

## Utilizing APSIM model for predicting wheat yield in no-tillage farming systems in Ninawa

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**Abstract.** This research explored how wheat responds agronomically when cultivated under no-tillage and multi-tillage farming scenarios, representing conservational and conventional systems, respectively. Using site-specific soil data, the Agricultural Production Systems sIMulator (APSIM) was calibrated to investigate the long-term (7 winter seasons) influence of tillage-induced soil health on crop yield, and some of the yield components. As a results, wheat yields and yield components were significantly ( $p$ -value < 0.05) higher under no-tillage conditions. In years with moderate rainfall ( $\approx$  230 to 400 mm in-season), the predicted values of grain yield and total biomass between no-tillage and multi-tillage systems showed superiority to no-tillage system. Despite the demonstrated superiority of the no-tillage system in providing the best values for the investigated indicators under dry conditions, the differences in grain yield and total biomass between the two farming systems decreased with increasing rainfall. The differences in simulated and observed data were 13% and 8% for grain yield and biomass, respectively, under no-tillage condition, and approximately 6% and 10% for grain yield and total biomass, respectively, under multi-tillage condition. APSIM simulated outcomes showed that increased productivity, and annual yield under no-tillage system, was able to increase total financial incomes of wheat by USD120–396 ha<sup>-1</sup> depending on in-season rainfall and the tillage system practiced. Therefore, no-tillage appears to offer a more sustainable and viable approach to boosting nutrition uptake and grain yield compared to the conventional technique in water-limited environments.

**Key words:** conservation agriculture, multi-tillage, conventional agriculture, wheat crop, yield components.

### INTRODUCTION

Modern agricultural systems face unprecedented challenges, including soil degradation, climate variability, and diminishing natural resources, which threaten global food security and ecological stability (Chamen et al., 2003; Botta et al., 2010;

Jørgensen, 2012). In response to these pressing issues, conservation agriculture has emerged as a transformative approach that redefines traditional farming paradigms (Zhu et al., 2025), which concentrate on minimal soil disturbance, permanent soil cover, and diversified crop rotations (Srean et al., 2025). Conservation agriculture seeks to harmonize agricultural productivity with environmental stewardship. Through prioritizing the preservation of soil structure and organic matter, this system enhances water infiltration, reduces erosion, and fosters microbial activity, thereby improving long-term soil health and resilience (AL-Wazzan & Muhammad, 2022; Zhang et al., 2025).

The adoption of conservation agriculture is increasingly recognized as a critical strategy for mitigating the adverse effects of climate change, particularly in regions vulnerable to droughts, extreme temperatures, and erratic rainfall patterns. Studies have demonstrated its capacity to sequester carbon, enhance biodiversity, and optimize water-use efficiency, offering a viable pathway to sustainable intensification. Furthermore, the integration of agroecological practices within conservation agriculture frameworks promotes synergies between crop and livestock systems, reducing reliance on synthetic inputs and lowering production costs for farmers (Hussein et al., 2021a, 2021b; Hassan et al., 2022).

Climate challenges are accelerating the use of predictive models in farm decision-making. These mechanistic tools simulate crop performance by explicitly representing causal processes (Challinor et al., 2009). The Agricultural Production Systems sIMulator (APSIM) is a key model for projecting yield responses to climate shifts and soil factors (Keating et al., 2003). Recognized globally for its sophistication, APSIM is capable of modelling complex agricultural systems through interconnected components covering plants, animals, soil, climate, and management (Akponikpè et al., 2010). As a leading dynamic simulator, APSIM is also capable of predicting water and nitrogen dynamics across different soil fertility scenarios. Over the years, this eco-physiological program has become well-established through comprehensive validation in diverse environments (Asseng et al., 2000; Chenu et al., 2011; Peake et al., 2011; Balwinder-Singh et al., 2011). APSIM stands out for its modular process-based approach, ability to simulate long-term soil-plant-management interactions, and integration with data-driven technologies. Compared to other tools (e.g., DSSAT or AquaCrop), this modelling software offers a unique combination of mechanistic depth, modular flexibility, and proven applicability to complex agricultural systems. Its ability to integrate multi-year climate data, precise soil-plant processes, and emerging technologies makes it especially valuable for studies aiming to optimize irrigation and enhance sustainability.

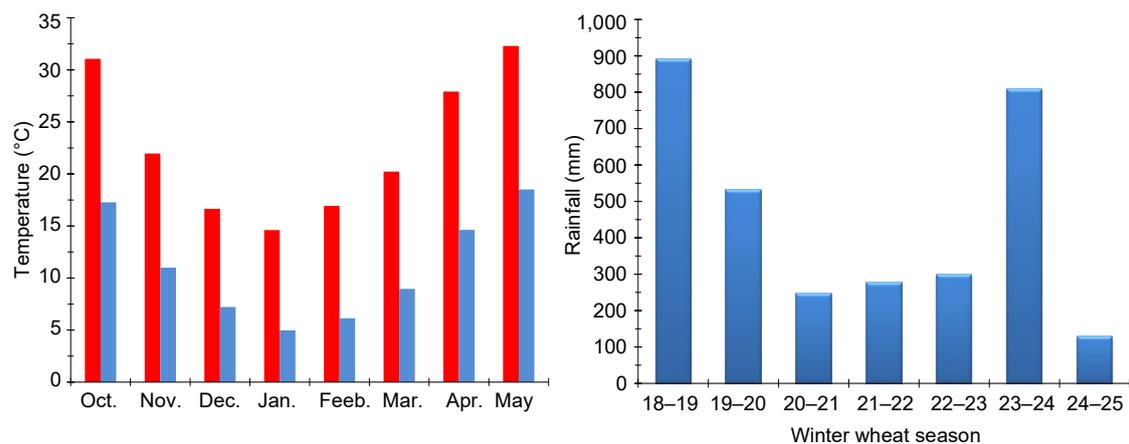
Improvements in soil structure under no-tillage systems also appear to improve plant uptake of water and nutrients. Despite its documented benefits, the widespread implementation of conservation agriculture in Iraq remains hindered by socio-economic, institutional, and knowledge-based barriers. Smallholder farmers, in particular, often face challenges related to access to appropriate technologies, financial resources, and extension services. This paper explores the multifaceted dimensions of conservation agriculture, examining its agronomic impacts on the performance of wheat crop under this particular farming system.

Despite APSIM's global validation (Carberry et al., 2013), its application to Iraqi agroecosystems, particularly contrasting conservational and conventional practices, represents a novel contribution. Therefore, the main objectives of this study were to (1) assess wheat yield response to soil preparations under different tillage conditions; (2) predict the Long-Term effects of soil health and weather changes on grain yield and biomass using APSIM to simulate 7 years crop productivity and hydrological outcomes, based on measured soil properties; (3) quantify the Long-Term economic returns based on the grain yields derived from APSIM model.

## MATERIALS AND METHODS

### Field experimental site

The field trial was conducted during the winter season of 2023–2024 at Tel kaif district, about 13 km Northeast of Mosul, within the Ninawa plains, Iraq (coordinates: 36°27'32.2", 43°9'22.5"). Overall, during the field experiment, temperatures remained close to historical norms, though springtime lows were slightly cooler (Fig. 1 left). Rainfall during the season (from the beginning of October to the end of April) was higher than the historical averages by recording more than 800 mm, which was similar to the growing seasons of 2018–2019 (890 mm) (Fig. 1 right).



**Figure 1.** Average monthly maximum and minimum temperatures (left) and total seasonal rainfall (October – May) during the modelled period (right), records for Mosul, Ninawa, Iraq (data sourced from Directorate of Agriculture).

The soil at the site is classified as a Black-Gray soil. It is moderately well-drained with minimal slope (< 0.5%). Particle size analysis revealed a high silt content ( $\approx 54\%$  in the top 200 mm), typical of soils used for cereal cropping in this region. The area had a history of at least three years of cereal production prior to the study.

### Field study

The trial was conducted on two adjacent farms representing the two farming system treatments (no-tillage and multi-tillage). The adjacent farms were chosen in order to eliminate the effects of environmental and soil differences on results. One of the farmers has been practicing conservation agriculture (no-tillage) since 2008, while the other

farmer still utilizes conventional tillage and seeding system (multi-tillage). During the experiment, primary tillage was done using a mouldboard plough, followed by seedbed preparation with two passes (one across the other) using a tine cultivator on the multi-tillage farm. This is the typical combination of tillage operations employed by farmers in Iraq. Wheat (*Triticum aestivum* L. variety: DİNÇ) was sown on 16 December 2023 at a target density of 300 plants m<sup>-2</sup> using a no-tillage planter with disc openers at 150 mm row spacing with both farming systems. The seeder slightly disturbed the soil to improve seed-to-soil contact without deep loosening. Crop establishment was uniform across all plots. One irrigation event ( $\approx$  25 mm) was applied after planting to ensure emergence. Two nitrogen sources were applied to the crop, namely, Urea (46% N) and Diammonium phosphate DAP (46% N). Each Fertiliser type was applied in two equal doses: first at the time of planting and then during stem elongation. Application rates were 100 kg ha<sup>-1</sup> for each fertilisation stage. The experimental plots consisted of stripes of 50 m wide and 100 m long. Three plots (replications) were randomly selected within 5 ha farmland of each of the two farming systems. During crop growth, plant height, spikes per m<sup>2</sup> and grains per spike were observed and recorded. Yield parameters evaluated in this study included crop biomass yield, grain yield and thousand grain weight (TGW).

### **Simulation Approach**

The Agricultural Production Systems sIMulator (APSIM), a process-based modelling platform (Holzworth et al., 2014), was employed to model dryland wheat production under contrasting soil management practices (conservational vs. conventional systems) over 7 years (2018–2025). Prior to this, the biomass and grain yield outputs of the model were validated against the field experimental results. Economic analysis of wheat production in the Ninawa Governorate based on the 7-year APSIM simulation result comparing the no-tillage and multi-tillage farming systems was also conducted. This included the total income per ha derived from the two farming systems and the difference between them for each simulated years, based on the 2024 Iraqi wheat market price of USD 600 ton<sup>-1</sup> (Ministry of Agriculture in Iraq, 2024).

Detailed model specifications, including module descriptions and codebase access, are available in the APSIM documentation repository (<https://www.apsim.info/>). A Black-Gray soil type was simulated, with climate inputs sourced from regional meteorological records. To assess soil compaction effects on crop development, the SoilWat module was selected to model soil-water dynamics, deviating from prior methodologies that utilized alternative modules (e.g., Huth et al., 2012; Antille et al., 2016).

Soil physical and hydraulic properties (Table 1) were measured during the one-year field experiment to calibrate and guide parameterisation and application of APSIM, and to model the long-term impacts of simulated soil conditions of no-tillage and multi-tillage farming systems on crop productivity and biomass. These properties were measured directly from soil samples taken from the study site. Specifically, undisturbed soil cores were collected from the top 300 mm layer at multiple locations within the experimental plots. Bulk density (BD) was determined using the core method. Saturation threshold (SAT) and upper drainage capacity (DUL, often equivalent to field capacity) were subsequently determined in the laboratory using the constant head method

(Klute, 1965). Saturated hydraulic conductivity (KSAT) values were restricted to the upper 150 mm for conventional system, while deeper profiles (300–600 mm) were extrapolated from historical datasets of analogous soils (Dalglish & Foale, 1998; Connolly et al., 2001). For conventional systems, pedotransfer functions based on particle-size distributions (Gee & Bauder, 1986) were applied to estimate lower moisture limits (LL) across all depths and DUL/SAT below 300 mm. Surface runoff coefficients were adjusted to 73 for multi-tillage (Kodur et al., 2017), with a 7-unit increment for multi-tillage scenarios (McCloskey et al., 2014), while evaporation parameters followed default APSOIL database configurations. The simulation was run to cover a continuous period of 7 years (2019–2025), enabling the prediction of multi-year future crop yield based on experimental measurements. The simulation was based on the Continued Wheat template of the APSIM software as this was the mostly closely aligned template to the environmental conditions of this study.

**Table 1.** Soil physical properties used in the APSIM simulations for conservation agricultural (no-tillage) and conventional farming (multi-tillage) conditions for a Black-Gray soil at Ninawa, Iraq

Depth (mm)	Bulk density (g cm <sup>-3</sup> )	Porosity (%)	Plant lower limit (m <sup>3</sup> m <sup>-3</sup> )	Drained upper limit (m <sup>3</sup> m <sup>-3</sup> )	Saturation (m <sup>3</sup> m <sup>-3</sup> )	K <sub>SAT</sub> (mm day <sup>-1</sup> )
Multiple-Tillage						
0–100	1.14	0.57	0.22	0.30	0.54	950
100–150	1.16	0.56	0.25	0.30	0.53	501
150–200	1.19	0.55	0.23	0.35	0.47	104
200–300	1.21	0.54	0.23	0.34	0.43	51
300–400	1.23	0.54	0.24	0.35	0.42	52
No-tillage						
0–100	1.36	0.49	0.21	0.25	0.47	52
100–150	1.24	0.53	0.24	0.27	0.48	26
150–200	1.33	0.50	0.23	0.36	0.43	20
200–300	1.29	0.51	0.24	0.34	0.40	21
300–400	1.26	0.52	0.25	0.35	0.40	25

Wheat (*Triticum aestivum* L.) was modelled annually with sowing triggered by cumulative rainfall thresholds ( $\geq 20$  mm within 5 days) between mid-November and mid-December. If the rainfall threshold was unmet, forced planting occurred by the end of December. Seeding density (300 plants m<sup>-2</sup>) and nitrogen application (200 kg ha<sup>-1</sup> urea and DAP) aligned with regional practices (Zadoks et al., 1974). Initial soil moisture (95% of maximum capacity) was equilibrated via a 7-year pre-simulation data.

Model outputs were calibrated against empirical yield data, with simulated yield disparities (13% between no - and multi-tillage) closely mirroring field observations (12%). Seasonal water-use efficiency, calculated as grain yield per unit seasonal rainfall (Hochman et al., 2009), served as a key performance metric.

### Statistical analysis

Statistical Package for the Social Sciences (SPSS-version 23) software was used to analyse the data derived from the field study (Swan & Sandilands, 1995). Means of yield and yield components were compared for significant differences using independent samples *t-test* at 5% level of probability. Linear regression analyses were applied to examine the relationships between grain yield and rainfall during the simulated seasons.

## RESULTS AND DISCUSSIONS

### Field Results

The results derived from the field investigation, presented in Table 2, indicate that measured yield components were significantly influenced by the tillage-farming system ( $P < 0.05$ ). Significantly higher grain yield ( $3,900 \text{ kg ha}^{-1}$ ), total dry biomass ( $10,433 \text{ kg ha}^{-1}$ ), plant height (105.5 cm) and TGW (29.5 g) were obtained where no-tillage technique was used, compared to the conventional tillage system ( $3,600 \text{ kg ha}^{-1}$ ,  $8,916 \text{ kg ha}^{-1}$ , 83.3 cm and 24.43 g for grain yield, biomass, plant height and TGW, respectively). No significant differences were observed in the other parameters (spikes per  $\text{m}^2$  and number of grains per spike).

**Table 2.** Measured yield components as affected by tillage-farming systems ( $n = 3$ )

Farming system	Biomass ( $\text{kg ha}^{-1}$ )	Spikes per $\text{m}^2$	Plant height (cm)	Grains per spike	TGW (g)	Yield ( $\text{kg ha}^{-1}$ )
Multi-tillage	8,916 b	395.67 b	83.30 b	31.12 b	24.43 b	3,600 b
No-tillage	10,433 a	399.50 b	105.50 a	32.50 b	29.50 a	3,900 a

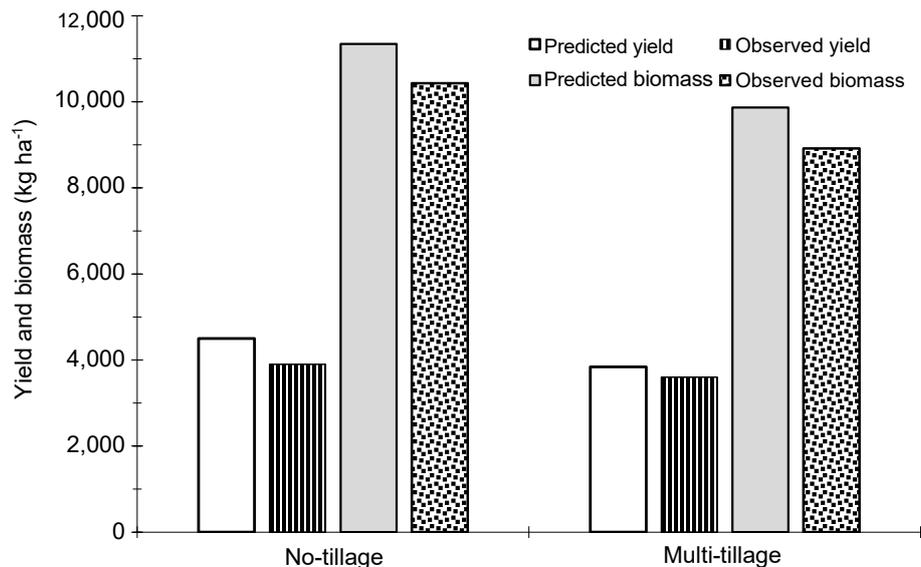
This finding suggests that the excessive use of tillage operations has negative effects across all agricultural domains, particularly impacting environmental sustainability and the economic viability of the agricultural sector. Farmers in Ninawa Governorate invest substantial funds in performing multi-tillage passes prior to planting. This practice, based on traditional farmer knowledge, aims to loosen and invert the soil to increase aeration as a result of increased porosity as evidence in Table 1. However, it overlooks the significant water wastage, as the large pores created between soil particles allow rainwater to percolate rapidly beyond the root zone, from which the crop derives little benefit (Alrijabo, 2014). These outcomes were also confirmed by Ghosh et al. (2015) who investigated the agronomic and economic benefits of adopting conservation farming technique.

### Validation of APSIM Results

Fig. 2 displays the differences between observed and predicted grain yields and total biomass for wheat during the growing season of 2023–2024 under both investigated farming systems. These results confirmed that field-model discrepancies remained within the acceptable ranges, showing approximately 13% and 8% differences for yield and biomass, respectively, under no-tillage farming system, versus 6% and 10% under conventional system.

This alignment demonstrates that rainfall patterns and tillage systems influence wheat productivity not only in empirical studies but also under simulated conditions

when environmental parameters are replicated. These predicted outcomes were within the range reported by previous studies (e.g., Radford et al., 2007), and other projects that compared the effects of compacted and non-compacted soils on simulated crop yield and yield components (e.g., Galambošová et al., 2017; Shaheb et al., 2018). The outcomes also confirm that the impacts of compaction due to no-tillage farming system on crop performance depends on the seasonal rainfall, minimum and maximum temperatures (McKyes et al., 1979). Such validation significantly supports pre-planting decision-making by farmers, particularly regarding farming system selection.

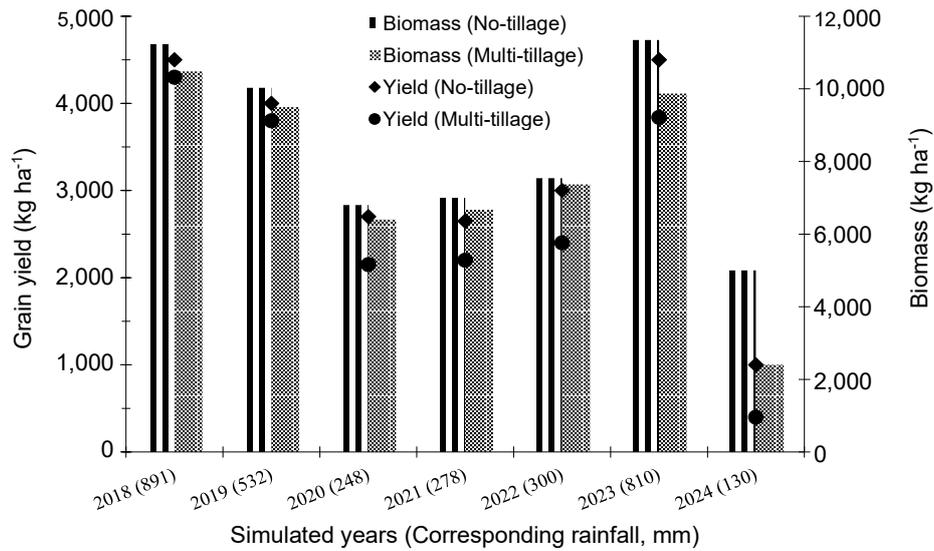


**Figure 2.** Differences between observed and predicted grain yields and biomass obtained from the field and APSIM model, respectively, during the 2023–2024 season.

### Long-Term Predicted Results

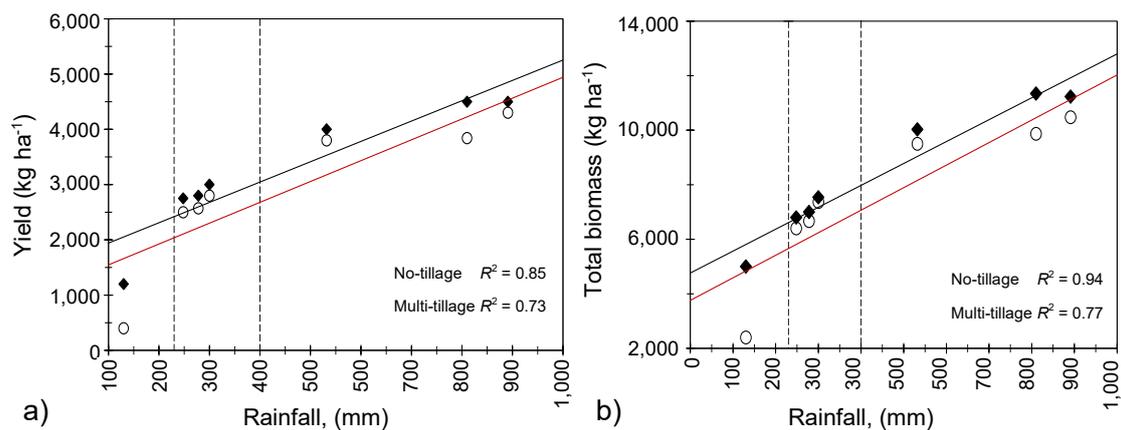
Fig. 3 shows the fluctuation in predicted wheat production (grain yield and total biomass) from 2018 to 2024 relative to seasonal rainfall. Peak values for grain yield and total dry weight were recorded during the rainy seasons of 2018–2019 and the 2023–2024 winter season. In contrast, the 2024–2025 season recorded the lowest predicted wheat production in the past seven years, with yields falling below 1,000 kg ha<sup>-1</sup> under conventional tillage systems and approximately 1,300 kg ha<sup>-1</sup> under no-tillage systems.

Simulated outcomes indicate that agricultural management systems exert sustained influence on crop productivity and biomass accumulation across diverse climatic scenarios, aligning with single-season trial observations. Repeated tillage operations demonstrate particularly adverse impacts on yield parameters and vegetative growth during suboptimal precipitation periods. In arid and semi-arid dryland ecosystems, pre-sowing soil moisture reserves fundamentally govern production viability. Consequently, modelled variations in this critical (water) resource dictate phenological outcomes and inform strategic sowing decisions (Zeng et al., 2021; Yu et al., 2024).



**Figure 3.** Grain yield and total biomass derived from the two farming systems and their relations with total seasonal rainfall during the simulated period (2018–2024).

Predicted yields and biomass under rainfall variability for no-tillage and multi-tillage conditions are shown in (Fig. 4, a and b), respectively. Conventional farming system represented by multi-tillage reduced grain yield and biomass, by 65% and 48%, respectively, when the rainfall condition fell below average (< 30<sup>th</sup> percentile = 230 mm). These differences between the two farming systems decreased within the average seasonal rainfall (2,700, 2,780 and 3,000 kg ha<sup>-1</sup> yield under conservational tillage farming system versus 2,500, 2,570 and 2,800 kg ha<sup>-1</sup> yield under the conventional farming system). The biomass response followed the same trend, with both farming systems. The differences between the two farming systems decreased in the years that received above average rainfall compared to the dry seasons which reflects similar behavior of crop response during the field studies.



**Figure 4.** Simulated long-term (2018–2025) wheat (a) Grain yield and (b) Total biomass within a wheat-fallow cropping system on Iraqi Black-Gray soil, comparing no-tillage and multi-tillage farming systems as a function of rainfall. The dashed vertical lines indicate the 30<sup>th</sup> (left) and 70<sup>th</sup> (right) rainfall percentiles.

### Economic analysis

Table 3 shows the economic analysis results of the two tillage-farming systems derived from APSIM-modelled grain yield during the 7-year simulated period. These outcomes focus exclusively on yield differentials and their resulting financial implications between the no-tillage and multi-tillage farming systems. Although, the operational costs disparities were not accounted, based on several studies (e.g., Loss et al., 2014; Loss et al., 2015; Luhaib et al., 2017; Hasan et al., 2022) conservational farming system have demonstrated superiority in reducing variable costs (e.g., fuel and lubrication, labor, and maintenance) by about USD 100 ha<sup>-1</sup> compared with conventional farming system.

Following the yield results presented in Fig. 2, the no-tillage system resulted in higher total income in all simulated seasons compared to the multi-tillage system (Table 3), based on Iraq's wheat grain price of USD 600 ton<sup>-1</sup> (Ministry of Agriculture in Iraq, 2024). The differences in income ranged from USD 120 in the 2018 season to USD 396 ha<sup>-1</sup> in the 2023 season, proving the higher profitability of no-tillage farming, especially in seasons with above average rainfall and when cost of production would be factored in.

**Table 3.** Financial returns from the two tillage systems based on 7-year APSIM outcomes

Season	Rainfall	Total income (USD ha <sup>-1</sup> )		
		No-tillage	Multi-tillage	Differences
2018	891	2,700	2,580	120
2019	532	2,400	2,280	120
2020	248	1,620	1,290	330
2021	278	1,589	1,320	269
2022	300	1800	1,440	360
2023	810	2,700	2,304	396
2024	130	600	240	360

## CONCLUSIONS

Enhanced wheat grain yield and total biomass in no-tillage farming system were mainly explained by avoidance of multi-tillage and minimized soil disruption in both short and long-term investigations. This was confirmed by differences in all agronomic indicators of crop performance in field experiment findings (number of spikes, plant height, number of grains per spike and thousand grain weight) observed in the two farming systems. Conservation agriculture appears to be a more effective practice to help increase input-use-efficiency (while reducing total farm operations), which in this study resulted in improved economic returns of USD 120 to 396 ha<sup>-1</sup>. In the long-term modelling investigation, the predicted outcomes revealed that the impact of the implemented farming system on grain yield and biomass is dependent on in-season rainfall with better results in years with rainfall above average and vice versa. Long-term simulations suggested that productivity of wheat in the arid and semi-arid conditions could be improved if the crop was managed under no-tillage system, depending on rainfall.

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