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Article

Superior Wheat Yield and Profitability in Conservation Agriculture with Diversified Rotations vs. Conventional Tillage in Cold Arid Climates

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Abstract

Wheat productivity in dry regions of the world such as Central Asia and the Mediterranean is experiencing significant declines due to erratic weather events. Conservation agriculture (CA) has been promoted as a promising alternative for drylands to address climate-change-induced water scarcity and soil degradation. A long-term experiment in the Central Anatolian region of Türkiye compared CA and conventional tillage (CT) using diversified two- and four-year rotations. All rotations outperformed the wheat–wheat control, with the highest yields in wheat–fallow and wheat–lentil rotations. Four-year rotations generally yielded more than two-year ones under both CA and CT, except wheat–fallow and wheat–lentil, which matched four-year results. In two-year-rotations, yield differences between CA and CT were largest in wheat–wheat and wheat–lentil, with CA increasing yields by around 50% and 60% for chickpea and lentil, respectively. Chickpea and lentil also had a similar positive effect on wheat yield in four-year rotations. All rotations were more profitable under CA than CT, with chickpea and lentil rotations achieving the highest gross margin. Soil organic matter content was significantly greater under CA compared to CT within each two-year crop rotation. Our study clearly demonstrated the advantages of CA over CT in terms of production, soil quality and economics.

Keywords: conservation agriculture; legumes; crop rotation; wheat productivity; agricultural resilience

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1. Introduction

Wheat productivity in dry regions of the world such as Central Asia and the Mediterranean is experiencing significant declines due to climate change and associated environmental stresses [1–3]. In Central Asia, wheat production is highly sensitive to climate variability, with drought stress potentially reducing yields by up to 71% in rainfed areas [4]. In the Mediterranean, the situation mirrors these trends, where changing precipitation patterns and increasing temperatures threaten wheat yields, necessitating the development of climate-resilient agricultural strategies [5,6].

Türkiye, situated between Central Asia and Mediterranean regions, ranks among the top ten global producers of wheat (*Triticum aestivum* L.), which is the most cultivated crop in the country [7]. About half of the cropland is in Central Anatolia (ca. 3 million hectares), producing 8.5 million tonnes of wheat in a cold and dry continental climate [8]. Similar to the trends in the surrounding regions, wheat yields are adversely affected by recurrent droughts and erratic rainfall in Türkiye [7,9,10]. A reduction of up to 40% of precipitation and an increase in temperature between 1.2 °C and 3.9 °C is anticipated to reduce wheat yield from 16% to 43% [10]. Such a reduction will have negative implications for global wheat and grain prices due to Türkiye's large contribution to global wheat markets.

Wheat is traditionally cultivated from October to July in a rotation with a 14-month fallow period to increase soil moisture that accumulates during winter and spring, reduce labor costs and stabilize yields in the face of erratic and low rainfall (long-term average of 332 mm; [8]). However, an extended fallow period with excessive tillage increases the risk of erosion, causing losses in soil carbon and water [9,11–14]. There is an urgent need to replace the fallow periods with sustainable alternatives in wheat-based production systems in Türkiye. Most of the precipitation is lost through evaporation, and less through losses by weeds, volunteer plants, runoff, deep seepage and snow blow off [15–17].

Conservation agriculture (CA) and its three principles of no soil disturbance, soil cover and diverse crop rotations has been promoted as a promising alternative for drylands to address climate-change-induced water scarcity and soil degradation [18–20]. CA improves the stability of the soil structure and increases soil carbon sequestration, which in turn improves soil water capture and storage in drylands [21–23]. Despite several projects since the 1970s that have promoted CA and supported farmers to apply CA through subsidies and technical advice, adoption remains negligible in Türkiye, the Mediterranean region and Western Asia in general [18,24]. Unofficial reports estimate a total of 100,000 ha under CA in Türkiye [13]. The low adoption rate is largely due to a lack of information, intellectual and cultural misconceptions about soil management [25,26] and the promotion of CA as a technological package without considering the local context, as well as limited awareness at the policy level [11,13,20,27].

The potential of CA for greater yields in drylands has been shown by several studies. Pittelkow et al. (2015) [19] compared 678 global studies in a meta-analysis and claimed CA performed best under rainfed conditions in dry climates, with yields mostly equal to or higher than tillage. The authors stated that water availability was the most limiting factor in dry climates and that higher soil moisture in CA increases biomass production, which has a positive effect on soil cover and soil structure. In water-limited regions such as the Great Plains of North America, greater water capture and storage is achieved through no-till [16,28]. The additional soil moisture accumulated in CA can be used to replace fallow with other crops to make more efficient use of available resources [29]. For instance, Lawrence et al. (1994) [30] found that water accumulation in the soil layer between 100 and 180 cm was twice as high in no-till (86 mm) than in conventional tillage (40 mm).

Wheat has high nutrient and agronomic requirements and is sensitive to pre-crops [16,31]. Many studies emphasize the cultivation of wheat with legume rotations, as legumes fix N and can be used for feed, food and biomass production [32]. Commonly grown legumes in Central Anatolia are chickpea, lentil and vetch, which are produced for the regional and export markets. Incorporating these legumes into the traditional wheat–fallow system can improve soil fertility and structure. Research comparing wheat yield in various crop rotations under dryland Mediterranean conditions showed a positive impact of alternating crops over monocropping and emphasize the long-term positive effect of legume-based rotations on yields and water use efficiency [14]. Studies in the central and northern Great Plains with similar climatic conditions replaced fallow with peas and lentils in a no-till cereal rotation and reported a reduced need for N fertilizers and benefits for wheat yields, organic carbon and forage supply [12]. These results have been confirmed by studies in Syria and Australia, suggesting that the inclusion of legumes can help improve cropping systems in Mediterranean-type climates [33]. There is surprisingly little data from cold regions in Asia such as Central Asia and Türkiye, which are one of the most important wheat growing regions in the world. This indicates the need for further research on the long-term effects of tillage on soil quality and crop productivity in such regions.

The objective of this study was to investigate the effect of management (CA and CT) and rotation (two- and four-year rotations) on wheat productivity and soil quality. We hypothesized that legume-based wheat rotation under CA can be an alternative farming system for Türkiye to stabilize and increase wheat yields. This study is the first long-term study (seven years) comparing CA with CT and crop rotations in the cold and dry Mediterranean region, which is characterized by cold winters and hot summers with variable rainfall. The results of this study are extremely important and relevant in terms of wheat production, food security and climate resilience for the cold and dry wheat production region across the Mediterranean and beyond (i.e., Central Asia).

2. Materials and Methods

2.1. Experimental Site

The experiments were carried out from 2016 to 2023 on the experimental field of Bahri Dağdaş International Agricultural Research Institute in Konya, central Türkiye (37.8667° N, 32.5167° E). The climate is classified as a cold semi-arid climate with cold and wet winters and warm and dry summers according to the Köppen climate classification [34]. The soil in the top 20 cm was loamy and characterized as light alkaline with an average pH of 8.21, a very high potassium availability (1104 kg ha^{-1}), a medium phosphorus availability (20 kg ha^{-1}) and a high calcium carbonate content of 26%. Soil texture was determined for two depth intervals (0–20 cm and 20–40 cm) using the hydrometer method, revealing a clayey texture with 50% clay, 32.52% silt and 17.81% sand in the 0–20 cm layer, and 50.39% clay, 23.54% silt and 26.07% sand in the 20–40 cm layer.

2.2. Experimental Design and Agronomic Practices

The trials were established in 2014 with barley on all plots as a first crop to reduce the impact of the previous crops as well as to test the homogeneity of the soil. In 2015, all rotational crops were sown but no data were collected. These two years ensured that there were no residual effects. The first data was collected in 2017 on crops sown in 2016 and the final data was collected in 2023. This meant that the two-year rotations completed four full cycles, and the four-year rotation completed two full cycles, where all phases of the rotations were present in all years to eliminate the year effect. Experiments were conducted in a split-plot design with four replications in 60 m^2 plots—tillage management as the main plot and rotation treatment as a subplot (Tables 1 and 2). Each crop rotation was studied under CA and CT.

Table 1. Summary of seeding and harvesting dates.

Crop	Seeding	Harvest	Variety
Wheat (*Triticum aestivum* L.)	October	July	Karahan '99
Chickpea (*Cicer arietinum* L.)	March	August	Azkan
Lentil (*Lens culinaris* Medic.)	March	August	Meyveci
Safflower (*Carthamus tinctorius* L.)	March	August	Göktürk
Hungarian Vetch (*Vicia pannonica* Crantz)	October	June	Altınova 2002

Table 2. Studied crop rotations.

Rotation Code	Year 1	Year 2	Year 3	Year 4
W-W	Wheat	Wheat		
W-L	Wheat	Lentil		
W-S	Wheat	Safflower		
W-H	Wheat	Hungarian vetch		
W-C	Wheat	Chickpea		
W-F	Wheat	Fallow		
W-F-W-H	Wheat	Fallow	Wheat	Hungarian vetch
W-F-W-C	Wheat	Fallow	Wheat	Chickpea
W-F-W-L	Wheat	Fallow	Wheat	Lentil
W-F-W-S	Wheat	Fallow	Wheat	Safflower

In the CT system, a moldboard plow was used after harvest or in fall at a working depth of 25 cm, followed by one cultivator pass before planting at a working depth of 10 cm. One to two additional cultivator passes were made depending on weed density and crusting. In crop rotations with a fallow period, plots were ploughed in spring and seed beds were prepared in the summer with secondary tillage, depending on weed density and crusting.

For seeding in CT plots, a 12-row universal cereal seeder from the company Özdöken (Konya, Türkiye) with an inter-row distance of 15 cm was used. For CA plots, a no-till 12-row seeder with an inter-row distance of 17.5 cm and a double disk from the company Şakalak (Konya, Türkiye) was used. On average, 3 L/ha of glyphosate was applied to CA plots with spring crops (lentil, chickpea and safflower) approximately three days before seeding. Depending on weed density, glyphosate was applied in May or end of June during the fallow period. Plant residues, except that of Hungarian vetch, were retained on the soil surface in all treatments. Post emergence, in wheat, the herbicides 2,4-D EHE at a concentration of 452.42 g/L (300 g a.e./L) + 6.25 g/L Florasulam was applied at a rate of 700 mL/ha. Chickpea and lentil were treated with 1250 mL/ha of 600 g/L of Aclonifen in the CA and in the CT system.

2.3. Soil Analysis

Soil samples were only collected from the two-year rotation plots for the depth 0–40 cm using a soil auger. Soil moisture samples were collected in April, May and June 2022. For the analysis, the wet, dry and tare weights were taken and combined to calculate the water content (gravimetric analysis) as described in Gardner [35]. Organic matter content was measured in 2021 using the Smith–Weldon method [36] on samples taken at 20 cm.

2.4. Economic Analysis

To determine the impact of crop rotations and CA and CT on total and gross income, the partial budget method was used. Production costs included tillage, sowing, planting, harvesting, fertilizers and herbicides and were based on average market prices in 2022. Product prices were based on the average Konya Commodity Exchange (https://www.ktb.org.tr/ accessed on 22 April 2024) prices for 2023, to which government subsidies were added. Only single-year prices for input and product prices were used to reduce the impact of market fluctuations over the economics of the crops' rotations. The data was analyzed using R-Studio package (R 4.3.2) lmm.

2.5. Yield Analysis and Quality Parameters

Wheat grain for yield estimation was collected from the whole plot using a Hege 140 plot harvester (Ried im Innkreis, Austria). All samples were dried for 2 days at 70 °C and weighed for dry matter content. Wheat yield components were collected according to the methodology of Bell and Fischer (1994) [37].

2.6. Statistical Analysis

The effect of tillage system and crop rotation on wheat yield and quality parameters was analyzed using the R software environment (R 4.3.2) [38]. Comparison of cropping systems (CA vs. CT) was performed using analysis of variance (ANOVA); post hoc pairwise comparison was performed for rotations using the Tukey's method, with a significance level of $p < 0.05$. To evaluate the effects of tillage and rotation while accounting for the hierarchical and repeated structure of the data, a linear mixed-effects model (LMM) was fitted using the lme4 package in R (R 4.3.2). The model included tillage system (CA, CT) and crop rotation as fixed effects, while year and replication were treated as random effects to account for temporal variability and experimental design structure.

Estimated marginal means (EMMs) for each treatment combination were computed using the emmeans package [39] to provide adjusted comparisons among factor levels, controlling for random effects and unbalanced data where applicable.

3. Results

During the experiment, the average precipitation was 44 to 214 mm less than the long-term annual average of 332 mm (Figure 1). Compared to all experimental years, the 2021 growing season was the driest with a total of 118 mm rainfall. Most of the precipitation occurred during the winter months. The average temperature during the wheat growing season (October to July) was 10.2 °C in all years of the experiment, and slightly above the long-term average of 9.9 °C. The highest average temperature was recorded in August (24.1 °C) and the coldest in January (−0.3 °C). As temperatures were ideal for wheat growth, rainfall was the limiting factor. The cropping seasons of 2017 and 2022 had the longest periods of snow cover, which were 72 and 59 days, respectively. Snow cover in other years ranged from 10 to 20 days.

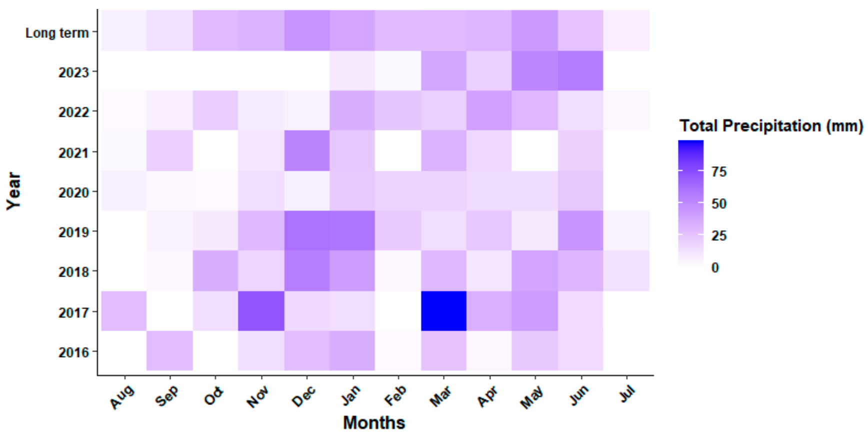

Figure 1. Average yearly precipitation (mm) compared to long-term data (1922 to 2022; Turkish State Meteorological Service, 2024). Average precipitation (mm): Long term= 332; 2016 = 177; 2017 = 271; 2018 = 281; 2019 = 286; 2020 = 148; 2021 = 181; 2022 = 174.

3.1. Soil Organic Matter and Moisture

The soil organic matter content in two-year rotation plots was significantly greater under CA compared to CT within each crop rotation in the sixth experimental year (Figure 2). The organic matter content of the plots managed under CA ranged from 2.5 to 3.1%, while under CT the content was between 1.9 and 2.8%. Wheat–lentil rotation when managed under CA had the highest organic matter content, while the wheat–wheat rotation under CT had the lowest OM. Soil moisture was also improved under CA (Figure 3). In all months, the soil moisture on plots under CA was greater than under CT. While there were differences among the rotations under CT, there were no significant differences among the rotations in terms of soil moisture under CA system.

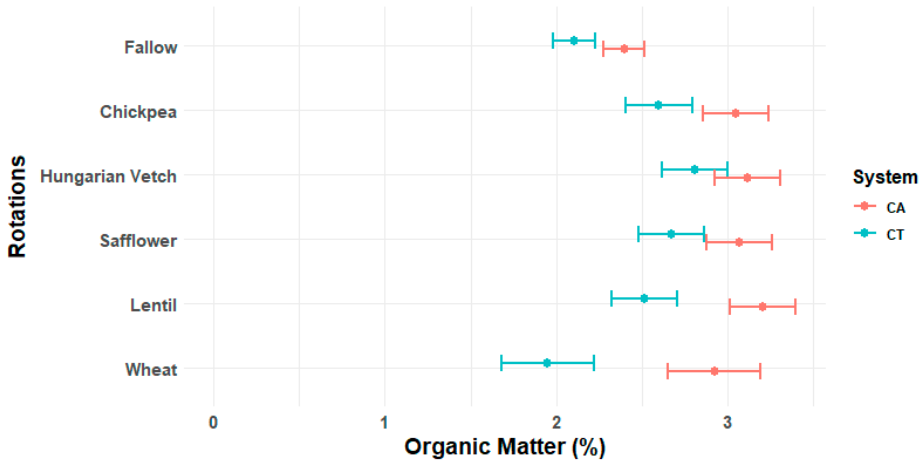

Figure 2. Soil organic matter (%) at 0–40 cm within different two-year wheat-based crop rotations under CA and CT systems.

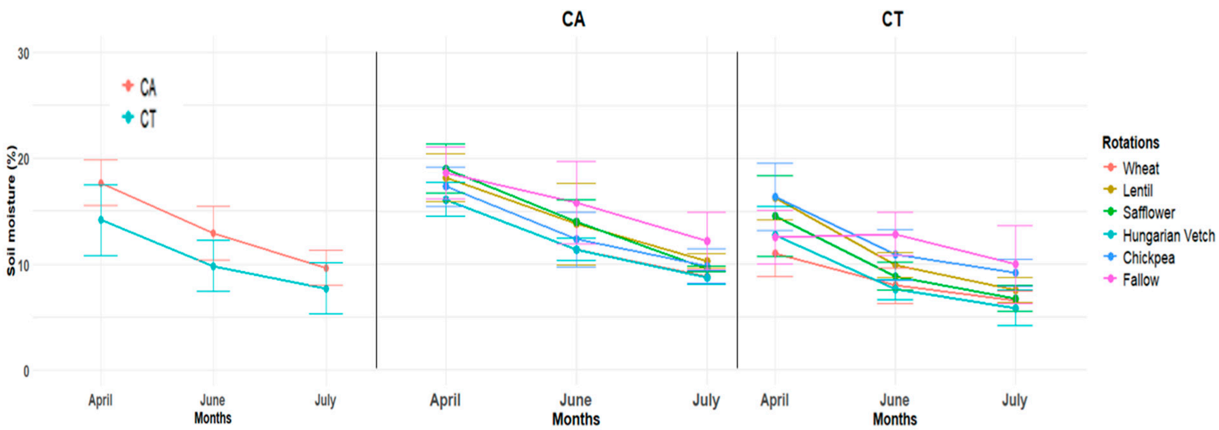

Figure 3. Comparison of soil moisture (%) between two-year wheat-based crop rotations under CA and CT in 2022.

3.2. Wheat Yield

Wheat yields fluctuated greatly under both systems over the years, but these variations did not correspond to annual rainfall patterns (Figure 4). The apparent low medians in 2018 and 2021 are a result of extremely dry climatic conditions during those years, which significantly reduced yields. The greatest yields were in 2017 at 3.2 and 3.4 t ha^{-1} for CT and CA, respectively. Over the seven-year duration of the experiment, the average cropping season (October to July) precipitation was around 227 mm, and most years received from 213 to 288 mm of precipitation, except in 2020/2021 where the precipitation was only 118 mm (Figure 1).

Under both CA and CT, the wheat yield and yield parameters like spike and grain number (Supplementary Materials) in four-year rotations were greater than those in two-year rotations, except in a wheat–fallow rotations which obtained yields similar to the four-year rotations. Under CA, the wheat–lentil rotation achieved yields similar to those in four-year rotations (Figure 5). All rotations performed better than the control (wheat–wheat) and the greatest yields were in wheat–fallow and wheat–lentil rotations (both two-and four-year rotations). Within the two-year rotations, the yield difference between CA and CT was much higher in wheat–chickpea and wheat–lentil rotations than in the other rotations. In these rotations, wheat yield managed under CA was around 50% and 60% greater than managed under CT for chickpea and lentil, respectively. Chickpea and lentil also had a similar positive effect on the wheat yield in four-year rotations.

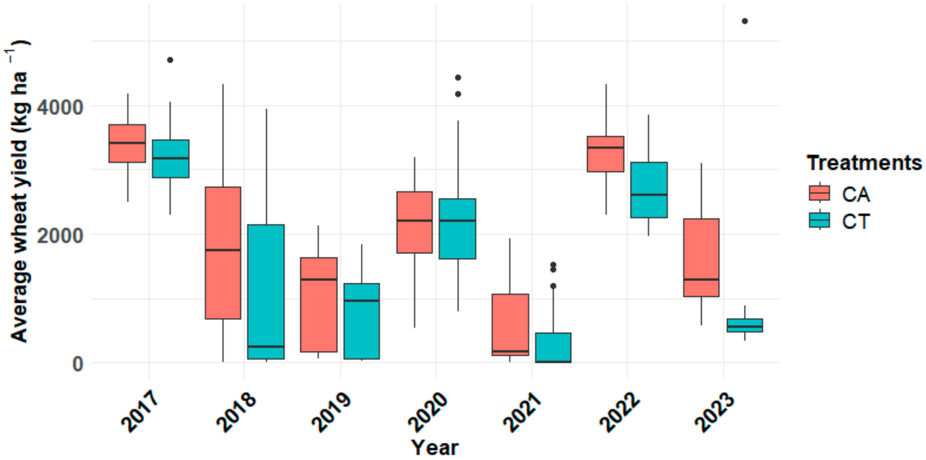

Figure 4. Distribution of annual wheat yields (kg ha^{-1}) under conventional tillage (CT) and conservation agriculture (CA), including both two- and four-year rotations, from 2015 to 2021. The boxplots show the median (horizontal line), interquartile range (box), and data range within 1.5 × IQR (whiskers). Dots represent outliers. The unusually low medians in 2018 and 2021 reflect extreme drought conditions during those years.

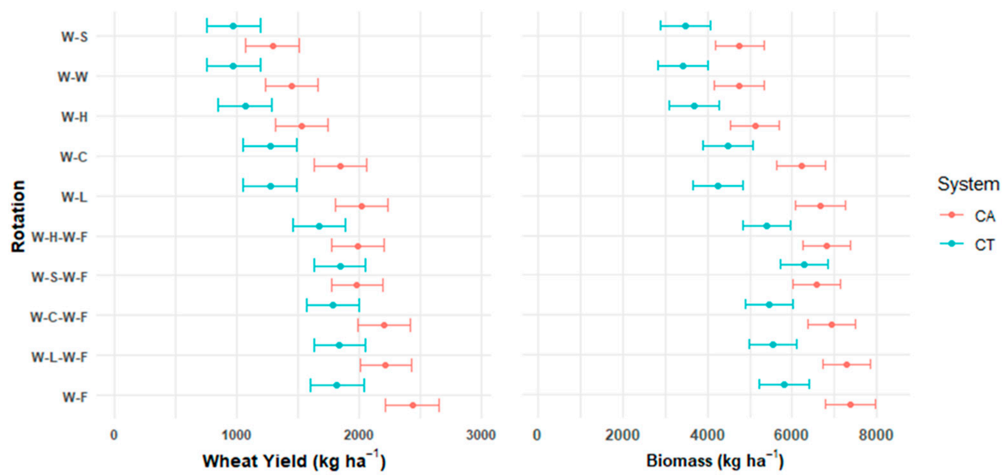

Figure 5. Estimated marginal means (EMMs) of seven-year average wheat yield and biomass under conventional tillage (CT) and conservation agriculture (CA), calculated from a linear mixed model. Error bars represent standard errors of the EMMs. Crop rotations include combinations of wheat (W), safflower (S), Hungarian vetch (H), chickpea (C), lentil (L) and fallow (F).

3.3. Economic Performance

All rotations were more profitable under CA than CT. The production costs for CA were 9 to 15.2% less than the costs in CT (Figure 6). This was mainly due to the tillage expenses, which involved around three or four operations. Within each rotation, tillage costs represented 15 to 28% of total costs. Safflower production cost was the lowest due to its low seed cost. Wheat–fallow and wheat–wheat rotations had the highest production costs due to extra need for fertilizers.

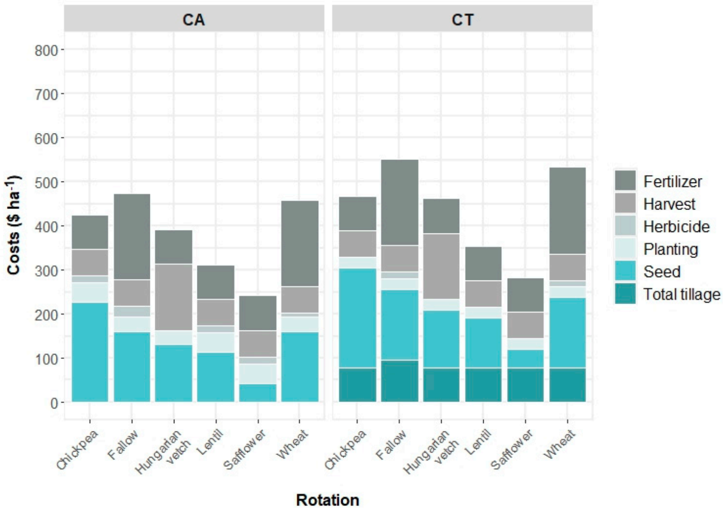

Figure 6. Production costs (USD ha^{-1}) for rotations under CA and CT.

While four-year rotations under both CA and CT generated positive gross margins for all rotations, under two-year rotations only chickpea and lentil rotations were consistently positive. The highest gross margins were obtained within rotations including chickpea and lentil under CA for both two- and four-year rotations (Figure 7). Wheat–chickpea and wheat–lentil rotations under CA generated on average around USD 1000 and USD 590 per hectare. Gross margins of two-year wheat–chickpea and wheat–lentil rotations under CA were about 100 and 217% more than those under CT, respectively. The wheat–fallow rotation under CT had a negative gross margin in some years, averaging USD −70 per hectare, while managed under CA it had a gross margin of USD 175 per hectare.

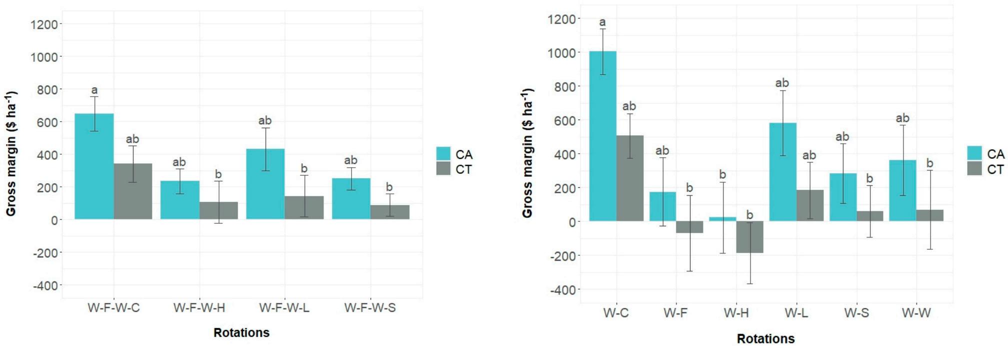

Figure 7. Average gross margin (USD ha^{-1}) of two- and four-year rotations. Bars labeled with different letters are significantly different (Tukey's HSD test, $p < 0.05$).

Similar trends were observed for four-year rotations, where wheat–fallow–wheat–chickpea and wheat–fallow–wheat–lentil rotations generated on average around USD 625 and USD 415 per hectare, respectively. These were more than 240 and 275% more than those under CT. Overall, two-year chickpea and lentil rotations were more profitable than the four-year rotations including chickpea and lentil only after four years.

4. Discussion

The results demonstrated a significant effect of the tillage system on the wheat yield and profitability. There are not many studies from drylands, particularly from the southern and eastern Mediterranean region, comparing CA with CT using pulses such as lentil and chickpea as rotational crops. Few previous short-term studies reported increased wheat yields under CA versus CT ranging from 12 to 62% [40–42]. Unlike the findings of the present study, where the wheat yield under CA was consistently greater than CT, these studies reported high variability within years in terms of CA performance. All cited low or variable rainfall as the main factor affecting wheat yield. One of the main differences between the present study and the past studies is that the present study was conducted in a region with cold and occasionally snowy winters. In such cold regions, snow cover is an important factor for soil water recharge [43]. Water in snow (during the cropping season) slowly seeps into the soil, hence retaining much more than rainfall, allowing crops to use almost all the precipitation that has fallen. The highest yields in 2017 and 2022 coincided with longest soil snow cover days of 72 and 59, respectively.

Another factor is that CA usually outperforms other tillage management methods during the driest years [44,45]. Our results also support the findings of Gristina et al. (2018) [46] where they discovered that CA performs better than CT under semi-arid climate conditions when the aridity index is lower than 0.52. The aridity index for the Konya region is less than 0.50 [47,48]. During the present study, precipitation was lower than long term averages and the reported precipitation of all the other comparable studies. This may have contributed to the fact that yields under CA were always better than CT in the current study.

The highest wheat yields were obtained in the traditional wheat–fallow system under CA most probably due to soil water storage during the fallow year [23]. Similar result was obtained in a long-term rotation in Syria, where wheat–fallow was the highest yielding rotation [33]. The wheat–fallow rotation was also the only two-year rotation that performed similar to the four-year rotations, clearly illustrating the advantage of the fallow system storing the previous year’s precipitation in soil. Depending on the cropping system, location and other factors, around 25% of the annual precipitation is stored in soil, but it could be as high as 40% under CA [49,50]. However, when considering annualized yields, the apparent advantage of fallow disappears because crop yields are halved in two-year rotations and reduced by a quarter in four-year rotations.

One surprising result was the poor performance of wheat after Hungarian vetch. Our results contrast with the previous research reporting increased wheat yields and precipitation use efficiency when forages are included in dryland wheat rotations [15,33,51]. In the present study, unlike other crops and residues that remain on the field until July or August, the soil was left bare and exposed during the summers until November after vetch harvest in June. Due to its high value as forage, all vetch residue was removed, leaving the soil bare—unable to capture and store precipitation or build soil organic matter and, consequently, good soil structure. Forage crops need to be properly managed to avoid wheat yield losses.

Wheat–lentil and, to a lesser extent, wheat–chickpea rotations consistently outperformed other rotations in terms of wheat yield and soil carbon content. Wheat–pulse rotations under CT practices has been shown to significantly enhance wheat yields and soil quality compared to fallow in semi-arid and Mediterranean regions [33], but there are only a few studies under CA. Yau et al. (2010) [52] reported no increase in wheat yield after chickpea in two years experiment in Lebanon. In a review of Moroccan CA experience, Mrabet [53], on the other hand, showed an increase in wheat yields after chickpea and a minor increase after lentil. A recent long-term study from Canadian prairies showed that the benefits of pulse crops increase with time and confirmed the benefit of pulses on wheat yields and soil carbon built up [44]. Our study confirmed the well-known benefits of wheat–pulse rotation [42,54] for the first time under CA in Türkiye, which is relevant and urgent information for the colder regions in West and Central Asia. The benefits of pulses were shown before in Türkiye but only under conventional tillage [55]. Similarly, the benefits of no-till were only shown for wheat–fallow or wheat–wheat rotations and only in terms of economic advantage [56]. Another striking finding of this study was the fact that under conventional systems, the only profitable two-year rotations were those including chickpea and lentil.

The difficulty with lentil harvest is an ongoing problem that discourages farmers from planting lentil in this region. Key agronomic difficulties include low pod clearance leading to harvest losses and uneven maturity causing shattering, as well as the plant's delicate structure making it prone to damage from mechanical handling [57]. Chickpea could be an alternative crop to lentil for farmers who are wishing to diversify their rotations. Similar to the findings of Christiansen et al. (2015) [33], wheat–chickpea rotation profitability was 45, 65 and 70% greater than lentil, wheat and safflower rotations under CA. Chickpea farm-gate prices are the main reason for this rotation's profitability. Despite this high profitability, many farmers do not cultivate chickpea under CA due to difficulty in weed management. Selective herbicides' high cost, as well as the need for a meticulous approach in timing and dosage, discourages many farmers from including this profitable crop in wheat-based CA rotations. One unexplored method is post-emergence in-row tillage weed control on no-till seeded chickpeas [58]. Such an approach would eliminate the need for rare and expensive herbicides and encourage farmers to include chickpeas in their rotations.

Another social factor is that many farmers reside in cities and rarely visit their fields, trying to minimize their labor. For such farmers, wheat–fallow rotation under CA may be attractive. Although not very efficient, a fallow phase may provide drought insurance for low but stable wheat yields. Considering our findings and the context (i.e., less than 300 mm precipitation), a farmer can spare 50% of the land to wheat, 25% to fallow and 25% to pulses or forage legumes to minimize labor, costs and risks. In such four-year rotations including chickpea and fallow, the gross margins were similar to two-year wheat–chickpea rotations (i.e., around USD 800 per hectare, per rotation cycle).

In regions receiving more than 300 mm of precipitation, fallow may not be needed. If wheat was not the focus strategic crop, safflower would have been an excellent replacement for drylands, but wheat consistently fails after safflower due to its residual allelopathic effect [59]. Safflower requires no or little input, eliminates weeds and is drought resistant.

5. Conclusions

Our study clearly illustrates the advantages of CA over CT in terms of production, soil quality and economic returns. Considering the clear advantages of CA over conventional tillage, there should be a concerted effort by government and NGOs to promote CA in Türkiye and areas with similar climates such as Central Asia. Erratic weather and stagnated global wheat yields are posing a serious risk to global food security. CA is one of the key tools to improve farming system resilience to climate change. Appropriate policy support, farmer incentives, advisory services, sustained (practical) research and knowledge transfer from research into practice can accelerate adoption [18,60]. Increasing soil literacy can increase the farmers' appreciation of soil and the application of conservation measures like suitable crop rotations.

Supplementary Materials: The supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land14071331/s1.

Author Contributions: Conceptualization, I.G., R.Z.A., F.P., F.Ö., Ş.A. and H.C.; writing—original draft, H.C. and M.S.; statistical design and analysis, T.H.K., A.R. and A.H.; writing—review and editing, all authors; funding acquisition, H.C., I.G. and F.Ö. All authors read and confirmed the final version of the manuscript.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: All Authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CA	Conservation agriculture
CT	Conventional tillage

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