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Simulating the effect of tillage practices on the yield production of wheat and barley under dryland condition

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Abstract. In arid and semiarid regions, soil tillage practices have major effects on soil water dynamics. In this study, we compared the effects of Zero Tillage (ZT) and Conventional Tillage (CT) on the grain yield of rainfed barley and wheat at three locations i.e. Barrani, El-Neguilla and Matrouh in the north western coast of Egypt. We also tested the performance of the DSSAT (Decision Support System for Agrotechnology Transfer). In the first season of 2017/2018, only barley plants in Barrani location were able to grow and produce yield due to insufficient rain. Results showed that ZT produced significantly higher grain yield (almost 200%) for barley as compared to the CT treatment. In the second season of 2018/2019, conventional tillage produced higher yields as compared to the zero tillage treatment over the three studied locations and for the two crops. The DSSAT model successfully simulated the grain yield, total biomass and harvest index with an excellent agreement between simulated and observed data with NSE values of 0.868 and 0.800 for grain yield and total biomass respectively and a satisfactory agreement with NSE of 0.431 in case of harvest index. Tillage had a noticeable impact on grain yield of barley and wheat and the DSSAT successfully simulated the effects of the tillage treatments.

Key words: wheat, barley, DSSAT, drylands, tillage, precipitation use efficiency.

INTRODUCTION

Tillage is defined as the soil disturbance process that provides an adequate physical condition for the plant growth (Ucgul et al., 2014; Busari et al., 2015), meanwhile it is an important crop production factor with a yield contribution of 20% (Khurshid et al., 2006). Conventional tillage is usually used to reduce the population of weed, diseases, insects and other pests, also to conserve the soil moisture during the fallow period. However, these aims may not be achieved efficiently and causes a significant damage in the soil structure resulting in compacting the soil and increasing the risk of soil erosion (Novak et al., 2019; Jordan et al., 2000). As a result, the strategy of zero tillage which ensures both minimal soil disturbance and moisture loss has been adopted worldwide (Saturnino & Landers 2002; Kassam et al., 2015). Under short term condition zero tillage treatment could improve the crop yield (Hemmat & Eskandari, 2004; Hemmat & Eskandari,2006; Mrabet, 2008; Mokrikov et al., 2019) and improve the physical

(Anikwe & Ubochi, 2007), chemical (Rahman et al., 2008) and biological (Cookson et al., 2008) properties of the soil. However, some studies have reported that no tillage didn't increase the crop yield (Monneveux et al., 2006; Masek & Novak, 2018). Furthermore it could cause soil compaction, reduce infiltration (Schwartz et al., 2010; Ferreras et al., 2000), therefore the impact of conservational agriculture usually depends on some environmental and ecological factors (Yang et al., 2018), also soil characteristics such as soil texture, slope and mulching might affect the impact of tillage operations (Mhazo et al., 2016).

Crop production in the North Western Coast of Egypt is characterized by a continuous cultivation of barley and small areas of wheat. The traditional tillage practices include one or two tillage operations before sowing and one operation after sowing, for seed coverage, following the first effective rain. The grain yield of wheat and barley is highly variable in this area based on the amount of annual rain which falls between October and March and peaks in December and January with an average of 140 mm. Precipitation in the region have changed dramatically in the past decades in terms of amount and distribution, in particular a decrease in annual precipitation and an increased incidence of prolonged dry spells have been observed most often in the last few years (El-Sadek & Salem, 2016) making the successful crop production challenging and highly variable. Barley yield usually ranges from 200 to 1,400 kg ha^{-1}, while for wheat it ranges from 150 to 900 kg ha^{-1}. Many studies in the region have reported an increase in barley yield (Gomaa et al., 2013; Sayed et al., 2017) and wheat yield (Salem et al., 2003, El-Sadek & Salem, 2016; Ali & El-Sadek, 2016) using different varieties and crop management practices under rainfed conditions.

Crop growth models are used to simulate crop growth and yield as a response of different weather conditions, soil characteristics and crop management. The Decision Support System for Agrotechnology Transfer (DSSAT; Jones at al., 2003) is a widely used model to simulate different crops growth and yield under a broad range of conditions and crop management scenarios e.g. nitrogen fertilization (Banger et al., 2018; Prasad & Mailapalli, 2018; Tovihoudji et al., 2019), irrigation management (Jiang et al., 2016; Babel et al., 2019; Malik & Dechmi, 2019), climate change (Ngwira et al., 2014; Tyagi et al., 2019), yield forecasting and soil management and crop rotation (Soler et al., 2011; Li et al., 2015; Puntel et al., 2016; Araya et al., 2017). In Egypt, the model was applied with sufficient reliability to simulate the growth and yield of different Egyptian wheat varieties under varied sowing dates (Fayed et al., 2015), maize and broad bean (Harb et al., 2016) and climate change impact on wheat production (Kheir et al., 2019).

The main aim of this study was to evaluate the ability of the two models CERES-barley and CERES wheat (Crop-Environment Resource Synthesis) through DSSAT to estimate the grain yield of rainfed barley and wheat under different tillage practices (conventional tillage versus zero tillage) at different locations in the North Western Coast of Egypt.

MATERILAS AND METHODS

Experimental site

The experiment was conducted at three locations i.e. Barrani, El-Neguilla and Matrouh along the North Western Coast of Egypt. Data in Table 1 shows the

Coordinates and sowing and harvesting dates for each location. The agriculture in this region is mainly rainfed and the region is characterized by a Mediterranean type of climate with cold wet winter and hot dry summer. The average annual precipitation is 140 mm, however it is increasing towards the west to be 180 mm in Barrani. The mean annual maximum and minimum temperatures are 22.54 and 19.23 °C.

Table 1. Location of the experimental sites, total rainfall, date of sowing and harvesting date in the two growing seasons

Location	Coordinates		Total rainfall	Sowing	Harvesting
	N	E	(mm)	dates	dates
Barrani (2017/2018)	31° 36' 0"	25° 52' 48"	79.00	28/11/2017	17/4/2018
Matrouh (2018/2019)	31° 22' 27.88"	27° 03'19.6	159.25	28/11/2018	28/3/2019
El-Neguilla (2018/2019)	31° 24' 33.6"	26° 40' 32.3"	162.14	10/12/2018	16/5/2019
Barrani (2018/2019)	31° 36' 0"	25° 52' 48"	115.96	22/11/2018	2/5/2019

Precipitation data for the two seasons of 2017/2018 and 2018/2019 were downloaded from The Tropical Rainfall Measurement Mission (TRMM) data 3B43 Version 07 daily Rainfall product (Table 1 and Fig. 1), which is a collection of rainfall data accumulated in millimeters per day with a spatial resolution of 0.25°. The daily weather data required for the model simulation including minimum and maximum temperature, solar radiation, wind speed and relative humidity were obtained from the National Center for Environmental Prediction; Climate Forecast System Reanalysis NCEP/CFSR. The data set is available for direct download free of charge from this website: http://rda.ucar.edu/pub/cfsr.html. Fig. 2 shows the average maximum and minimum temperature at Matrouh station.

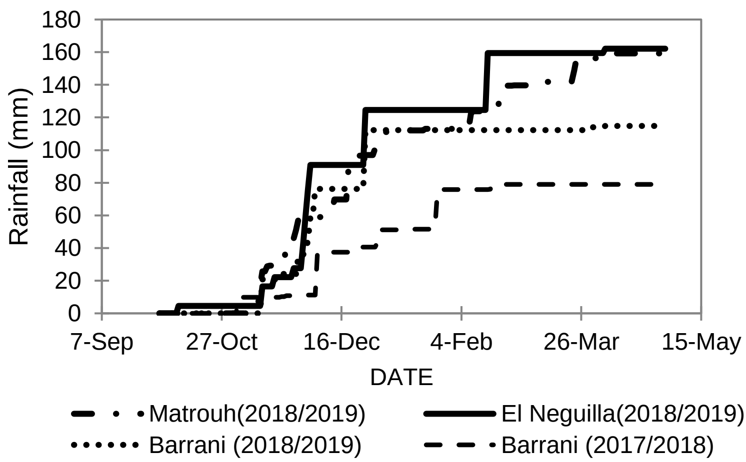

Figure 1. Cumulative rainfall for the study sites in the two growing seasons.

Total precipitation during the growing seasons (from October through April of the following year) was 79 mm in Barrani, 48.63 mm in El-Neguilla and 38 mm in Matrouh in the first season of 2017/2018, and was 115.96 mm in Barrani, 162.14 mm in El-Neguilla and 159.25 in Matrouh in the second season 2018/2019. The highest percentage of precipitation usually occurs in December and January. Cumulative precipitation for the study locations is presented in Fig. (1). The rainy season started very late in 2017 beginning in late November, and it was represented mostly by two excessive events; the first event of 25.75 mm in December, 6th and the second event was in 25/1/2018 with a 23.5 mm of rain.

The main soils of the region have been classified as Aridisols and Entisols, and are generally low in soil organic matter (SOM), nitrogen (N) and plant-available phosphorus (P). soils in the studied locations mostly have a coarse and moderately coarse soil texture. Soils are highly calcareous (~20% $CaCO_3$) with a pH ranges from 7.5–8 and EC around 0.7 ds m^{-1} (fresh soil). The soil is classified as Typic Torriorthents.

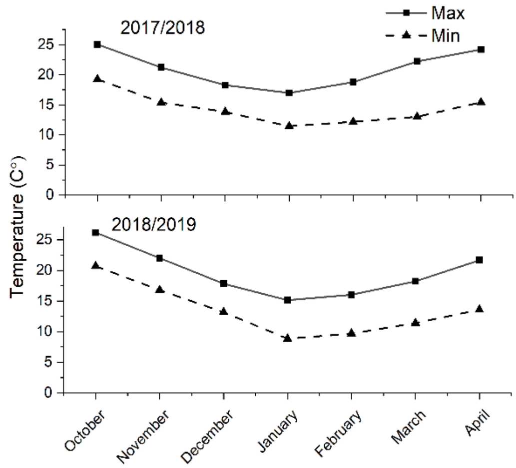

Figure 2. Average maximum and minimum monthly temperatures at Matrouh station.

Experimental design and treatments

In the first season of 2017/2018, only Barrani's barley was able to grow and produce yield due to insufficient rain in this season. The effects of two tillage treatments on barley's yield were investigated, including conventional tillage (CT) and Zero tillage (ZT). Each treatment was replicated four times in a randomized complete block design with a total of 8 plots. While in the second season of 2018/2019, for each crop the three locations of Matrouh, El-Neguilla and Barrani and the tillage treatments (CT and ZT) were arranged in a split plot design, where locations were allocated in the main plots, while the sub plots were assigned for the tillage treatments. In both seasons, each plot was 24 m^2 (4 m × 6 m) in area. There were 2-m spaces between adjacent blocks and 1-m spaces between adjacent plots.

Soil was plowed twice at a depth of 20 cm before and after sowing (CT) as a traditional practice performed by the local farmers. whereas no tillage was used for the ZT treatment, however the plots with the zero tillage had been tilled the previous years. The cultivars used in this study were Giza 171 for wheat and Giza 126 (six-rowed) for barley at a rate of 75 kg ha^{-1} for the two crops. In the CT treatment, seeds were broadcasted by hand, while for the ZT treatment, both crops were sown using a small no till seeder at 20 cm width. Neither chemical fertilizers nor pesticides were applied throughout the two growing seasons.

Grain yield, straw yield and biological yield (total dry biomass) were measured from hand- harvested plants from a 1 square meter quadrate. Plant height at maturity (harvest) was measured as the height from the soil surface to the tip of the head of the plant. To measure yield components, sub-samples of plants for wheat and barley were randomly selected and threshed and separated to calculate no of grains/spike from each single ear and 1,000-grain weight from a sub-sample of ears of each quadrate. Harvest index was calculated by dividing the grain yield by the biological yield. Precipitation

Using Efficiency (PUE) was calculated by dividing crop grain yield (kg ha^{-1}) by growing season precipitation.

All data were analyzed using analysis of variance (ANOVA) with a significance level of 5% to determine the significance of the main effects and their interaction. Least significant difference (LSD) test was performed to determine the significant differences between individual means. All statistical analyses were performed using the SAS statistical software (SAS institute 2007).

The DSSAT model

The two models CERES-barley (Otter-Nacke et al., 1991) and CERES wheat Godwin et al., 1989 were examined in this study within the framework of DSSAT 4.7 (Decision Support System for Agrotechnology Transfer). Model inputs include information about the conducted experiment (site soil profile and soil surface data , crop management data, preceding crop, residues,….etc), daily data for the climate parameters (precipitation, minimum and maximum temperature, solar radiation), soil physical and chemical parameters, and the cultivar specifications. The model simulates the phonological development and yield components of many crops, more information about the model can be found in Hoogenboom et al., 2012. Simulated model outputs can be calibrated against the real data by adjusting the cultivar genetic coefficients.

Model evaluation

To evaluate the model performance and to compare the simulated grain yield, biomass and harvest index versus the observed data, three statistical measurements were used: the coefficient of determination (R^2), Nash- Sutcliff efficiency (NSE) (Nash & Sutcliffe, 1970), and the root mean square error (RMSE)-observation's standard deviation ratio (SR) collectively called RSR (Eq. 1,2 and 3).

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})]^2}{[\sum_{i=1}^{n}(O_i - \bar{O})^2][\sum_{i=1}^{n}(P_i - \bar{P})^2]} \quad (1)$$

Where, Pi are the predicted values, Oi are the observed values, n is the total number of observations, is the mean of the observed data and is the mean of the predicted data. R^2 ranges from 0 to 1, with higher values indicating less error variance

$$NSE = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (2)$$

NSE, ranges between –∞ and 1, The value of NSE = 1 corresponds to a perfect match between predicted and observed data

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right]} \quad (3)$$

where, STDEV obs is the standard deviation of observed values, The RSR value varies from the optimal value of 0, which indicates 0 RMSE or residual variation and a perfect model simulation, to a large positive value.

Economic parameters

Production costs were calculated for each of the two tillage systems. Inputs such as seeds were purchased from the Central Administration for Seeds, Ministry of Agriculture and Land Reclamation, and the exact price was recorded. For labour and tillage operation costs, we used data from the local farmers. Gross margin ($ ha^{-1}) was calculated from net income for crop after deducting all variable costs.

RESULTS AND DISCUSSION

Precipitation

In the first season, the two early high events resulted in a poor grain yield for barley due to inappropriate timing of rain that missed the two critical growth stages of anthesis and grain filling. While, In the second growing season, the rainfall started as early as November, 13th. The rainfall was well distributed along the growing season having a significant event every month from November to March. Rainfall variation in quantity and time had a significant impact on plant growth and yield. In this season the high amount of rainfall and its proper distribution produced a higher yield. The proper delivery of plant water requirement, soil and crop management practices plays a critical role in the produced yield (Silungwe et al., 2019).

Tillage effects on grain yield

In the first season, there was a significant difference between the two tillage systems i.e., zero tillage and conventional tillage for spike length, number of grains/ spike, grain yield, straw yield, total dry biomass, harvest index and precipitation use efficiency (Table 2). Average grain yield for barley under zero tillage condition was more than double of that under conventional tillage. The superior average grain yield of no till as compared to other systems was also recorded by Hemmat & Eskandari (2006). The higher yield from zero tillage treatment may be due to the fact that zero tillage improved the soil water content which resulted in a better crop growth and yield (Morell et al., 2011). This positive impact of zero tillage was higher in dry years as compared to wet years. Same conclusion also was drawn by Bescansa et al. (2006) who reported that zero tillage positively increased the soil water storage. Also, the number of plants in the unit area was higher in zero-tillage treatment as compared to the conventional tillage. Farmers in the North Western Coast (NWC) of Egypt used to plow the soil before and after sowing, this usually increased the chance of the soil to be drier driven by moisture loss unless rain falls directly after sowing. This explains the good establishment of seedlings in case of ZT treatment.

In the second season of 2018/2019, conventional tillage produced a higher yield as compared to the zero tillage treatment over the studied locations (Table 2). Decreasing the grain yield in the second season for the zero tillage treatment, as compared to the conventional tillage, maybe due to the fact that conservation tillage (zero tillage in our case) usually reduces the leaching loss of calcium carbonate (which is very high in our study sites) as compared to the conventional tillage in rainfed areas (Murillo et al., 2004 and 2006). Tillage also improves the soil physical characteristics reducing the soil penetration resistance in the first 0–10 cm depth as a result of loosening the soil and macrospores formation (Jabro et al., 2009).

Table 2. Mean values of plant height, spike length, no. of plants/m^2, no. grains/spike, 1,000-grain weight, grain yield, straw yield, biological yield, harvest index and precipitation use efficiency in 2017/2018 and 2018/2019 seasons

Treatments	PH, cm	SL, cm	NP/ m^2	NGS	TGW, g	GY, kg ha^{-1}	SY, kg ha^{-1}	BY, kg ha^{-1}	HI, %	PUE, kg ha^{-1} /mm
	2017/2018 Season (barley only)									
ZT	42.38	5.67	67.00	40.00	24.88	571.20	1,220.2	1,849.4	30.88	13.09
CT	44.72	4.33	42.00	34.67	20.19	257.30	974.4	1,231.7	20.55	5.667
LSD 0.05	**NS**	**NS**	**1.29**	**NS**	**NS**	**26.67**	**126.40**	**114.66**	**6.24**	**1.39**
	2018/2019 season (barley)									
Locations										
Barani	25.50	3.50	163.17	27.00	30.71	716.46	1,059.6	1,776.0	40.42	6.13
Matrouh	25.000	3.17	116.33	14.83	29.65	243.07	886.43	1,129.5	21.44	1.53
El-Neguilla	39.333	5.67	116.67	38.17	43.63	1165.67	2,016.9	3,182.5	36.58	7.19
LSD 0.05	**2.37**	**0.66**	**22.94**	**1.42**	**1.38**	**67.40**	**116.13**	**132.08**	**3.14**	**0.54**
Tillage										
ZT	28.56	3.67	131.44	23.00	33.28	649.47	1,184.36	1,833.82	32.42	4.62
CT	31.33	4.56	132.67	30.33	36.06	767.33	1,457.56	2,224.89	33.75	5.28
LSD 0.05	**1.94**	**0.54**	**NS**	**1.16**	**1.13**	**55.03**	**94.82**	**107.84**	**NS**	**0.44**
	2018/2019 season (wheat)									
Locations										
Barani	48.33	6.00	154.67	25.67	31.77	537.73	1,501.3	2,039.0	26.41	4.60
Matrouh	47.33	7.00	136.67	28.00	29.43	471.77	1,454.6	1,926.3	24.43	2.96
El-Neguilla	60.33	6.83	163.33	28.50	45.12	1,315.17	1,552.6	2,867.8	45.25	8.11
LSD 0.05	**4.30**	**0.89**	**19.03**	**NS**	**1.94**	**70.55**	**NS**	**167.7**	**2.94**	**0.46**
Tillage										
ZT	49.11	5.11	147.78	19.44	33.88	593.89	1,236.73	1,830.6	31.13	4.11
CT	54.89	8.11	155.33	35.33	37.00	955.89	1,768.91	2,724.8	32.93	6.34
LSD 0.05	**3.51**	**0.73**	**NS**	**2.57**	**1.59**	**57.61**	**120.3**	**136.9**	**NS**	**0.38**

ZT: Zero Tillage; CT: Conventional Tillage; PH: plant height at harvest; SL: spike length, NP/m$^{2:}$ no. of plants/ m^2; NGS: number of grains per spike; TGW: thousand grain weight; GY: grain yield; SY: straw yield; BY: biological yield; HI: harvest index and PUE: precipitation use efficiency.

Tillage effects on yield components

The main components of grain yield for cereals are number of ears per square meter, number of kernels per ear and the kernel weight. Table (2) shows the response of various yield components to tillage systems for barley in the first season and for barley and wheat in the second season. Results show that, there was a significant effect of the tillage systems on the number of plants/m^2 in the first season. Zero tillage treatment produced more plants/m^2 as compared to the conventional tillage, these results are in agreement with those obtained by Moret et al., (2007) who concluded that no tillage practice increased the percentage of crop emergence for barley plants with no significant difference as compared to the other tillage systems. No significant effect was recorded for 1,000-grain weight as a result of the tillage treatments, Similar results were recorded on wheat by Hemmat & Eskandari (2006).

In the second season plant height, spike length, number of grains/spike and 1,000-grain (kernel) weight were significantly affected by the tillage systems, and were higher for the conventional tillage treatment in both crops. Plants were taller by 2.77 and 5.78 cm under conventional tillage as compared to zero tillage in barley and wheat, respectively (Table 2). Spike length was significantly affected by the tillage systems and recorded its highest values of 4.56 cm for barley and 8.11 cm for wheat under conventional tillage treatment. Highest values of number of grains/spike (30.33 and 35.33) and 1,000-grain weight (36.06 and 37.00 g) were observed under conventional tillage for barley and wheat, respectively (Table 2). Lower values of yield components under zero tillage treatment were probably due to the water deficit in the root zone resulted from low infiltration rate and high soil bulk density (Busari & Salako, 2012).

Tillage effects on total dry biomass and harvest index

In the dry season (2017/2018), zero tillage treatment produced a higher above ground biomass (biological yield; kg ha^{-1}) as compared to the conventional tillage. However, in the wetter season i.e., 2018/2019, biomass accumulation was greater in conventional tillage for both crops and over all the studied locations. A higher total biomass produced in the dry year is mainly due to the higher availability of soil moisture. HI was higher (30.88%) with the zero tillage as compared to the conventional tillage in the first season. However, the two treatments had a similar impact on harvest index in the second season for both wheat and barley overall the studied locations.

Tillage effects on precipitation use efficiency

The precipitation use efficiency was significantly influenced by the tillage systems in the two growing seasons. In the first season, zero tillage treatment recorded a higher PUE as compared to the conventional treatment. Similar results were obtained by Hemmat & Eskandari (2006) when the PUE was averaged across the growing seasons. However, in the second season, the conventional tillage treatment produced a slightly higher PUE as compared to the zero tillage for both crops (Table 2). There was also a significant effect of locations on PUE when averaged across the tillage systems and for the two studied crops. PUE depends mainly on the amount of precipitation (Fensholt & Rasmussen, 2011) and the crop rotation followed in the region as concluded by Hemmat & Eskandari (2004).

Crop performance in response to tillage and location

In the second season, we performed the interaction between the two studied factors i.e., location and tillage (Table 3). Results showed that there was a significant location × tillage interaction for all the studied characters in both crops. Plant height varied with location and recorded the highest values of 61 cm for wheat and 45 cm for barley in El-Neguilla, tending to be higher under the conventional tillage treatment. Spike length and number of plants /m^2 showed a significant location × tillage interaction (Table 3), spikes were taller in wheat as compared to barley with highest values in El-Neguilla location under the conventional tillage treatment (Table 3).

Number of grains per spike showed a significant location × tillage interaction with more grains in spike under the CT treatment at El-Neguilla location for barley and at Matrouh location for wheat. The 1,000-grain weight was significant in location × tillage interaction (Table 3), where the maximum values of 45.93 g for barley and 48.00 g for wheat were recorded in El-Neguilla with the conventional tillage treatment. The highest grain yields of barley and wheat of 1,351.3 and 1,691.8 kg ha^{-1} respectively were at El- Neguilla under conventional tillage treatment. Same trends were also for the straw and biological yields in barley and for the biological yield only in wheat. Precipitation use efficiency values were also higher at El-Neguilla location under the conventional tillage treatment with the highest rainfall recorded for this season of 162 mm. Bonfil et al., (1999) stated that the PUE changes according to the amount of precipitation.

Table 3. Effect of location × tillage interaction on plant height (cm), spike length (cm), no. of plants /m^2, no. grains/spike, 1000-grain weight (g), grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}), harvest index (%) and precipitation use efficiency (kg ha^{-1} per mm) in 2018/2019 season

Location	Tillage	PH	SL	NP/ m^2	NGS	TGW	GY	SY	BY	HI	PUE
Barley											
Barrani	ZT	26.00	3.00	177.0	20.00	29.37	762.9	969.3	1,732.3	43.99	6.52
	CT	25.00	4.00	149.3	34.00	32.07	670.0	1,149.8	1,819.8	36.85	5.73
Matrouh	ZT	26.00	3.00	105.3	15.67	29.13	205.5	848.5	1,054.0	19.50	1.29
	CT	24.00	3.33	127.3	14.00	30.17	280.7	924.3	1,205.0	23.38	1.76
El-Neguilla	ZT	33.67	5.00	112.0	33.33	41.33	980.0	1,735.2	2,715.2	36.13	6.04
	CT	45.00	6.33	121.3	43.00	45.93	1351.3	2,298.5	3,649.9	37.03	8.33
LSD 0.05		**3.55**	**0.94**	**31.81**	**2.01**	**1.96**	**95.31**	**164.2**	**186.8**	**4.44**	**0.77**
Wheat											
Barrani	ZT	42.67	4.33	158.7	19.33	30.67	542.3	1491.5	2,033.6	26.72	4.66
	CT	54.00	7.67	150.7	32.00	32.87	533.3	1511.1	2,044.4	26.10	4.56
Matrouh	ZT	45.00	6.00	128.0	17.67	28.73	301.0	930.9	1,231.9	24.44	1.89
	CT	49.67	8.00	145.3	38.33	30.13	642.5	1978.3	2,620.8	24.42	4.04
El-Neguilla	ZT	59.67	5.00	156.7	21.33	42.23	938.5	1287.9	2,226.4	42.24	5.79
	CT	61.00	8.67	170.0	35.67	48.00	1691.8	1817.4	3,509.2	48.27	10.43
LSD 0.05		**6.08**	**1.26**	**26.92**	**4.46**	**2.75**	**99.78**	**208.4**	**237.1**	**4.16**	**0.66**

ZT: Zero Tillage; CT: conventional tillage; PH: plant height at harvest; SL: spike length; NP/m^2: No. of plants/ m^2; NGS: number of grains per spike; TGW: thousand grain weight; GY: grain yield; SY: straw yield;BY: biological yield; HI: harvest index and PUE: Precipitation Use Efficiency.

Previous studies drew different conclusions about the response of crop yield to different tillage systems. Piggin et al., (2015) found that wheat and barley were less responsive to zero tillage as compared to legumes in eleven seasons (five for wheat and six for barley). On the other hand, Mrabet (2000) found that, overall the growing seasons, wheat grain yield was maximum under No-tillage condition with no difference compared to chisel plow or deep tillage. However, under the dry condition (season 1998/1999) with a total rainfall of 195 mm, no tillage treatment produced the highest grain yield and total dry biomass as compared to the other tillage systems.

Traditional tillage may result in a better root growth, an increase in nutrient and water uptake and ultimately the agronomic yield, while ZT causes a soil compaction which impedes the root growth (Martinez et al., 2008). We believe that under our conditions, tillage can be more effective in case of implemented with other conservation agriculture treatments i.e. residue retention and crop rotation which found to increase the crop yield in dryland rainfed areas (Piggin et al., 2015; Pittelkow et al., 2015).

Being in a dryland Mediterranean environment, the amount and distribution of rainfall was the major driver for the crop performance in our study area. High and well distributed rainfall in Matrouh (159.25 mm) and El-Neguilla (162.14 mm) in the second season under CT treatment produced higher yields for wheat as compared to barley (Table 3). However, barley as a more drought resistant crop as compared to wheat, produced a better yield in Barrani (with less rainfall) in the second season. Moreover in the first season, barley was able to grow in at least one location where wheat couldn't survive.

In the present study, under very scarce rainfall 74 mm in the first season, the zero tillage was more productive than the conventional tillage, but in the second season, with rainfall between 116 and 169 mm, which is also a small amount, we found the reverse. One of the possible reasons of this apparent contradiction may rely on the fact that the beneficial effects of zero tillage on the structure of the soil will become more evident after several years of following the same soil management and, during the meantime, soil properties will pass through a transitional stage.

DSSAT model testing: barley and wheat yields

The variables used for calibration were grain yield, total produced biomass and harvest index. The calibration process revealed that the model predicted the grain yield and total biomass of both wheat and barley well, with NSE and R^2 values ≥ 0.8 (Table 4 and Fig. 3). The calibration results showed that RSR values were 0.098, 0.447 and 0.754 for grain yield, total biomass and HI respectively, which showed good model performance for the total biomass and HI and excellent performance for the crops grain yield. This implies that the model was successfully calibrated for the three treatments of the experiment i.e., location, crop and tillage. Similar results were obtained by another study of Soldevilla-Martínez et al. (2013), working under dryland condition with different crop rotations and tillage systems, concluded that CERES-Barley was able to accurately predict yield and total biomass of barley. The model showed a difference in yield and biomass associated with the tillage systems and locations.

Table 4. Simulated and observed values for barley and wheat and comparison statistics in the different locations and tillage systems

Crop, year and location	Tillage	Grain yield, kg ha^{-1}		Biomass, kg ha^{-1}		HI	
		Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
Barley 2017/2018 (Barrani)	ZT	545	571	1,560	1,849	0.35	0.30
	CT	550	257	1,468	1,231	0.37	0.21
Barley 2018/2019 (Matrouh)	ZT	385	205	1,484	1,054	0.26	0.20
	CT	370	281	1,515	1,205	0.24	0.23
Wheat 2018/2019 (Matrouh)	ZT	386	301	1,003	930	0.38	0.24
	CT	655	642	2,414	2,620	0.27	0.24
Barley 2018/2019 (El-Neguilla)	ZT	927	980	2,587	2,715	0.36	0.36
	CT	1,123	1,351	3,263	3,649	0.34	0.37
Wheat 2018/2019 (El-Neguilla)	ZT	1,190	938	2,589	2,226	0.46	0.42
	CT	1,459	1691	2,902	3,504	0.50	0.48
Barley 2018/2019 (Barrani)	ZT	742	763	2,081	1,732	0.36	0.44
	CT	743	670	2,085	1,819	0.36	0.36
Wheat 2018/2019 (Barrani)	ZT	579	542	2,075	1,491	0.27	0.27
	CT	577	533	2,062	1,511	0.28	0.26
NSE		0.868		0.800		0.431	
R^2		0.909		0.856		0.552	
RSR		0.098		0.447		0.754	

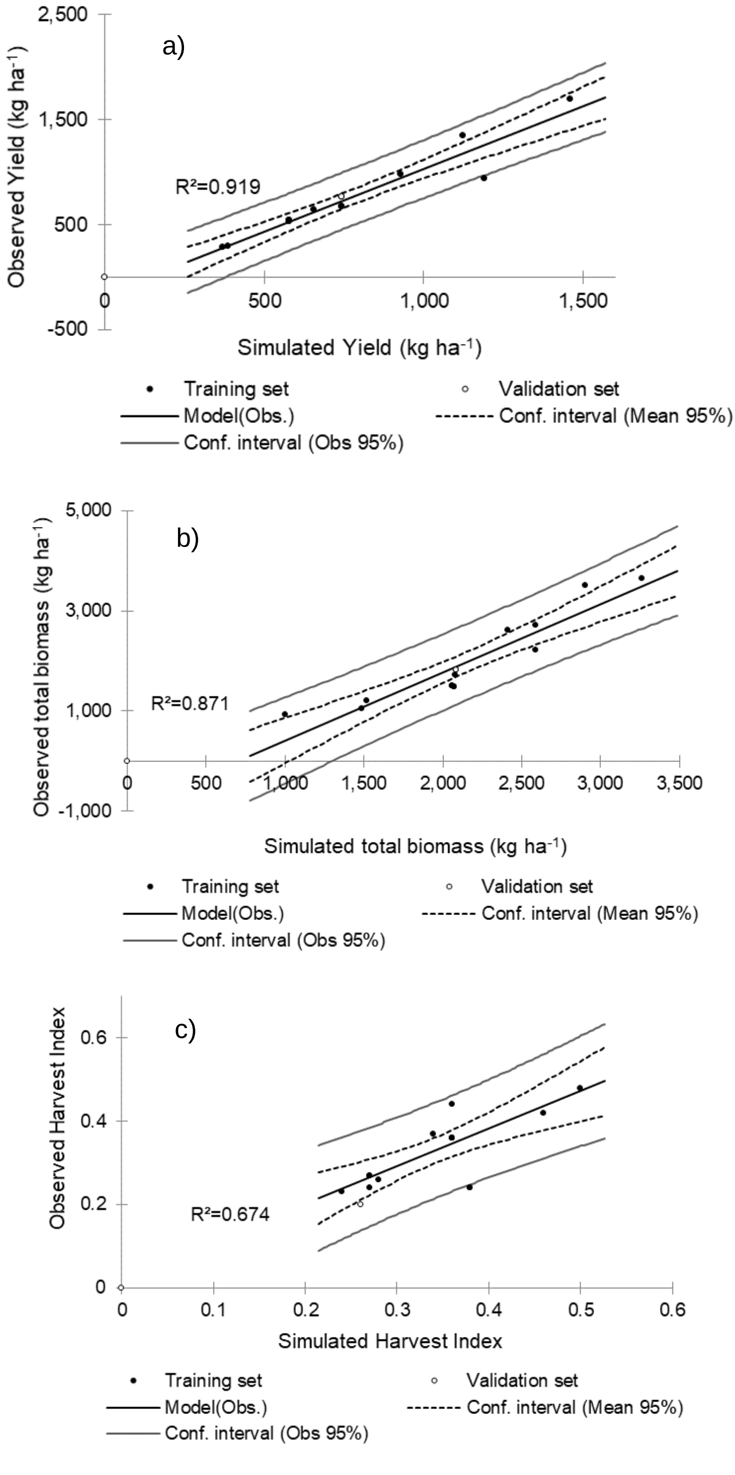

Figure 3. Barley and wheat grain yields (a) total biomass (b) and HI after calibration in the two growing seasons.

In the North Western Coast of Egypt, Mahmoud & Meselhy (2019) studied the impact of different sowing dates; 15th Nov, 30th Nov and 15th Dec, tillage treatments (conventional versus zero tillage) and three treatments of supplemental irrigation (0, 70, 140 mm) on barley yield. Results showed that under all the studied treatments, conventional tillage operation produced higher biomass and grain yields of 2.85 and 1.07 t ha^{-1} as compared to the No tillage operation. Barley yield was simulated using the Aqua Crop model (Raes et al., 2009; Steduto et al., 2009) under all the above mentioned treatments. The model adequately simulated the crop yield with an $R^2 > 0.85$ under the two tillage systems.

A sensitivity analysis was performed for the CENTURY-based soil module in DSSAT model inputs. Results showed that the model is less sensitive to tillage as compared to other factors (Porter et al., 2010). The model simulated higher yield and biomass for the CT in the second season which may be caused by a higher soil water storage in the CT treatment accompanied by higher precipitation in this season. The performance of the present simulation was therefore at the same order as that obtained by Soldevilla-Martínez et al. (2013) who used DSSAT to simulate different tillage systems and crop rotations under rainfed conditions in Spain. They found that the model simulated well the grain yield and biomass of barley and tended to overestimate both outputs for the conventional tillage and no-tillage systems. A study conducted by Liu et al. (2011) concluded that the model is having trouble in tracking the change in the soil physical properties over time caused by compaction, soil erosion and consolidation, and that finding was supported by Joshi et al., 2017.

Crop profitability in response to tillage over two years

Table 5. Comparison of gross margins of wheat and barley under different tillage treatments over the two growing seasons

Crop	Location and Season	Tillage	Total variable costs \$ ha^{-1}	Total income \$ ha^{-1}	Gross margin \$ ha^{-1}
Barley	Barrani (2017/2018) season	ZT	56.39	66.92	10.53
		CT	58.07	25.47	-32.6
	Matrouh (2018/2019) season	ZT	58.43	63.69	5.26
		CT	84.79	87.00	2.20
	El-Neguilla (2018/2019) season	ZT	138.46	303.08	165.33
		CT	202.32	439.58	237.25
	Barrani (2018/2019) season	ZT	116.03	236.50	120.47
		CT	125.03	207.07	82.66
Wheat	Matrouh (2018/2019) season	ZT	77.61	102.64	25.03
		CT	131.32	219.10	87.78
	El-Neguilla (2018/2019) season	ZT	150.08	320.04	169.96
		CT	254.30	576.90	322.60
	Barrani (2018/2019) season	ZT	105.02	184.86	79.84
		CT	122.62	181.86	59.24

The estimated mean of total cost, total income and gross margins for each treatment are presented in Table (5). In the first season ZT treatment was more profitable than CT treatment with an increase in the gross margins from -32.6 to 10.53 \$ ha^{-1} for barley. However, in the second season ZT was more profitable in Matrouh for barley and in

Barrani for barley and wheat. In El-Neguilla location, CT treatment had a gross margins almost double that recorded by ZT treatment for both crops because of the high grain yield produced in this location. The highest gross margins of 322.60 $ ha^{-1} was recorded in El- Neguilla for the wheat crop under the CT treatment.

CONCLUSION

Barley and wheat yields are erratic in the rainfed area of the NWC of Egypt due to a highly year to year variable precipitation. Comparison of the two years revealed that higher yields were recorded in the second season due to a high and well distributed above average amount of precipitation. Two of the three studied locations failed to produce any yield in the first season due to the severe drought condition. In this year ZT produced a higher barley yield as compared to the CT. Long term study should be conducted to measure the effectiveness of the ZT system on the crop performance and profitability. Farmers will be keen to eliminate plowing when they feel that it saves their time and money.

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