Effects of different tillage systems on soil water conservation, grain yield and water use in winter wheat and spring maize cropping systems: A Meta-analysis

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Abstract

Climate change is a major threat to food security. The global population is increasing at a stimulated rate. Wheat and maize are the globally important crops. There is a need to focus on the methods that help to improve crop production. Since, conventional tillage (CT) is the major tillage practice in rain-fed areas. Conservation tillage methods are practiced to conserve soil moisture in order to increase crop productivity. However, the effects of conservation tillage methods under varying soil textures, precipitation and temperature patterns are still unknown. We took data from 119 peer-reviewed published articles and carried a meta-analysis to assess the effects of 3 conservation tillage practices including no tillage (NT), reduced tillage (RT) and subsoil tillage (ST) on precipitation storage efficiency (PSE), soil water storage at crop planting (SWSp), grain yield, evapotranspiration (ET) and water use efficiency (WUE) under varying precipitation and temperature patterns and soil textures in dry land wheat and maize cropping systems. We took conventional tillage as a control treatment and compared it with different types of fallow conservation tillage systems. Compared to conventional tillage (CT), conservation tillage methods overall increased PSE, SWSp, grain yield, ET and WUE by 22.6%, 17.8%, 24.1%, 6.5% and 12.1%, respectively in winter wheat. Among conservation tillage methods, NT had a better performance on SWSp, grain yield and WUE compared to RT and ST. Fine-textured soils showed better response of tillage methods on PSE, SWSp and ET than medium and coarse-textured soils, while medium-textured soils showed greater positive response ratio (RR) of conservation tillage methods on grain yield and WUE. The enhancement of conservation tillage on PSE and grain yield was greater in the regions having mean annual precipitation (MAP) of >600 mm, while crop yield, ET and WUE were greater when MAP was <400 mm. Conservation tillage methods also increased PSE, grain yield and WUE in the regions where mean annual temperature (MAT) was 8-15 , while SWSp was greater when MAT was <8 . In dryland spring maize, conservation tillage overall increased PSE, SWSp, grain yield, ET and WUE by 38.1%, 20.6%, 29.6%, 16.9% and 11.0%, respectively. The regions having medium-textured soils showed better response of tillage methods on PSE, SWSp, ET and WUE, while coarse-textured soils showed greater positive response ratio (RR) of tillage methods on grain yield. Compared to CT, the RR of conservation tillage on PSE, grain yield, ET and WUE was greater when MAP was <400 mm, while SWSp was greater when MAP was 400-600 mm. Conservation tillage also increased PSE, SWSp and ET in the regions where MAT was <8 , while grain yield and WUE were greater when MAT was >15 . We conclude that NT is a global promising practice among all conservation tillage methods to increase soil water storage and crop production under varying precipitation and temperature patterns and soil textures in both winter wheat and spring maize cropping systems.

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Keywords: Conservation tillage, soil water conservation, crop production, food security, climate change.

Introduction

Climate change is seriously endangering humans and biodiversity by impairing agricultural productivity (FAO, 2020; Chandio et al., 2021). The climatic changes related to floods, changing patterns of rainfall and temperature and draining water reservoirs are affecting the major agricultural crop production (Appiah et al., 2018; Abbas, 2020). Global hunger and food insecurities are continuously rising as a result of the remarkable rise in population around the world and the agriculture sector's stagnant performance. One of the main goals of the SDGs is to eradicate hunger and provide food security.

Food security is achieved when all people at all times have physical and economical access to sufficient, safe and nutritional food to fulfill their dietary needs and food preferences for an active and healthy life (FAO, 1996). The major factor contributing to global food insecurity is climate change (FAO, 2017). To cope food insecurity, there is a need to develop methods that are helpful in increasing crop production. Different factors such as poor seed management, soil infertility, water scarcity and expensive field treatments are playing major role in declining crop productivity (Abdullaev et al., 2007). Countries such as Middle East and Australia are facing the soil problems because of land changes, deforestation and climatic conditions that bring more detrimental effects in arid and semi-arid conditions (Nosrati and Collins, 2019; Zeraatpisheh et al., 2020). Future plans may focus on development of land for agriculture sector within populations of different communities without depleting natural resources (Broman and Robèrt, 2017). Sustainable agriculture is basic part in making long term plans for land development such as these strategies have low environmental hazards and better crop production (Busby et al., 2017). Sustainable agriculture is ecofriendly, less expensive and protects the habitats that ensure security and conservation for plants and animal life (Yadav et al., 2018).

Crop production in dry lad areas is mainly dependent on precipitation. The conventional tillage (CT) practiced by most farmers is to leave soil bare after harvesting the crops until planting of the next crop in dry land regions of the USA, China and Canada. In dry land agriculture farming system, conventional tillage with the use of moldboard plough is inefficient to conserve soil moisture during fallow period (Cruse et al., 1982; Dao, 1993). The soil becomes denser as a result of CT and forms a hardpan below the plough layer that impedes air and water flow, stunts root growth and eventually lowers crop production. Furthermore, wind erosion and soil deterioration are exacerbated by little precipitation (200 mm per year) and finely pulverized top soil brought on by repetitive ploughing.

Conservation tillage is referred to any tillage method which is practiced to minimize soil and water loss (Benites et al. 1998). With this classification, many practices are considered measures of conservation tillage, including shallow top and sub-soil tillage (ST), reduced tillage (RT) and no-tillage (NT) (Rasmussen, 1999; Lampurlanés et al., 2002; Wang et al., 2003). Conservation tillage systems (NT, RT and ST) have been introduced as alternatives to conventional tillage systems (Schillinger, 2001). Conservation tillage is advised as a crucial step in dry land farming to reduce the deterioration of soil physical and chemical properties and boost the water usage efficiency of crops (Huang et al., 2008). Since tillage has an impact on root growth in the sub soil, the development and dispersion of roots in the soil profile is crucial for plant's ability to absorb water and nutrients (Godwin, 1990). However, tillage plays the most important role in soil-plant system such as continued use of conventional tillage method creates hard pan in soil that may damage the root proliferation below the plough layer (Maurya, 1988; Gill and Aulakh, 1990).

Several elements are taken into consideration about how soil behaves when NT is applied. These elements include the characteristics of soil, management history of land, weather and the type and intensity of tillage applied (Mahboubi et al., 1993). Reduced tillage directs to higher soil water content because it promotes soil penetration and decrease surface runoff and evaporation (Zhai et al., 1990). Moreover, conservation tillage can boost crop yield, lower the operational costs and have positive economic effects (O'Leary and Connor, 1997; Gicheru et al., 2004; Fabrizzi et al., 2005). However, Taa et al. (2004) found that the yield of no-till wheat can occasionally be lower compared to conventionally grown wheat such as Lampurlanés et al. (2002) described that crop productivity and water use efficiency were not affected by the type of tillage system.

Wheat (*Triticum aestivum* L.) is among the most important cereal crops (Adil et al., 2022; Bukhari et al., 2021; Bruning et al., 2020). It is accounted for 40% of China's food grains and is cultivated on 4.3 million hectares of land on the Loess Plateau (Tong et al., 2003). It is planted on more than 2.2 million acres in the interior Pacific Northwest of the United States (Schillinger and Papendick, 2008). A wild grass in central Mexico gave rise to maize (*Zea mays*) around 7000 years ago (Ranum et al., 2014). It is cultivated all over the world and has an energy density of 365 Kcal/100g. Maize comprises roughly 72% starch, 10% protein and 4% fat. However, the USA, China and Brazil are the top three maize-producing countries in the world such as these countries produce on an average of 563 of the 717 million metric tons of maize per year (Ranum et al., 2014). It is generally believed that in the nutrient deficient environment, water is the major yield limiting factor in dry areas (French and Schultz, 1984). There is an even indication that the excessive rainfall may actually reduce crop yields in dry land agriculture systems (Mason and Fischer, 1986). Moreover, inconsistent crop yields were obtained by different tillage systems (Su et al., 2007).

So, there is a need to check the yield difference of these two most important crops among different tillage methods around the globe. We hypothesized that (1) conservation tillage methods would have an overall positive effect on soil and plant parameters in both cropping systems; (2) such effect will differ between winter wheat and spring maize and/or within conservation tillage methods; and (3) edaphic and climatic conditions of several regions will modify the effect of conservation tillage methods on soil and plant parameters.

Materials and Methods

2.1. Collection and screening of data

To check the effect of fallow tillage methods on soil and plant parameters in winter wheat and spring maize cropping systems, we carried a search in peer-review journals from 1973 to 2022 in Google Scholar and Web of Science with keywords SWS, PSE, WUE, ET, wheat and maize as affected by CT, NT, RT and ST. Initially 845 publications were collected and screened by following criteria:

i. Tillage methods should be tested in the field cropping systems. In every study, conventional tillage (CT) should be used as the control treatment. The NT, RT and ST should be compared with CT.

ii. Experiments that are completely dependent on natural precipitation should be selected and the irrigation should not be applied at any point throughout the experimentation such as only precipitation should serve as the source of moisture.

iii. Simulation and model studies were not included.

The table 1 provides a brief introduction to tillage techniques. 1. Fig. 1 shows the geographic details of 119 trial sites around the globe. The data collection, partition and selection has shown in Figure 7. The literature compares several conservation tillage techniques against conventional tillage during fallow.

2.*2. Creation of database*

The data were homogenized into groups based on the various tillage techniques. Mean annual air temperature (MAT) was split into three categories: $>$ 15 °C, 8-15 °C, and 8 °C. Mean annual precipitation (MAP) was divided into three categories: $>$ 600 mm, 400-600 mm, and 400 mm. There are three broad categories for soil texture (fine, medium and coarse). We manually estimated PSE when PSE was not calculated in the publications, but the SWS with fallow precipitation was present (Nielsen and Vigil 2010). If the study did not contain information on latitude and longitude and weather, we collected these observations from an online search engine (https://www.whatsmygps.com). GetData graph digitizer 2.20 software (http://getdata-graph-digitizer.com/index.php) was used to extract data from the figures. The soil texture ranged from fine to coarse, the MAP ranged from 141 to 830 mm, whereas the MAT ranged from 4.1 to 22.1°C. We estimated the standard deviation (SD) value using the following formula by using the standard error (SE) value:

$SD = SE \times \sqrt{n}$ (1)

Where "n" represents the number of samples.

Possibly, we collected data on climatic and geographical conditions including longitude and latitude, fallow and annual precipitation, annual temperature, altitude, experimental location and duration of experiment and publication years.

2.3. Data analysis

Data was analyzed by following the procedures given by Adil et al. (2022).

Results

3.1. Tillage effects on winter wheat

3.1.1 Tillage effect on wheat PSE and SWSp

The number of paired observations for PSE and SWSp were 120 and 334, respectively (Figures 2a and 2b). Data showed significant heterogeneities, as shown by high Qt values of 112 for PSE and 321 for SWSp. Compared to CT, conservation tillage methods overall increased PSE by 22.6% (P [?] 0.05) (Figure 2a). The biggest increase in PSE was obtained with RT (25.1%) followed by ST (23.9%) and NT (15.9%) (P [?] 0.05) across conservation tillage methods. The response ratio (RR) of PSE to conservation tillage techniques was significant in overall soil textures (Figure 3a). The medium and coarse-textured soils increased PSE by 22.1% and 16.4%, respectively, while fine-textured soils increased PSE by 25.7%. The enhancement of conservation tillage on PSE was greater when MAP was >600 mm than 400-600 and <400 mm. Conservation tillage also increased PSE in the regions where MAT was 8-15 than >15 and <8 (Figure 3a).

The conservation tillage methods raised SWSp by 17.8% as compared to CT (P [?]0.05, Figure 2b). This beneficial impact on SWSp varied with tillage methods. In comparison to CT, SWSp increased by 26.9%, 24.4%, and 13.1% from NT, RT, and ST, respectively (P [?] 0.05). Under all soil textures, the RR of SWSp under conservation tillage methods was significant as compared to CT (Figure 3b). SWSp increased by 26.4% in fine-textured soils, while PSE increased by 22.1% and 17.7% in medium- and coarse-textured soils, respectively. The benefits of conservation tillage on SWSp were greater under MAP of 400-600 mm. The SWSp improved with conservation tillage methods in the regions where MAT was below 8 degC (Figure 3b).

3.1.2. *Tillage effect on wheat grain yield, ET and WUE*

Total 331 observations for grain yield, 34 for ET and 103 for WUE were measured. The data were heterogeneous for grain yield (Qt = 318), ET (Qt = 29), and WUE (Qt = 101) (Figures 2c, 2d, and 2e). Compared to CT, overall conservation tillage methods enhanced grain yield by 24.1% (P [?] 0.05, Figure 2c). According to the categorical meta-analysis, the grain yield was increased by 31.4%, 21.1%, and 18.2% with NT, RT, and ST, respectively. The fine and coarse textured soils increased grain yield by 20.3% and 22.1%, respectively, and medium textured soils increased wheat yield by 24.1% (Figure 2c). The enhancement of conservation tillage methods on grain yield was greater in the regions where MAP was >600 mm. Conservation tillage methods also increased grain yield in the regions where MAT was 8-15 (Figure 3c).

There was a significant effect of overall conservation tillage methods on wheat ET. The NT and RT increased ET by 11.6% and 14.1%, respectively (*P [?] 0.05* , Figure 2d). However, ST had no significant effect on ET. Fine-textured soils increased ET by 18% while medium and coarse textured-soils enhanced ET by 2% each. The enhancement of conservation tillage methods on ET was greater when MAP was <400 mm. Conservation tillage methods increased ET in the regions where MAT was >15 (Figure 3d).

Winter wheat WUE increased by 12.1% under overall conservation tillage methods over the fallow period (P [?] 0.05, Figure 2e). The NT, RT and ST increased the WUE by 18.4%, 11.3% and 5.4%, respectively, as compared to CT. Overall soil types exhibited an increase in wheat WUE when conservation tillage methods were applied, although medium-textured soils exhibited the greatest increase (22.3%) compared to fine and coarse-textured soils (Figure 3e). Conservation tillage methods had a stronger positive impact on WUE in regions having the MAP <400 mm. Conservation tillage methods increased WUE in areas where MAT was 8–15 degC (Figure 3e).

3.2. Tillage effects on maize

3.2.1. Tillage effect on maize PSE and SWSp

We gathered 76 paired observations for PSE, and 139 paired observations SWSp (Figures 4a and 4b). As perceived by high Qt values of 73 and 133 for PSE and SWSp, the data showed strong heterogeneities. Compared to CT, conservation tillage methods generally enhanced PSE by 38.1% (P [?] 0.05) (Figure 2a). The highest increase in PSE was perceived with NT (45.7%) followed by ST (14.9%) (P [?] 0.05). PSE increased by 28% in medium-textured soils and 17% in both fine and coarse-textured soils under conservation tillage methods compared to conventional tillage. Compared to CT, the RR of conservation tillage on PSE was greater in the regions having MAP <400 mm. Conservation tillage also increased PSE in the regions where MAT was 8-15 (Figure 5a).

Overall SWSp was enhanced by 20.6% in comparison to CT (P [?] 0.05, Figure 4b). However, the beneficial impact on SWSp differed according to the tillage techniques. In comparison to CT, SWSp increased by 36.1% under NT, 3.8% under RT and 4.9% under ST (P [?] 0.05). In all soil textures, the RR of SWSp under conservation tillage methods to CT was favorable (Figure 5b). SWSp increased by 26.4% in fine-textured soils, while PSE increased by 22.2% and 17.1% in medium and coarse-textured soils, respectively. When MAP was 400-600 mm, the RR of conservation tillage on SWSp was higher compared to CT. Additionally, conservation tillage raised SWSp in areas where MAT was between 8 and 15 .

3.2.2. *Tillage effect on maize grain yield, ET and WUE*

Overall, 158 observations were measured for grain yield, 97 for ET and 58 for WUE. Data was heterogeneous for yield (Qt = 154), ET (Qt = 89) and WUE (Qt = 52) (Figures 4c, 4d, and 4e). Conservation tillage methods increased grain yield by 29.6% compared to CT (*P [?] 0.05* , Figure 4c). The categorical meta-analysis showed that NT, RT and ST increased grain yield by 33.1%, 23.8 and 21.2%, respectively. The RR of yield under conservation tillage methods was positive in all soil textures (Figure 5c). Coarse-textured soils increased yield by 25.5%, while fine and medium soils increased grain yield by 11.1% and 16.2%, respectively. Compared to CT, the RR of conservation tillage on grain yield was greater when MAP was <400 mm. Conservation tillage increased grain yield when MAT was >15 (Figure 5c).

There was a significant effect of overall conservation tillage methods on crop ET. The NT, RT and ST increased spring maize ET by 10.1% and 14.7% and 16.8%, respectively (*P [?] 0.05* , Figure 4d). Medium-textured soils increased ET by 18% while fine and coarse textured-soils enhanced ET by 12.0% and 9.7%, respectively. Compared to CT, the RR of conservation tillage on ET was greater when MAP was <400 mm. Conservation tillage also increased ET in the regions where MAT was <8 than >15 and 8-15 (Figure 5c).

Maize WUE increased by 11.0% with overall conservation tillage practices (*P [?] 0.05* , Figure 4e). The NT, RT and ST increased WUE by 19.4%, 3.1% and 10.7 %, respectively. Maize WUE increased with conservation tillage during fallow period in all soils, but the effect of conservation tillage methods was more prominent in medium-textured soils with an increase of 21.3% (Figure 5e). Compared to CT, the RR of conservation tillage on WUE was greater when MAP was <400 mm. Conservation tillage methods also increased WUE when MAT was >15 (Figure 5c).

Discussion

4.1. Effects of conservation tillage methods on winter wheat

Averaged across all locations, conservation tillage methods overall increased winter wheat PSE, SWSp, grain yield, ET and WUE by 22.6%, 17.8%, 24.1%, 6.5% and 12.1%, respectively (*P* [?] 0.05 Figure 2) which corresponds to a recent meta-analysis by Adil et al. (2022) that described the positive effects of conservation tillage methods and fallow mulching in dry lad cropping systems, and also to the results obtained by Li et al., (2007) who described that conservation tillage methods are effective in increasing soil water storage and crop yield. The positive effect of conservation tillage methods on soil water storage compared to conventional tillage clearly confirmed our 1st hypothesis that conservation tillage methods will improve soil water storage during fallow period which is probably due to the reduced soil disturbance, reduced soil bulk density and improved aggregate stability by NT (Oyedeleet al., 1999; Zhang et al., 2007). Similarly, conservation tillage methods are effective conservation tillage methods (Li et al., 2007; He et al., 2009) that reduced the soil compaction, improved soil structure which eventually increased yield and WUE (Pikul Jr and Aase, 1999; Pikul and Aase, 2003). Moreover, previous studies in Chinese Loess Plateau also reported higher water content and yield with conservation tillage methods during fallow period compared to CT (Liang et al., 2002; Wang et al., 2003) and is consistent with the results of current meta-analysis that also corresponds to the previous studies conducted in other areas including Victoria (Australia), Nebraska (USA) (Lyon et al., 1998; Cantero-Martinez et al., 1999), and Texas (USA) (Baumhardt and Jones, 2002), Great Plains of the Northern USA (Lenssen et al., 2007), semi-arid Kenya (Gicheru et al., 2004).

In our study, RT increased wheat PSE by 25.1% compared to CT and this effect was slightly more than that of ST (23.9% increase compared to CT) (Figure 2). ST had good results than CT may be due to the deep loosening of the soil which resulted in better infiltration and the breaching up of the permanency of flow paths in the soil (Hillel, 1998). Although, NT increased PSE by 10.9% compared to CT (Figure 2), which is in accordance with (Halvorson et al., 2000) who described the effect of NT and CT under dry conditions.

In our study, 24.1% increase IN wheat yield was obtained with NT compared to CT and the similar results were obtained by Jin et al. (2007) who described that after 6 years of experiment, NT showed highest yield by improving soil physical and chemical properties and stabilizing the bulk density of soil after 5 years of NT practice (Fabrizziet al., 2005).

4.2. Effects of conservation tillage methods on spring maize

Compared to CT, conservation tillage methods also increased spring maize PSE, SWSp, grain yield, ET and WUE by 38.1%, 20.6%, 29.6%, 16.9% and 11.0%, respectively (P [?] 0.05 Figure 4) which corresponds to the results obtained by Li et al. (2007) and Heet al. (2009) who stated that conservation tillage methods are effective in improving soil water storage and crop yield. Among conservation tillage methods, the highest PSE (45.7%) and SWSp (36.1%) were observed with NT (Figure 2) which confirms our 2nd hypothesis (such as the highest PSE under wheat cropping system was obtained by RT, Figure 2) that the effects of conservation tillage methods will differ among winter wheat and spring maize cropping systems, that corresponds to (Jin et al., 2007) who found that NT is the best tillage practice in fallow period for water conservation with the effective storage efficiency of rainwater (Figure 4). Similarly, highest increase in maize yield (33.1%) and WUE (19.4%) were obtained by NT and is corresponding to the results of Li et al. (2007) and He et al. (2009) who stated that conservation tillage methods are effective methods and can reduce soil compaction, improve soil structure which eventually increase yield and WUE (Pikul Jr and Aase, 1999; Pikul and Aase, 2003). Previous studies in the Loess Plateau also reported higher water content and yield with conservation tillage methods during fallow period compared to CT Liang et al. (2002) and Wang et al. (2003), which is consistent with the results found in other areas including Victoria (Australia), Nebraska (USA) (Lyon et al., 1998), (Cantero-Martinez et al., 1999), and Texas (USA) (Baumhardt and Jones, 2002), Great Plains of the Northern USA (Lenssenet al., 2007), semi-arid Kenya (Gicheruet al., 2004).

4.3. Variations with soil textures and climatic conditions

Soil and climatic conditions of several regions affected soil water storage with conservation tillage methods compared to conventional tillage methods as coarse-textured soils stored the lowest amount of water compared to fine-textured soils while the RRs of fine and coarse-textured soils were quite similar in overall conservation tillage methods (Figure 2 and Figure 4) which is consistent with (McConkey et al., 1996) who stated that lowest soil water volume observed in sandy loam in 1983 and with silt loam and clay soil in 1990, for silt loam, the estimated SWSp with CT and NT were 123 and 125 mm and 31, 128 and 128 mm for RT and NT, respectively. Increased SWSp in fine soils and PSE, crop yield and WUE with medium-textured soils (Figure 2 and Figure 4) indicate that coarse to medium-textured soils stored more water and improved yields in both crops. The improved initial soil moisture storage was reported in clay soil with NT and as a result, higher crop yield was expected (Cox et al., 1986; Tanaka and Aase, 1987), while lower yield were obtained with NT under silt loam (Tessieret al., 1990).

According to Hammel et al. (1981), soil texture affects soil hydraulic properties that may have an impact on how much water is lost when using different tillage techniques. For example, according to Papendick et al. (1973) the average WUE of the conservation tillage techniques for three years of study was significantly higher than CT. Large fluctuations in diurnal temperature occur in the top 15 cm of soil and may affect the vapor movement in the dry layer in the Northwest, where the majority of water loss occurs in fallow land in a dry layer of 10 cm or more in thickness (Papendick et al., 1973). Macro pores and cracks can also affect water balance with RT in bare fallow period (Hartzog and Adams, 1989) because of the fast-downward movement of water with significant contribution to the fallow performance in cracking clay soil texture in southern Queensland (Marley and Littler, 1989). Deep movement of water in NT fallows explained the cracking behavior of the soil at Dooen (Australia) while at nearby locations, saturated hydraulic conductivity significantly increased from 14 mm to over 200 mm h^{-1}after 10 years of NT (Bissett and Oleary, 1996) while NT accumulated 47 mm additional water than CT (O'leary and Connor, 1997).

Conservation tillage methods had significant effects on winter wheat PSE, SWSp, crop yield, ET and WUE in all precipitation patterns except for WUE with >600 mm MAP which remained non-significant (Figure 3).

Similarly, MAP of >600 mm had non-significant effect on spring maize PSE, except for that, conservation tillage had significant effect on all variables (Figure 5). Similarly, greater positive RR for crop yield and WUE was achieved with conservation tillage practices when MAP was <400 mm which corresponds to Jin et al. (2007) who found that NT is the best tillage practice in fallow period for water conservation with the effective storage efficiency of rainwater leading to higher winter wheat yield and PSE. Similarly, spring maize crop yield with >600 mm MAP was relatively low as compared to <400 mm (Figure 5) which could be due to the saturated field conditions at the end of the fallow period and the time of sowing of the main crop is delayed (Jin et al., 2007). Similarly, the difference between conservation and conventional tillage was more pronounced with relatively dry rainfall (365 mm and 292 mm) years such as overall 42% of fallow precipitation was stored in the soil with comparatively low runoff, which means 58% of fallow precipitation was vanished due to evaporation (Jin et al., 2007). However, the advantages of conservation tillage for soil differ depending on periodic rainfall and soil texture (Unger, 1979; Gajri et al., 2002). Previous studies found that the degree and depth of soil disturbance under the NT, ST, and CT treatments affected rainfall infiltration, soil water-holding capacity and ET (Huang et al., 2006). In three-year research, regardless of the amount of rainfall during the fallow season, water storage status improved to varied degrees with all tillage techniques. In comparison to CT, the NT and ST treatments increased SWS and PSE in order to more effectively store fallow precipitation into the soil (Hou et al., 2012). This is due to the fact that conservation tillage techniques with less soil disturbance result in enhanced rainfall penetration and decreased soil water evaporation (Li et al., 2007; Pikul and Aase, 2003; Amir and Sinclair, 1996). By removing the plough pan layer, ST considerably reduces soil bulk density and allows more precipitation to be stored in the soil (Pikul Jr. and Aase, 1999; Mohantyet al., 2007). Contrarily, excessive soil tillage (CT) leads to a relatively high rate of soil water evaporation (Debaeke and Aboudrare, 2004; He et al., 2010).

4.4. Correlations of wheat and maize grain yield, ET and WUE to SWSp

The RR of wheat and maize grain yield increased linearly with increase of the RR of SWSp for conservation tillage practices (Figure 6). An increase of 24.1% in wheat and 29.6% in maize yields can be explained by the increase of the RR of SWSp for conservation tillage practices. The RR of ET to SWSp under conservation tillage methods was significant for wheat but remained non-significant for maize. Similarly, the RR of wheat and maize WUE was also related to with that of SWSp, which can be attributed to 12.1% increase in wheat and 11.0% increase in maize WUE under conservation tillage methods (Figure 6).

Conclusion

The meta-analysis results showed that conservation tillage methods overall increased soil water storage, grain yield and crop water use in both winter wheat and spring maize cropping systems compared to conventional tillage. Although overall conservation tillage methods increased PSE, SWSp, grain yield, ET and WUE in both of the cropping systems but the intensity was greater in spring maize as compared to winter wheat. Soil texture and precipitation pattern played a significant role in determining the results. High precipitation increased PSE, SWSp and wheat grain yield and the effect was opposite in case of maize. Fine-textured soil increased PSE, SWSp and ET in both of the cropping systems while medium-textured soil showed increased grain yield and water use in both cropping systems. Even though different conservation tillage methods had variable effects on soil water conservation under different edaphic and climatic conditions, however, overall conservation tillage methods can improve soil physical health and enhance crop productivity to obtain food security under climate change scenario.

Ethical Approval

All authors approve the submitted version of the manuscript. We also ensure not to submit the manuscript in another journal while it is under consideration and is not under review in any journal.

Consent to Participate

All authors had a positive consent in writing and publishing of this manuscript.

Consent to Publish

All authors approved that the data used for analysis was genuine and the results are according to the data.

Authors Contributions

HL, MA, ZY and SL conceived the review, drafted, and finalized the manuscript. CZ, JW, IG, MP and LR helped to improve the draft by providing useful suggestions and information. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare no conflict of interest.

Availability of data and materials

Data and materials will be available on demand.

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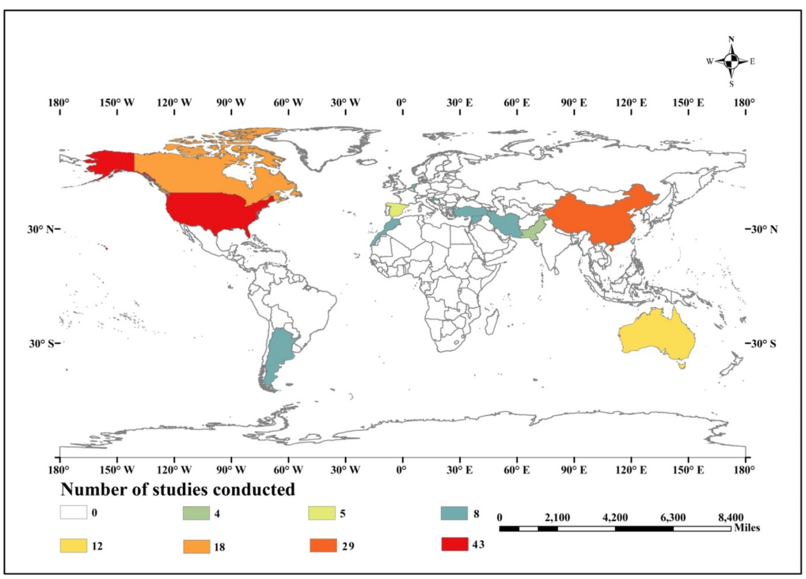
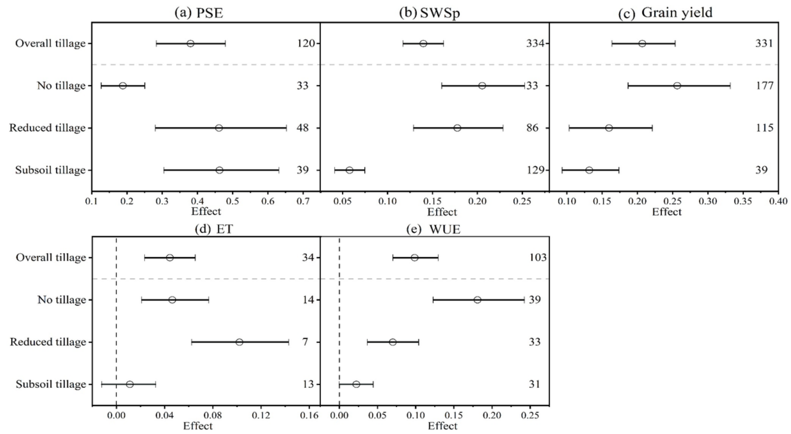
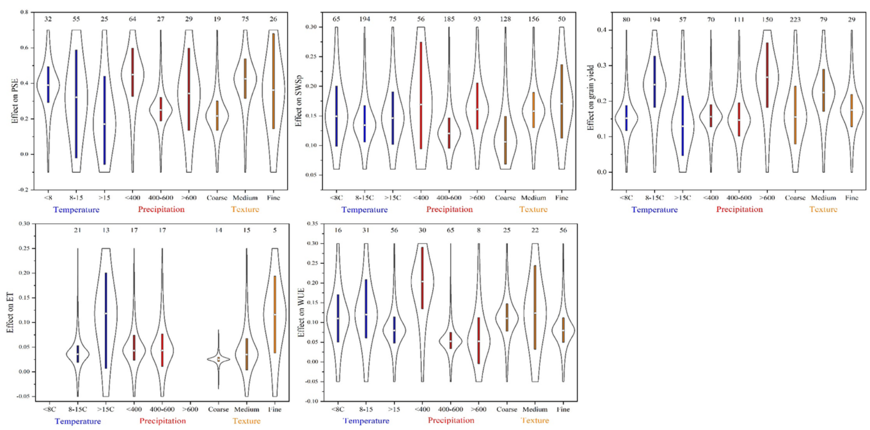


Figure 1 Distribution of 119 experimental sites around the globe from where the data was collected for the meta-analysis.





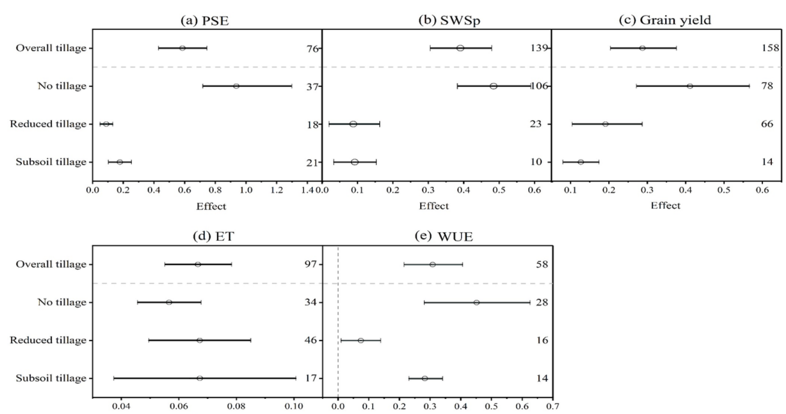
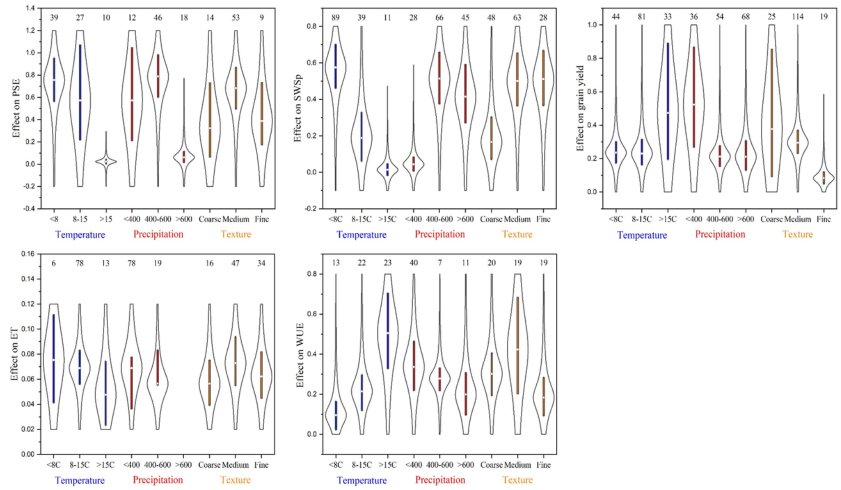


Figure 4. Impacts of various tillage practices on (a) precipitation storage efficiency (PSE) (b) soil water storage at main crop planting (SWSp), (c) grain yield, (d) evapotranspiration (ET) and (e) water use efficiency (WUE) related to conventional tillage (CT) in spring maize cropping system. The reference line (RR = 0) specifies no variation between conservation tillage and conventional tillage. Data points are the weighted response ratio with 95% confidence intervals. Numbers along bars indicate the sample size.



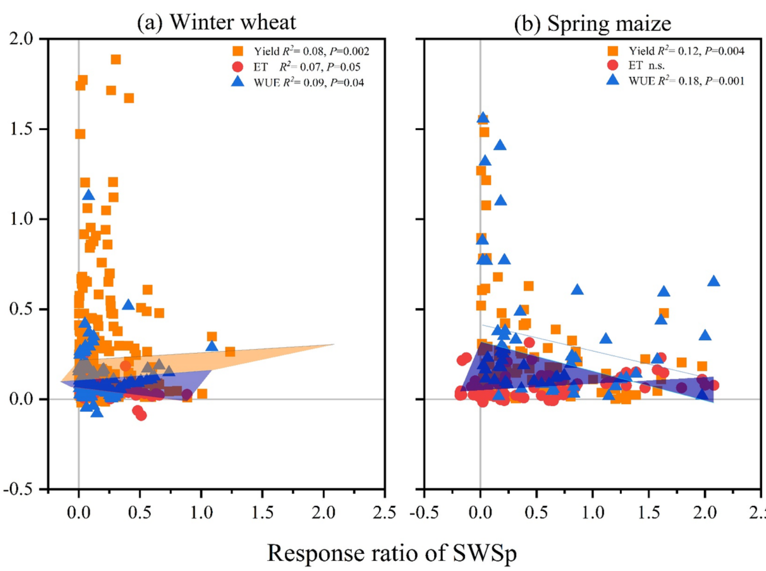


Figure 6. Correlations of the response ratio of grain yield, evaportranspiration (ET), and water use efficiency (WUE) to that of soil water storage at crop planting (SWSp).

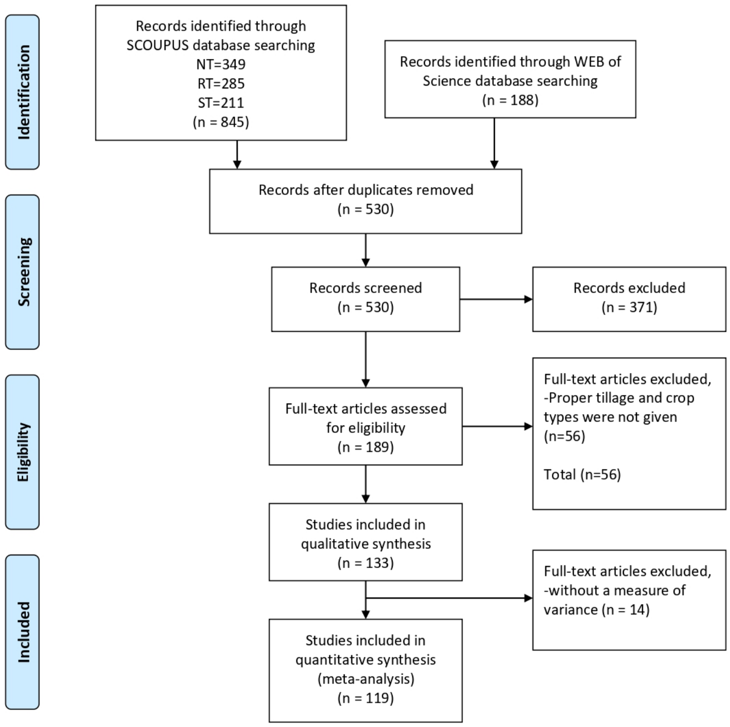


Figure 7. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) diagram for the meta-analysis

Table 1. A brief introduction to the various tillage practices along with control treatment during fallow period.

Management Practices	Brief Description
Conventional Tillage (CT) (control)	Farmers frequently use a tractor-mounted moldboard plough to a depth of 20–25 cm
NT	After the main crop was harvested, the previous crop wastes were removed, leaving t
RT	After the main crop was harvested, previous crop residues were cut down, and the so
ST	After the primary crop was harvested, previous crop leftovers were cut down, and the