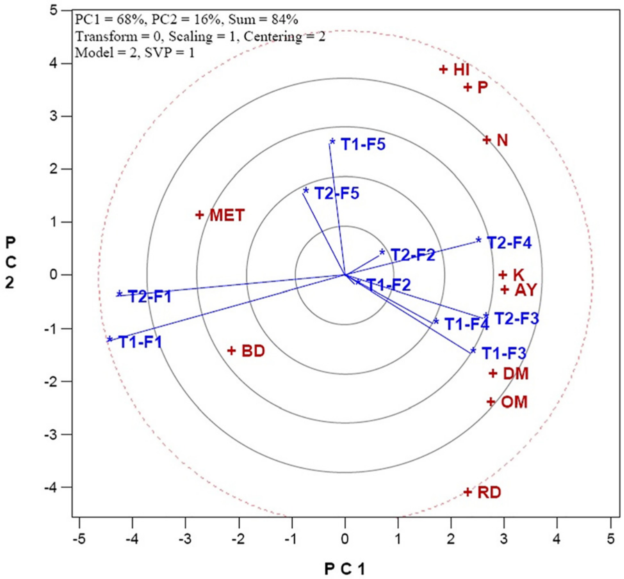

Figure 2: Relationship among entries (treatments) in treatment by trait (TT) biplot. Traits are nitrogen (N), potassium (K), phosphorus (P), root depth (RD), days to maturity (DM), harvest index (HI), achene yield (AY), mean emergence time (MET), organic matter (OM) and bulk density (BD).

two treatment combinations are approximated by the magnitude of cosine in their angles, thus this graph of T × T biplot model shows interrelationships among the treatment combinations via amounts of loadings from first two PCs. Thus, the most outstanding interrelationships by this figure are: a positive association between T1-F1 and T2-F1; between T1-F5 and T2-F5; between T2-F4 and T2-F2; and among T1-F3, T1-F4 and T2-F3 as shown by the tiny obtuse angles of related vectors ($r = \cos 0° = +1$). There was relatively a zero association between T1-F1 and T2-F1 with T1-F5 and T2-F5 as well as T2-F4 and T2-F2 with T1-F5 and T2-F5 (Figure 2) as shown by the perpendicular vectors ($r = \cos 90° = 0$). There was a negative association between T1-F1 and T2-F1 with T2-F4 and T2-F2 as shown by the huge obtuse angles between their signs ($r = \cos 180°$). Most of mentioned results for associations between treatment combinations can be verified via Pearson correlation coefficients matrix due to high explanation of biplot model (84 %). However, some little discrepancies between predictions of the T × T biplot model and original Pearson correlation coefficients will be observed because the model accounted for <100 % of the observed variation in sunflower data.

The performance of achene yield (AY) as final economic trait was examined based on treatment by trait (TT) biplot (Figure 3), and indicated that T2-F3 and T2-F4 treatment combinations produced the highest achene yield followed by T1-F3 and T1-F4 treatment combinations. Also, T1-F2 and T2-F2 treatment combinations produced above average achene yield. However, it seems that using reduced tillage system plus F3 (40 t ha^{-1} farmyard manure) or F4 (20 t ha^{-1} farmyard manure plus

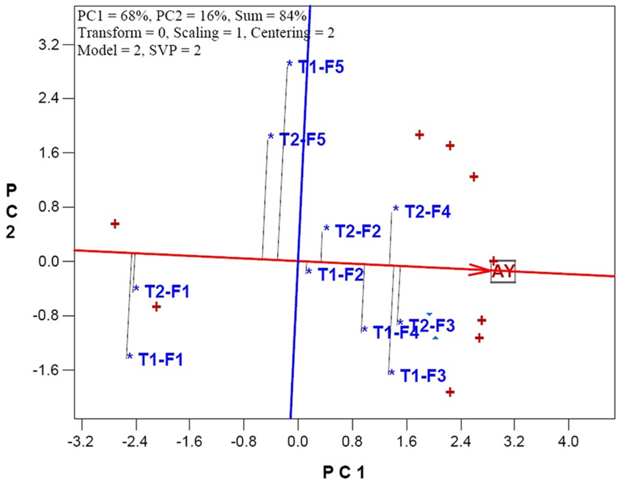

Figure 3: Examining the performance of/at achene yield (AY) in treatment by trait (TT) biplot.

50:25:25 kg ha^{-1} NPK) can be very useful for obtaining high yield performance as well as reaching to sustainable agriculture targets via both farmyard manure application and reduced tillage usage. The performance of T1-F1 and T2-F1 (control fertilizer at both tillage system) as well as T1-F5 and T2-F5 (full chemical fertilizer at both tillage system) treatment combinations regarding achene yield was below average (Figure 3). It is interesting that no fertilizer application (control) or only chemical fertilizer usage cannot produce high economic yield performance at both tillage systems, so the impact of fertilizer and its type is more than only type of tillage system.

An Ideal Entry (treatment combination) has been determined as the treatment that contains various favorable traits, according to Figure 4, the Ideal treatment combination is close related to as T2-F4 while T1-F1 following to T2-F1 were not suitable because they were far from the Ideal Entry position. The rank of the other treatment combination based on the Ideal Entry position were T2-F3 > T1-F4 > T1-F3 > T2-F2 > T1-F2 as the above average treatments followed by T1-F5 and T2-F5 as the blow average treatments (Figure 4). The role of organic fertilizers in determining position of Ideal Entry (treatment combination) was more important than tillage system type and using both organic fertilizer as well as reduced system was more efficient in yield high production of sunflower and obtaining good performance of achene yield for the other measured morphological traits.

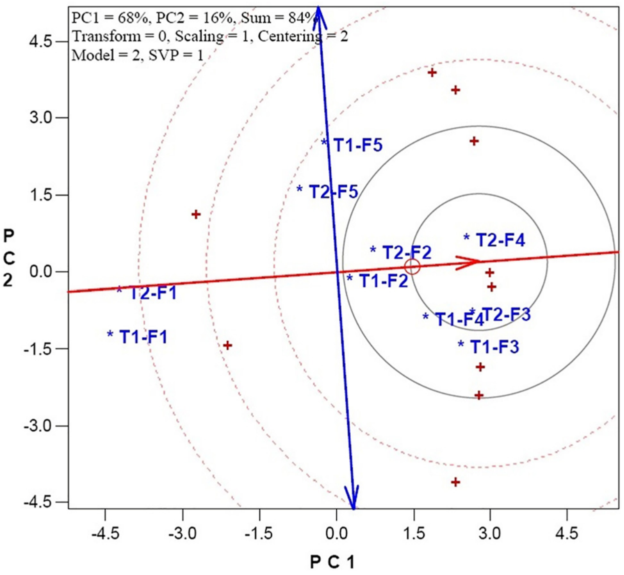

Figure 4: Ideal entry (treatment) view of treatment by trait (TT) biplot showing the position of ideal treatment.

4 Discussion

We found that the reduced tillage system plus 20 t ha^{-1} farmyard manure with 50:25:25 kg ha^{-1} NPK could increase sunflower yield while the reduced tillage system without the organic fertilizer will lead to good results. However, tillage system types could be reason for degradation in soil structure and soil porosity, thereby increasing soil bulk density. Our results verified both effects of reduced tillage and organic fertilizer must be regarded in filed management but the impact of farmyard manure was more outstanding than tillage systems. It is essential to use considerable magnitudes (40 t ha^{-1}) of farmyard manure to achieve the final targets or add half of the recommend doge of chemical fertilizers to organic fertilizer. Such suitable operation caused to the considerable increase in soil organic matter content and then will increase macro-aggregate stability, soil microbial populations and the aggregation of soil particles (Nouraein et al. 2019a; Mayer et al. 2020). Otherwise, plant root structures can enhance soil aggregation and accelerate the formation and stability of aggregates by physical entanglement or the secretion of cementing substances (Lehmann and Rillig 2015).

These increase in activity of soil microbial populations following to reduced tillage system, increase soil organic matter and protect the soil against erosion which confirmed report of Hati et al. 2021). The slow release of farmyard manure elements prevents some losses like high level release and supplied proper magnitudes of NPK and some microelements like Mn, Zn, and Fe. Also, the farmyard manure provides balanced source of macro and micro-elements for plant growth season, thus prevents the future nutrient shortage (Ekbic et al. 2022). A sufficient supply of nitrogen and other essential exempts via farmyard manure was one of the main reasons for better performance of F3 (40 t ha^{-1} farmyard manure) and F4 (20 t ha^{-1} farmyard manure plus 50:25:25 kg ha^{-1} NPK) treatment combinations. Rotta et al. (2015) reported that a loss in phosphorus content is predictable in conventional tillage system while long root depth was recorded in such system. However, over-compaction of soil due to the reduced tillage operation has several harmful effects on soil nutrients availability and root growth, thus, the reduced tillage restricts the involving of soil by plant roots (Kim et al. 2022; Nouraein et al. 2019a). However, long-term using of farmyard manure reduces soil compaction and useful for improvement of physical properties.

Our results indicated that sunflower achene yield can be improved via improving soil properties. It seems that sink–source adjusting is responsible for this issue via gaining the crop physiological source volume. The increase of photosynthetic potential of crop tissues maintains the source capability in and increase yield performance in sunflower. We found that a small positive change in physical and chemical properties of soil cause yield improvement. The positive effect of farmyard manure was due to full impacts of organic matter and the slow distribution of essential nutrients. This research demonstrated that, in upland semi-arid areas, using of only farmyard manure or combining it with some chemical fertilizer under reduced tillage system can provide stable agriculture circumstances where the impacts of most chemical fertilizers will be more predictable. This investigation indicated that the T × T biplot model is a useful statistical option for the visual analysis of sunflower dataset and explore the main patterns of tillage system by fertilizer interaction.

Based on T × T biplot model, the likeness and unlikeness among traits and treatment combinations are visualized effectively. This analysis was indicated to be more instructive than routine statistical models for identification of treatments and traits characteristics (Sabaghnia and Janmohammadi 2016). Regarding routine statistical models, the T × T biplot has some benefits as (i) the graphical offering the dataset; (ii) the more potential for explain; and (iii) providing the detection of sections of traits or treatments (Sabaghnia et al. 2018; Yan 2019). A real restrict for the biplot model is that it may fail to show exact and real structure of the data. This issue is occurring with large datasets which several PCs need to form the main idea, but in our dataset 84 % of data variability is described by the two first PCs and this restrict was not the main problem. However, even under such circumstances, it can be avouched that the biplot model still indicates the main linear structures of the dataset although, other types of biplot models, like PC3 and PC4, may be needed to grasp the original dataset's structure.

5 Conclusions

This investigation demonstrated that the best performance for sunflower achene yield was obtained with using reduced tillage system plus F3 (40 t ha^{-1} farmyard manure) or F4 (20 t ha^{-1} farmyard manure plus 50:25:25 kg ha^{-1} NPK) because the farmyard manure improved some soil properties like organic matter. Application no fertilizer (control treatment) or using only chemical fertilizers (50:25:25 kg ha^{-1} NPK) could not improve sunflower performance in both conventional and reduced tillage systems.

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