Conservation tillage improves productivity of sunflower (*Helianthus annuus* L.) under reduced irrigation on sandy loam soil

Ahmad Sher¹*, Muhammad Yasir Arfat¹,², Sami Ul-Allah¹, Abdul Sattar⁴*, Muhammad Ijaz¹, Abdul Manaf², Abdul Qayyum⁵, Ali Tan Kee Zuan⁴*, Omaima Nasif⁶, Kristina Gasparovic⁶

¹ College of Agriculture, Bahauddin Zakarya University, Bahadur Sub-Campus Layyah, Layyah, Pakistan, ² Department of Agronomy, PMAS- Arid Agriculture University Rawalpindi, Rawalpindi, Pakistan, ³ Department of Agronomy, The University of Haripur, Haripur, Pakistan, ⁴ Department of Land Management, Faculty of Agriculture, University Putra Malaysia, Selangor, Malaysia, ⁵ Department of Physiology, College of Medicine and King Khalid University Hospital, King Saud University, Medical City, Riyadh, Saudi Arabia, ⁶ Institute of Plant and Environmental Sciences, Slovak University of Agriculture, Nitra, Slovakia

* ahmad.sher@bzu.edu.pk (AS); abdulsattar04@gmail.com (AS); tkz@upm.edu.my (ATKZ)

Abstract

Sunflower production is significantly lower in arid and semi-arid regions due to various crop management problems. Conservation of tillage provides the most excellent opportunity to reduce degradation of soil reserves and increase soil productivity. The main objective of this study was to investigate the combined effects of conservation tillage and drought stress on growth and productivity of different sunflower hybrids. Experimental treatments included two sunflower hybrids (‘NK-Senji’ and ‘S-278’), two drought stress treatments (i.e., well-watered and drought stress at flowering and grain filling stages) and three tillage practices (i.e., conservation, minimum and deep tillage). The results indicated that morphological and physiological parameters, and yield-related traits were significantly (*P* < 0.05) affected by all individual factors; however, their interactive effects were non-significant. Among sunflower hybrids, ‘NK-Senji’ performed better for morphological, physiological, and yield-related traits than ‘S-278’. Similarly, conservation tillage observed better traits compared to the rest of the tillage practices included in the study. Nonetheless, conservation tillage improved growth and yield-related traits of hybrid ‘NK-Senji’ under drought stress. Hence, it is concluded that conservation tillage can improve the productivity of sunflower under low moisture availability. Therefore, conservation tillage could be suggested in the areas of lower water ability to improve sunflower production. Nonetheless, sunflower hybrids or varieties need thorough testing for their adaptability to conservation tillage and low moisture availability before making recommendations.

Introduction

Sunflower (*Helianthus annuus* L.) is an annual oilseed crop cultivated in the world on 24.77 million hectares with a production of 44.31 million metric tons, which shares 8% of the world’s
oilseed market [1]. Its achene consists of 40–50% oil and 17–20% protein; thus, have a clear ability to reduce the difference between production and consumption of edible oil. Sunflower is moderately tolerant to heat and water deficiency [2]; thus, has adaptability potential to semi-arid and subtropical regions of the world. Advances in development of sunflower hybrids in the recent years have dominated the open pollinated varieties in the field. Sunflower is usually grown in a wide range of climatic conditions ranging from temperate to tropical and semi-arid regions. Erratic rainfall patterns due to climate change and water shortage are faced during sunflower growth period. Therefore, most of the sunflower hybrids are area and climate-specific; hence, perform differently in different areas [3, 4]. Due to the reason, it is necessary to evaluate the growth and yield performance different hybrids under specific climatic conditions to choose the best suited one for higher yield and productivity.

Sunflower is a tropical and subtropical crop, often cultivated in dry land on supplemental irrigation [5]. Although sunflower is relatively tolerant to heat and drought stresses, extreme water deficiency severely affects its reproductive growth, resulting in yield losses [6]. Drought stress drastically reduced head diameter, achene yield, achene oil content and oil yield in sunflower [7–10]. The highest sunflower yield can be acquired by irrigating the crop at all critical growth stages, i.e., flowering and achene formation [10, 11]. Sufficient availability of water at early growth stages contributes towards good vegetative growth. However, low water availability at flowering and grain filling phases significantly reduces yield due to high transpiration requirements [10, 11].

Conservation of tillage provides an excellent opportunity to reduce the degradation of soil reserves and increase soil productivity [12]. Conservation tillage has attracted increased attention in recent years due urgent needs for erosion control and water conservation in various geographic regions of the world. Soil and water conservation-oriented tillage methods include conservation tillage, strip tillage, and mulch tillage [13]. Conservation tillage is an extreme type of tillage resulting in a negligible soil interruption [14, 15]. Conservation tillage is widely used in large-scale farming systems, where machinery is necessary for cultivation. Sustainable agriculture and increasing fuel costs in soil tillage inspire farmers to switch cultivation practices and urge them to find alternative tillage methods that are cost effective. The benefits of conservation tillage include enhanced surface water deposits, enhanced soil organic matter content, fertilizer recovery and protection from water and wind erosion [15–17].

Sunflower is a high yielding oil crop and serious efforts are required to increase its domestic production in Pakistan. This study was conducted to assess the productivity of sunflower hybrids sown under various tillage practices and water availability regimes. Major objective of study was to identify the most suitable tillage practice for better performance of sunflower hybrids under low water availability. The results would help to improve sunflower productivity under arid and semi-arid regions.

Materials and methods
Experimental site
A two-year (2018–19) field study was carried out at experimental farm of Bahauddin Zakariya University, Bahadur Sub-Campus Layyah-Pakistan (30°57’N; 70°56’E; 151 m a.s.l). The region is subtropical semi-arid with cool winters and hot summers. The soil of the experimental site was sandy-loam having EC (154–156 dS m⁻¹), pH (7.9–8.0), organic matter (0.67–0.69%), available phosphorus (9–10 ppm) and nitrate-nitrogen (1.6–1.8 mg kg⁻¹). Average maximum and minimum temperatures, and mean rainfall during the growth period of sunflower in both years are given in Fig 1.
Experimental treatments
The treatments comprised of two water availability regimes (i.e., well-watered and drought stress at flowering and grain filling stage), two sunflower hybrids (‘NK-Senji’ and ‘S-278’) and three tillage methods (i.e., conservation, minimum and deep tillage). Experiment was laid out according to randomized complete block design with split-split arrangement. Tillage practices, water availability regimes and sunflower hybrids were kept in main, sub and sub-sub plots, respectively. The net plot size was 3 m × 5 m. The crop was sown by hand drill without ploughing the soil in conservation tillage. The soil was ploughed with a cultivator to a depth of 10 cm and then crop was sown. Only the area where crop rows were sown was tilled, while the remaining field was not tilled. In deep tillage, whole experimental field was ploughed to 20 cm depth and then crop was sown.

Cultivation practices
The crop was sown with hand drill by maintaining row-to-row distance of 75 cm. The crop was sown on March 8, 2018, and March 2, 2019. All agronomic practices were kept uniform following the local recommendations. Basal dose of N (90 kg ha⁻¹) and P (60 kg ha⁻¹) was applied at the time of sowing in the form of urea (46% N) and DAP (18% N, 46% P₂O₅) as source, respectively. The mature crop was harvested on May 2 and 7 during 2018 and 2019, respectively.

Data collection
Randomly selected ten plants from each plot were measure for plant height from the base to the tip of plant and averaged. Stem diameter and head diameter were calculated with the help of Vernier Caliper.
Two central rows were harvested from each plot to count the number of achenes per head and biological yield. Harvested samples were sundried by keeping horizontal for few days. Dried samples were threshed and weighed to record achene yield in kg ha\(^{-1}\). Thousand-achene weight was counted by using the seed counter available in the Agronomy Lab.

Five plants were randomly selected from each plot were used to measure the chlorophyll index with the help of SPAD meter (CCM-200 plus). Fully developed leaves were used to measure physiological parameters (i.e., photosynthetic rate, transpiration rate, CO\(_2\) concentration and stomatal conductance) with the help of IRGA (InfraRed Gas Analyzer).

### Statistical analysis

The collected data were tested for normality and homogeneity of variance, which indicated that data were normally distributed. Differences among years were tested by paired t test, which indicated significant differences among years. Therefore, data of both years were analyzed and interpreted, separately. Three-way analysis of variance (ANOVA) was used to infer the significance in the data. Means were compared by least significant difference test where ANOVA indicated significant differences. The analyses were performed on Statistix statistical software.

### Results

#### Morphological and yield traits

Morphological and yield traits were significantly (\(P \leq 0.05\)) affected by tillage practices, water availability regimes and sunflower hybrids. All three-way interactions were non-significant with some exceptions (Table 1).

Conservation tillage significantly improved plant height (32.7 vs 31.4%), stem diameter (68.2 vs 78.2%), head diameter (62.2 vs 57.1%), number of achenes head\(^{-1}\) (6.7 vs 32.4%), 1000-achene weight (33.8 vs 42.7%), biological (12.8 vs 10.9%) and achene yield (18.8 vs 35.6%).

### Table 1. Analysis of variance (ANOVA) of morphological and yield-related traits of sunflower hybrids as influenced by various tillage practices and water availability regimes.

| Source          | df | plant height | Stem diameter | Head diameter | Number of achenes head\(^{-1}\) | 1000-achene weight | Biological yield | Achene yield |
|-----------------|----|--------------|---------------|---------------|-------------------------------|-------------------|-----------------|--------------|
|                 |    | 2018 2019    | 2018 2019     | 2018 2019     | 2018 2019                    | 2018 2019         | 2018 2019       | 2018 2019    |
| Replication     | 2  | 388.1 383.7  | 1.31 1.01     | 4.0 3.6       | 111.1 8154                   | 55.8 2043.5       | 644136 668344   | 359 3658     |
| Tillage (T)     | 2  | 4148.6** 4131.4** | 10.9** 20.52** | 42.3** 36.7** | 18065.6** 408076**           | 1680.6** 3164.8** | 2113269** 1790519** | 199905** 716325** |
| Main plot error | 4  | 100.5 101.9  | 0.8 3.36      | 0.8 1.2       | 702.9 5905                    | 98.2 8.7           | 164990 93303    | 2006 22517    |
| Drought (D)     | 1  | 2085.4 2070.3** | 2.6** 19.05** | 21.1 8.8ns     | 12806.7** 340472**            | 1921.4** 1521.0** | 1716100** 1964669** | 1583822** 336593** |
| T × D           | 2  | 142.2 ns 144.3ns | 0.8** 3.45ns  | 0.5ns 0.2ns    | 1751ns 4591ns                 | 131.4ns 156.3ns   | 47308ns 46919ns | 11482 ns 3930ns |
| Sub plot error  | 6  | 245.1 245.3  | 0.04 0.81     | 1.8 3.6       | 763.6 3776                    | 63.6 63.7          | 95922 117061    | 2997 32957    |
| Hybrids (H)     | 1  | 1089.0** 1100.0** | 6.2** 20.69** | 15.3** 43.6** | 9900.2** 322056**             | 294.7** 940.4**   | 3336711** 3535225** | 31506** 280017** |
| T × H           | 2  | 96.6ns 94.1ns  | 2.6** 3.57ns  | 4.6** 3.7ns    | 228.6ns 6265ns                | 7.2ns 10.1ns       | 46936ns 85908ns | 505ns 75ns    |
| D × H           | 1  | 40.1ns 38.0ns  | 0.5ns 0.02ns  | 3.3 0.2ns      | 3154.7ns 42367**              | 283.4** 18.8ns     | 15211ns 145669ns | 462ns 182ns   |
| T × D × H       | 2  | 10.2ns 10.1ns  | 0.1ns 0.11ns  | 1.2ns 0.1ns    | 266.4ns 516ns                 | 30.3ns 14.8ns      | 51586ns 54253ns | 432ns 1339ns |
| Error           | 12 | 111.0 111.6  | 0.2 1.09      | 0.5 1.2       | 1052.4 4021                    | 33.8 30.42         | 156453 173994   | 915 25937     |

Ns = non–significant; 
* = significant at \(P \leq 0.05\); 
** = \(P \leq 0.01\).

https://doi.org/10.1371/journal.pone.0260673.t001
compared to deep tillage system. Likewise, irrigation regimes significantly altered morphological and yield-related traits of sunflower hybrid type in 2018 and 2019.

| Tillage Practices | Plant height (cm) | Stem diameter (cm) | Head diameter (cm) | Number of seeds head\(^{-1}\) | 1000-achene weight (g) | Yield (g ha\(^{-1}\)) | Biological | Achene |
|-------------------|------------------|-------------------|-------------------|----------------------------|-----------------------|--------------------------|------------|--------|
|                   | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  | 2018  | 2019  |
| Conservation      | 149.6 a | 154.6 a | 2.22 a | 3.67 a | 9.65 a | 9.49 a | 1225.7 a | 1484.3 a | 91.7 a | 107.17 a | 7391.7 a | 7866.7 a | 1623.8 a | 1852.9 a |
| Minimum           | 127.3 b | 132.2 b | 1.83 b | 2.51 b | 7.26 b | 7.85 b | 1182.3 b | 1244.9 b | 80.1 b | 96.83 b | 6959.2 b | 7488.3 a | 1481.4 b | 1573.1 b |
| Deep              | 112.7 c | 117.7 c | 1.32 c | 2.06 c | 5.95 c | 6.04c  | 1148.3 c | 1121.7 c | 68.0 c | 75.33 c | 6552.5 c | 7094.2 b | 1366.1 c | 1366.1 c |
| **LSD (p ≤ 0.05)** | 11.4  | 11.4  | 1.02  | 2.07  | 1.01  | 1.22  | 30.05  | 87.09   | 11.23 | 3.35   | 46.40   | 346.23   | 50.7  | 170.09  |

**Water availability regimes**

| Well-watered | 137.4 a | 142.4 a | 1.53 a | 3.14 a | 8.39 a | 8.28 a | 1204.3 a | 1380.9 a | 87.2 a | 99.61 a | 7186.1 a | 7716.7 a | 1694.2 a | 1705.1 a |
| Water stress  | 122.2 b | 127.3 b | 0.99 b | 1.68 b | 6.86 b | 7.29 b | 1166.6 b | 1186.4 b | 72.6 b | 86.61 b | 6749.4 b | 7249.4 b | 1280.7 b | 1500.7 b |
| **LSD (p ≤ 0.05)** | 12.7  | 12.8  | 0.16  | 0.73  | 1.08  | 1.55  | 22.53  | 50.12   | 6.50  | 6.51   | 252.6   | 279.06   | 44.7  | 148.07  |

**Sunflower hybrids**

| NK-Senji | 135.3 a | 140.4 a | 1.67 a | 3.17 a | 8.27 a | 8.88 a | 1202.0 a | 1378.2 a | 82.8 a | 98.22 a | 7272.2 a | 7797.2 a | 1520 a | 1685.6 a |
| S-278    | 124.3 b | 129.3 b | 0.84 b | 1.65 b | 6.97 b | 6.68 b | 1168.8 b | 1189.1 b | 77.0 b | 88.0   | 6663.3 b | 7168.9 b | 1460.8 b | 1509.2 b |
| **LSD (p ≤ 0.05)** | 7.65  | 7.67  | 0.33  | 0.75  | 0.52  | 0.78  | 23.56  | 46.05   | 4.22  | 4.00   | 287.3   | 302.95   | 21.9  | 116.97  |

Letter sharing same number in each column does not have significant (P≤0.05) difference.

https://doi.org/10.1371/journal.pone.0260673.t002

**Physiological traits**

Physiological traits were significantly (P≤0.05) affected by individual effects of tillage systems, water availability regimes and sunflower hybrids. The two- and three-way interactions were non-significant with some exceptions (Table 3).

Among sunflower hybrids, 'NK-Senji' had higher photosynthetic rate, transpiration rate, CO\(_2\) quantity, and stomatal conductivity as compared to 'S-278'. Likewise, under well water condition, better physiological traits were recorded compared to drought stress. Among tillage practices, conservation tillage system performed better as compared to other tillage during both years (Table 4).

**Discussion**

Conservation tillage is any soil cultivation practice that leaves the crop resides (such as corn stalks or wheat stubble) in the fields prior to and after cultivation to mitigate soil erosion and runoff losses [13]. Conservation tillage systems may have been efficient than traditional tillage systems and result in improved soil quality. In current study photosynthetic rate, stomatal conductivity, carbon dioxide quantity, transpiration rate and chlorophyll pigments were higher under the conservation tillage compared to the rest of the tillage systems included in the study. Conservation tillage saves soil water, since the soil is relatively dense, with less water and soil nutrient leaching down [15–17], all of which contributed to better crop growth.
Better physiological growth resulted in improved morphological characteristics and yield (Table 3). Our results are in line with several previous findings [18, 19] regarding sunflower growth and yield under different tillage systems. Wang et al. [18] reported that conservation tillage confers stable microbial colonies and nutrient utilization which improve soil properties and results in improved growth and productivity of sunflower. Contrary to this, Paul et al. [15] recorded higher yield with maximum soil disturbance and minimum yield with zero tillage which attributed to the hard clay soil used in that experiment, while the soil in our experiment

### Table 3. Analysis of variance (ANOVA) of chlorophyll index and physiological traits of sunflower hybrids as influenced by various tillage practices and water regimes.

| Source         | df  | Chlorophyll content | CO₂ concentration | Transpiration rate | Stomatal conductance | Photosynthetic rate |
|----------------|-----|---------------------|-------------------|-------------------|----------------------|---------------------|
|                |     | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| Replication    | 2   | 12.8 | 16.1 | 4645.4 | 6626.8 | 4.2 | 3.73 | 0.027 | 0.03 | 0.1 | 6.4 |
| Tillage (T)    | 2   | 821.5** | 832.2** | 12970.4** | 12094.4** | 39.5** | 37.7** | 0.221* | 0.22 | 114.2** | 99.3** |
| Main plot error| 4   | 12.7 | 8.5  | 739.8 | 761.7 | 0.6 | 0.7  | 0.034 | 0.03 | 0.1 | 1.9 |
| Drought (D)    | 1   | 99.3** | 121.4** | 17117.4** | 17380.0** | 18.2** | 16.8** | 0.036** | 0.04 | 49.5** | 44.8** |
| T × D          | 2   | 10.4ns | 10.8ns | 1590.0ns | 1577.0ns | 0.3ns | 0.4ns | 0.021** | 0.02 | 1.2ns | 0.7ns |
| Sub plot error | 6   | 4.8  | 4.2  | 1141.9 | 1127.4 | 0.4 | 0.3  | 0.003 | 0.00 | 0.9 | 0.8 |
| Hybrids (H)    | 1   | 220.0** | 457.2** | 17911.4** | 17556.3** | 34.1** | 32.1** | 0.134** | 0.13 | 63.3** | 67.8** |
| T × H          | 2   | 14.2ns | 11.0ns | 3550.4** | 3571.1** | 0.4ns | 0.5ns | 0.034ns | 0.03 | 0.102 | 0.4ns |
| D × H          | 1   | 11.8ns | 5.2ns  | 2384.7ns | 2352.3ns | 0.1ns | 0.3ns | 0.004ns | 0.00 | 0.1ns | 0.1ns |
| T × D × H      | 2   | 11.3ns | 9.9ns  | 392.7ns | 399.1 ns | 0.2ns | 0.2ns | 0.002ns | 0.00 | 0.1ns | 0.2ns |
| Error          | 12  | 19.4 | 15.9 | 614.6 | 636.6 | 1.1 | 1.0  | 0.004 | 0.00 | 0.4 | 0.9 |

Ns = non–significant; * = significant at $P \leq 0.05$; **, $P \leq 0.01$.

https://doi.org/10.1371/journal.pone.0260673.t003

---

### Table 4. Chlorophyll contents and physiological attributes of two sunflower hybrids as affected by tillage practice and water availability regimes.

| Tillage Practices | Chlorophyll index (SPAD values) | CO₂ concentration | Transpiration rate | Stomatal conductance | Photosynthetic rate |
|-------------------|---------------------------------|-------------------|-------------------|----------------------|---------------------|
|                   | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| Conservation      | 43.6 a | 45.1 a | 271.7 a | 275.8 a | 9.4 a | 10.4 a | 0.33 a | 0.43 a | 12.9 a | 14.9 a |
| Minimum           | 34.1 b | 37.4 b | 239.3 b | 243.5 b | 7.6 b | 8.6 b | 0.09 b | 0.19 b | 9.7 b | 11.8 b |
| Deep              | 27.1 c | 28.5 c | 205.9 c | 210.3 c | 6.9 c | 7.9 c | 0.14 b | 0.23 b | 6.8c | 9.1 c |
| LSD ($p \leq 0.05$) | 4.03 | 3.31 | 30.82 | 31.28 | 0.90 | 0.94 | 0.20 | 0.20 | 0.43 | 1.55 |

Water availability regimes

|                 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| Well-watered    | 36.6 a | 38.8 a | 260.8 a | 265.2 a | 8.3 a | 9.3 a | 0.20 a | 0.30 a | 10.9 a | 13.1 a |
| Water stress    | 33.2 b | 35.2 b | 217.2 b | 221.2 b | 6.9 b | 7.9 b | 0.14 b | 0.23 b | 8.7 b | 10.8 b |
| LSD ($p \leq 0.05$) | 1.78 | 1.66 | 27.56 | 27.38 | 0.51 | 0.44 | 0.04 | 0.04 | 0.78 | 0.74 |

Sunflower hybrids

|                 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| NK-Singi        | 37.4 a | 40.6 a | 261.3 a | 265.3 a | 8.6 a | 9.6 a | 0.23 a | 0.33 a | 11.1 a | 13.3 a |
| S-278           | 32.4 b | 33.4 b | 216.7 b | 221.1 b | 6.6 b | 7.7 b | 0.11 b | 0.21 b | 8.5 b | 10.6 b |
| LSD ($p \leq 0.05$) | 3.20 | 2.89 | 18.00 | 18.32 | 0.74 | 0.72 | 0.04 | 0.04 | 0.43 | 0.69 |

Letter sharing same number in each column does not have significant ($P \leq 0.05$) difference.

https://doi.org/10.1371/journal.pone.0260673.t004
was sandy loam. Wasaya et al. [20] analyzed the effects of various tillage systems on soil properties in a four-year experiment and confirmed that different tilling practices did not alter soil bulk density, moisture content and hydraulic conductivity of sandy loam soils. In this analysis, therefore, better microbial activities and nutrient retention may result in higher productivity of sunflower under conservation tillage.

Drought is a physiological phenomenon that restricts water supply to fulfil its transpiration needs. Drought stress limits regular growth and reduces the morphological traits, such as stem dry weight (SDW), total dry matter (TDM), plant height, stem diameter [10, 19, 21, 22]. It suppresses stem elongation and eventually reduces the development of sunflower biomass. Decrease in biomass production under water deficit was noted in several studies on sunflower [10, 21, 22]. In our experiment, gas exchange parameters and chlorophyll content decreased under water stress conditions due to a reduced availability of water [10, 23] resulting in reduced plant growth and development. Water deficit compromised the formation of chlorophyll, photosynthesis, stomatal conductivity, and transpiration and resulted in declining plant biomass [22, 24]. Reduction in growth and development is accompanied by less carbon accumulation, unfair mineral nutrients, and abscisic acid (ABA) accumulation, which causes plant wilting [23, 24]. Reproductive stage is regarded as most drought sensitive stage of sunflower, and drought at this stage results in poor pollination and acene filling [25–28]. In the current study, under water deficiency, sunflower head diameter, achene yield, achene oil content and oil yield were significantly affected by the stress. Overall, drought stress affects all aspects of sunflower growth and development. In start, water deficiency stress decreases germination, stem elongation and leaf area [26, 27] and at reproductive stage, it results in pollen abortion resulting in empty acene [29–31].

Conclusions
It is concluded that conservation tillage had positive impact on physiology and productivity of sunflower on sandy loam soil under normal and reduced irrigation. Conservation tillage seemed most economical option as it saves expenses incurred on tillage. Based on the results conservation tillage may be recommended for sandy loam soils of semi-arid regions for higher sunflower productivity. However, specific area and climatic conditions may also be considered for the recommendation of sunflower hybrids.

Acknowledgments
This study is a part of M.Sc. (Hons.) thesis of MYA. This project was supported by Researchers Supporting Project number (RSP-2021/257), King Saud University, Riyadh, Saudi Arabia.

Author Contributions
Conceptualization: Ahmad Sher, Sami Ul-Allah, Abdul Sattar, Abdul Manaf, Abdul Qayyum, Ali Tan Kee Zuan, Omaima Nasif, Kristina Gasparovic.
Data curation: Muhammad Yasir Arfat.
Formal analysis: Sami Ul-Allah, Muhammad Ijaz.
Funding acquisition: Ahmad Sher, Abdul Sattar, Ali Tan Kee Zuan, Omaima Nasif.
Investigation: Muhammad Ijaz.
Methodology: Sami Ul-Allah, Abdul Qayyum.
Project administration: Ahmad Sher, Abdul Sattar.
Resources: Muhammad Ijaz.
Supervision: Ahmad Sher.
Validation: Muhammad Yasir Arfat, Abdul Manaf.
Visualization: Muhammad Yasir Arfat, Abdul Manaf.
Writing – original draft: Muhammad Ijaz.
Writing – review & editing: Ahmad Sher, Sami Ul-Allah, Abdul Sattar, Muhammad Ijaz, Abdul Manaf, Abdul Qayyum, Ali Tan Kee Zuan, Omaima Nasif, Kristina Gasparovic.

References
1. Haytowitz DB, Pehrsson PR. USDA’s National Food and Nutrient Analysis Program (N FnAP) produce high-quality data for USDA food composition databases: Two decades of collaboration. Food chemistry, 238, 134–138. https://doi.org/10.1016/j.foodchem.2016.11.082 PMID: 28667083
2. Ramu VS, Paramanatham A, Ramegowda V, Mohan-Raju B, Udayakumar M, Senthil-Kumar M. Transcriptome analysis of sunflower genotypes with contrasting oxidative stress tolerance reveals individual-and combined-biotic and abiotic stress tolerance mechanisms. Plos One. 2016 11(6):157–522.
3. Bonnafous F, Fievet G, Blanchet N, Boniface MC, Carrère S, Gouzy J, et al. Comparison of GWAS models to identify non-additive genetic control of flowering time in sunflower hybrids. Theor Appl Genet. 2018 31:319–332. https://doi.org/10.1007/s00122-017-3003-4 PMID: 29098310
4. Cvejić S, Jocić S, Miladenov V, Banjac B, Radeka I, Jocković M, et al. Selection of sunflower hybrids based on stability across environments. Gene. 2019 51(1):81–92.
5. Pekcan V, Evci G, Yilmaz MI, Nalçayi ASB, Erdal Ş, Cicek N, et al. Drought effects on yield traits of some sunflower inbred lines. Int J Agric For. 2015 61(4):101–107.
6. Debaeke P, Bedoussac L, Bonnet C, Bret-Mestries E, Seassau C, Gavaland A, et al. Sunflower crop: environmental-friendly and agroecological. OCL.2017 24(3):1–304.
7. Kazi BR, Oad FC, Jamro GH, Jamil LA, Oad NL. Effect of water stress on growth, yield and oil content of sunflower. Pak J Appl Sci.2002 2:550–552.
8. Haq MA. Abscisic acid, a stress hormone helps in improving water relations and yield of sunflower (Helianthus annuus L.) hybrids under drought. Pak J Bot. 2010 42:2177–2189.
9. Saensee K, Machikowa T, Muangsan N. Comparative performance of sunflower synthetic varieties under drought stress. Int J Agric Biol. 2012 14:929–934.
10. Hussain M, Farooq S, Hasan W, Ul-Allah S, Tanveer M, Farooq M, et al. Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives. Agric Water Manage.2018 201:152–166.
11. Garcia-López J, Lorite IJ, García-Ruiz R, Ordoñez R, Dominguez J. Yield response of sunflower to irrigation and fertilization under semi-arid conditions. Agric Water Manage.2016 176:151–162.
12. Nandan R, Singh SS, Kumar V, Singh V, Hazra KK, Nath CP, et al. Crop establishment with conservation tillage and crop residue retention in rice-based cropping systems of Eastern India: yield advantage and economic benefit. Paddy Water Environ. 2018 16:477–492.
13. Galzki JC, Biri AS, Mulla DJ. Identifying critical agricultural areas with three-meter LiDAR elevation data for precision conservation. J Soil Water Conserv. 2011 66(6):423–430.
14. Mohammed YA, Abdullah BH, Al-Kaisy ALM, Abood NM, Cheyed SH. Weeds Grown In the Sunflower Fields (Helianthus annuus L.) As Influenced By No Tillage And Phosphorus Fertilization. Plant Arch. 2019 19:3735–3742.
15. Paul PLC, Bell RW, Barrett-Lennard EG, Kabir E. Variation in the yield of sunflower (Helianthus annuus L.) due to differing tillage systems is associated with variation in solute potential of the soil solution in a salt-affected coastal region of the Ganges Delta. Soil Till Res. 2020 197:104–489.
16. Lopez MV, Moret D, Gracia R, Arrue JL. Tillage effects on barley residue cover during follow in semi-arid Aragon. Soil Till Res. 2003 72:53–64.
17. Bhatt R. Conservation tillage for mitigating global warming consequences and improving livelihoods in South Asia. In Environmental Sustainability and Climate Change Adaptation Strategies. IGI Global. 2017 126–161.
18. Wang Z, Li T, Wen X, Liu Y, Han J, Liao Y, et al. Fungal communities in rhizosphere soil under conservation tillage shift in response to plant growth. Front. Microbiol. 2017 8:1301. https://doi.org/10.3389/fmicb.2017.01301 PMID: 28744278

19. Sher A, Suleman M, Qayyum A, Sattar A, Wasaya A, Ijaz M, et al. Ridge sowing of sunflower (Helianthus annuus L.) in a minimum till system improves the productivity, oil quality, and profitability on a sandy loam soil under an arid climate. Environ. Sci. Pollut. Res. 2018 25(12):11905–11912.

20. Wasaya A, Tahir M, Ali H, Hussain M, Yasir TA, Sher A, et al. Influence of varying tillage systems and nitrogen application on crop allometry, chlorophyll contents, biomass production and net returns of maize (Zea mays L.). Soil Till Res. 2017 170:18–26.

21. Kaya Y, Pekcan V, Cicek N. Effects of drought on morphological traits of some sunflower lines. Ekin J Crop Breed Genetic.2016 2:54–68.

22. Jan AU, Hadi F, Akbar F, Shah A. Role of potassium, zinc and gibberellic acid in increasing drought stress tolerance in sunflower (helianthus annuus L.). Pak J Bot. 2019 51:809–815.

23. Farooq M, Hussain M, Wahid A, Siddique KHM. Drought stress in plants: an overview. In: Aroca R. (Ed.), Plant Responses to Drought Stress: From Morphological to Molecular Features. Springer-Verlag, Germany, 2012 1–36.

24. Lisar SY, Rahman IM, Hossain MM, Motafakkerazad R. Water Stress in Plants: Causes, Effects and Responses. Intech Open Access Publisher2012.

25. Chimenti C, Pearson A, Hall H. “Osmotic Adjustment and Yield Maintenance under Drought in Sunflower,” Field Crops Res. 2002 75:235–246. https://doi.org/10.1016/S0378-4290(02)00029-1

26. Fulda S, Mikkat S, Stegmann H, Horn R. Physiology and proteomics of drought stress acclimation in sunflower (Helianthus annuus L.). Plant Biol. 2011 13(4):632–642. https://doi.org/10.1111/j.1438-8677.2010.00426.x PMID: 21668604

27. Fatemi SN. Germination and seedling growth in primed seeds of sunflower under water stress. Ann Rev Bio. 2014 4(23):3459.

28. Cechin I, Cardoso GS, Fumis TDG, Corniani N. Nitric oxide reduces oxidative damage induced by water stress in sunflower plants. Bragantia. 2015 74:200–206.

29. Lyakh VA, Totisky IV. Selective elimination of gametes during pollen storage at low temperature as a way to improve the genetic structure of sporophytic population for cold tolerance. Helia. 2014 37(61):227–235.

30. Totisky IV, Lyakh VA. Pollen selection for drought tolerance in sunflower. Helia. 2015 38(63):211–220.

31. Chimenti CA, Pearson J, Hall AJ. Osmotic adjustment and yield maintenance under drought in sunflower. Field Crops Res. 2002 75(2):235–246.