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OPTIMIZING THE SOWING DATE AND PATTERN TO IMPROVE WHEAT PRODUCTIVITY USING A CROP GROWTH SIMULATION MODEL IN KHARGA OASIS-EGYPT

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The timing and methods of sowing wheat can significantly impact its productivity, especially in the face of climate change. To investigate this, two field experiments were conducted over consecutive winter seasons in 2021/22 and 2022/23 in Kharga Oasis, Egypt. The aim was to assess the effects of five different sowing dates (30th October, 10th, 20th, and 30th of November, and 10th of December) using four distinct sowing methods (flatbed broadcast, ridges, rows, and raised-bed) on the productivity of the wheat cultivar Giza 171. The Decision Support System for Agrotechnology Transfer (DSSAT) software was employed to simulate wheat yield. The results of the experiments revealed that planting wheat on the optimal date of 20th November proved superior for grain yield in the first season. However, the highest grain yield in the second season was achieved with a sowing date of 10th November, which showed no significant difference compared to the 30th of October and 20th of November. Among the different sowing methods, raised-bed cultivation consistently produced the highest values for most of the parameters studied in both growing seasons. Furthermore, the DSSAT model effectively simulated grain yield, total biomass, and harvest index, with the Nash-Sutcliff efficiency (NSE) values exceeding 0.75. The findings highlight the significant impact of sowing dates and patterns on wheat yield and its associated attributes. Moreover, the successful simulation of these effects by the DSSAT model further validates its usefulness in predicting the outcomes of different management practices.

Keywords: wheat, DSSAT, sowing date, sowing pattern, raised-bed

INTRODUCTION

Egypt, renowned for its extensive agricultural heritage spanning millennia, is presently confronted with fresh challenges exacerbated by the effects of climate change, which are anticipated to exert a substantial influence on the agricultural sector. A collaborative study conducted in conjunction with the Egyptian government has revealed that agricultural production may witness a decline ranging from 8 to 47% by the year 2060, potentially resulting in a corresponding decrease in agricultural employment of up to 39%. Consequently, this could give rise to a notable surge in food prices, with estimates ranging from 16 to 68% (UNDP, 2013). The impact of climate change is particularly pronounced among small-scale farmers in Egypt, who encounter a myriad of difficulties including but not limited to extreme temperatures, storms, winds, and water scarcity (Mahmoud, 2019 and USAID, 2023).

Wheat, the most crucial grain crop in Egyptian agriculture, is highly susceptible to the detrimental impacts of climate change. These effects present significant challenges to the country's food security and economy. The escalating temperatures resulting from climate change can have adverse consequences on the growth and development of wheat. Specifically, the heightened temperatures experienced during the growing season can induce heat stress, which directly affects the grain filling process and ultimately reduces yields (Abou Kheira et al., 2016; Paymard et al., 2018 and Dubey et al., 2020). Moreover, climate change also disrupts the traditional wheat cultivation schedule by altering the timing and duration of growing seasons. Consequently, this necessitates adjustments in planting dates and farming practices to align with the optimal growing conditions (Eid et al., 2019 and Wen et al., 2023). These changes pose additional challenges to farmers and require them to adapt their strategies to ensure successful wheat production.

In a recent study conducted by Gamal et al. (2021), the effects of global warming on maize and wheat yields in Egypt were thoroughly examined. The researchers utilized projections from the Inter-Sectors Impact Model Intercomparison Project (ISI-MIP) to analyze the impact of two levels of global warming, namely 1.5 and 2°C. The findings of this study revealed intriguing spatial variations in the influence of temperature change on crop yield. Specifically, it was observed that there was a 5% change in the national average wheat yield under both GW1.5 and GW2.0 scenarios. However, it is important to note that while GW1.5 exhibited a positive effect on wheat yield, this beneficial impact diminished as the temperature rose to 2°C. These results highlight the critical importance of limiting the temperature rise to 1.5°C in order to safeguard crop production. Climate change poses a significant threat to agricultural productivity, particularly in vulnerable regions. Therefore, it becomes imperative to implement innovative agronomic management plans and cultivate drought-resistant crops as effective measures to mitigate the adverse effects of climate change.

Given the existing challenges, the concept of climate-smart agriculture emerges as a promising remedy. Climate-smart agriculture is a holistic approach that aims to improve productivity, resilience, and environmental sustainability (Lipper et al., 2014; Qureshi et al., 2022 and Zhao et al., 2023). By implementing this strategy, wheat farming in Egypt has the potential to undergo a significant transformation, ensuring food security and minimizing the negative impacts of climate change.

Several research studies conducted in the past thirty years have consistently demonstrated the effectiveness of altering sowing dates as a means of mitigating the adverse effects of climate change on crop productivity. By identifying the optimal sowing date, farmers can either counterbalance or minimize the negative impact of climate change on their crops. This adaptation strategy has been supported by recent studies conducted by Ding et al. (2016) and Rezaie et al. (2022). When determining the appropriate sowing dates, various factors such as temperature, precipitation, and the photoperiod sensitivity of wheat varieties need to be taken into account. It has been found that the timing of wheat sowing significantly influences the yield outcomes and overall performance of the crop, as highlighted by Asseng et al. (2015). Given the changing climate patterns, it is crucial to reevaluate and adapt traditional planting practices to ensure the long-term sustainability of wheat production.

Numerous studies in the field of agronomy and crop science have delved into the exploration and examination of different planting patterns. These patterns range from the traditional flat planting method to more inventive approaches like furrow irrigated raised-bed planting, as highlighted by Zhang et al. (2007) and Lamichhane and Soltani (2020). The findings of these studies have revealed that the selection of a specific planting pattern can exert a substantial influence on crucial factors such as water use efficiency, nutrient uptake, and pest control. This is supported by the research conducted by Odhiambo and Raun (2004), Bhatt et al. (2016) and Du et al. (2022).

The spatial arrangement of wheat plants in the field has a significant impact on various aspects of wheat cultivation. Not only does it affect the overall yield, but it also plays a crucial role in resource utilization, pest management, and the resilience of the crop. Given the challenges posed by climate change and population growth, understanding the influence of different planting patterns on wheat cultivation becomes increasingly important in the field of agriculture. According to Swelem et al. (2015), raised bed systems have proven to be the most profitable due to their ability to save labor, time, water, and energy costs. In their study, it was observed that the use of raised beds with widths of 120 or 100 cm, along with a nitrogen fertilizer application rate of 180 kg N ha^{-1}, resulted in the highest wheat grain production and nutrient uptake. Furthermore, raised beds with a width of 75 cm and lower nitrogen levels were found to reduce water usage by 15%. Therefore, in regions with warmer climates and limited water availability, the implementation of raised beds with the appropriate amount of nitrogen fertilizer could prove to be beneficial, particularly in terms of water conservation and nutrient efficiency.

The development of crop growth models has been a continuous process that has spanned several decades. This evolution has been driven by advancements in technology, the availability of data, and a deeper understanding of plant physiology. Notable contributions in this field include the creation of models like the Agricultural Production Systems Simulator (APSIM) and the Decision Support System for Agrotechnology Transfer (DSSAT). These models have significantly enhanced our understanding of how crops respond to different environmental conditions (Wolday and Hruy, 2015 and Abayechaw, 2021). By providing valuable insights, they enable informed decision-making in diverse agricultural contexts.

This research article focuses on the relationship between sowing dates and the various planting patterns of wheat. It aims to explore how different sowing dates and patterns impact crop performance and sustainability. Additionally, the article aims to investigate the relevance of the DSSAT model in simulating wheat yield under different sowing dates and planting patterns specifically in Kharga oasis in Egypt. By examining these factors, the study aims to contribute to our understanding of how to optimize wheat cultivation in this specific region, taking into account the unique environmental conditions and challenges it presents.

MATERIALS AND METHODS

1. Experimental Site Description and Soil Properties

A field experiment was performed to evaluate the impact of five sowing dates and four planting patterns on the yield and its components of wheat (Giza 171) at a farmer field in Kharga Oasis (25.56° N , 30.62° E) New Valley governorate, Egypt. The experiments were conducted during the two succeeding seasons of 2021/2022 and 2022/2023. Soil samples were taken from the experimental site before sowing in both study seasons to estimate the physical and chemical analyses.

Table (1). Some soil physical and chemical characteristics of the experiment site.

Depth (cm)	pH	EC[a] (dS m^{-1})	OM[b]	Available macro-nutrients (mg kg^{-1})			Available micro-nutrients (mg kg^{-1})				ESP[c]	Texture class
				N	P	K	Fe	Mn	Zn	Cu		
0-30	8.8	3.2	0.24	53.9	5.3	296.4	17.1	11.7	0.8	0.11	23.7	Clay loam
30-60	8.4	6.8	0.10	38.5	1.9	199.6	7.2	3.3	1.3	0.13	19.7	Sandy clay loam

[a]Electrical conductivity measured in soil paste extract
[b]Soil organic matter
[c]Exchangeable sodium percentage

Throughout the wheat growing cycle, spanning from October to April, the meteorological data from the weather meteorological station in Kharga Oasis was collected. These data are visually represented in Fig. (1).

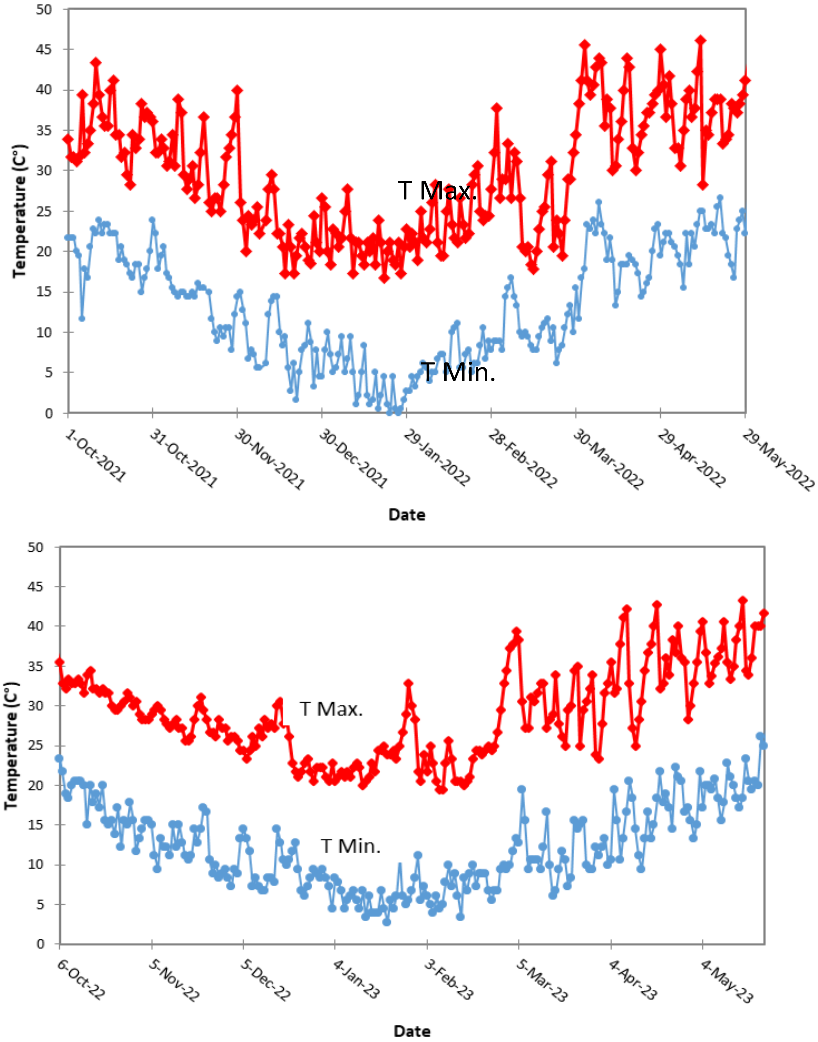

Fig. (1). The temperature fluctuations throughout the wheat growing season in **a.** 2021-22 and **b.** 2022-23 seasons.

2. Experimental Design and Layout

The experimental treatments were arranged in a split-plot design with three replications. The main plots represented five sowing dates: October 30th, November 10th, November 20th (the common sowing date in the study site), November 30th and December 10th. The sub- plots represented four planting methods: flat broadcast (FB), drill at 15 cm apart rows (R), drill at 25 cm apart ridges (RD), and Raised bed (RB), which were randomly distributed.

Three doses of nitrogen fertilizer (ammonium nitrate 33.5% N) were applied at a rate of 250 kg N/ha at three doses i.e., at the time of sowing, after 25 days of sowing and after 50 days of sowing. Prior to sowing, 375 kg /ha of super-phosphate fertilizer (15.5% P_2O_5), and 150 kg/ha of potassium sulphate (48% K_2O) were applied. The flood irrigation system that draws its water from the only available source of water i.e., groundwater was employed.

The plot measured 60 m^2 (10 m x 6 m). The top and bottom of the beds on bed planting techniques measured 120 and 30 cm, respectively. Drilling was done by hand in 15 cm rows and 25 cm between ridges. The planting rate per hectare was 142.8 kg ha^{-1}. According to recommendations from the Ministry of Agriculture, Desert Research Center in Kharga, all agronomic practices were maintained standard and uniform for all treatments. Wheat was manually harvested in April for all the sowing dates in the two growing seasons.

3. Studied Characters and Measurements

At harvest, plant height and spike length (in centimeters) were measured by randomly taking ten tillers' heights within an experimental unit. By physically counting the grains and threshing ten selected spikes from each plot, the grains $spike^{-1}$ was recorded. Once a thousand grains were physically counted, the weight of the grains (in grams) was recorded. Grain and biological yields were measured in the 1 m^2 center area. At harvest, the amount of grain per plot was determined, corrected for 14% moisture basis, and transformed to t ha^{-1}. By dividing the grain yield by the biological yield and multiplying the result by 100, the harvest index (%) was calculated.

4. Statistical Analysis

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. The least significant difference (LSD) test was performed to determine the significant differences between individual means. All statistical analyses were performed using the XLSTAT software (XLSTAT, 2014).

5. The DSSAT Model

DSSAT provides a user-friendly interface, enhancing accessibility for researchers, extension agents, and farmers (Hoogenboom et al., 2023). DSSAT incorporates crop models like CERES (Crop Estimation through Resource and Environment Synthesis) to simulate the growth and development of various crops (Jones et al., 2003). This study looked at the CERES wheat (Godwin et al., 1989) using DSSAT 4.7 as a framework. The data used to build the model includes daily data on climate parameters (precipitation, minimum and maximum temperatures, solar radiation), soil physical and chemical parameters, cultivar specifications, and information about the experiment that was carried out (site soil profile and soil surface data, crop management data, previous crop, residues, etc.). More details regarding the model can be found in Hoogenboom et al. (2023). The model replicates the phonological development and yield components of several crops. Through the adjustment of cultivar genetic coefficients, the outputs of the simulated model can be calibrated against the actual data.

6. 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 and Sutcliffe, 1970), and the root mean square error ($RMSE$) (Eq. 1,2 and 3).

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

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

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

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

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \quad (3)$$

where, The RMSE is defined as the square root of the mean squared error. In modeling, this is used to measure the geometric difference between observed and modeled data.

RESULTS AND DISCUSSION

1. The Impact of Sowing Dates on Wheat Performance

Table (2) illustrates the influence of sowing date on wheat grain yields and its components in two distinct seasons. The plant height findings suggest that the sowing date has a significant impact on wheat plant height in both seasons. In the first season, the treatments sown on October 30th, November 10th, November 20th, and December 10th resulted in relatively tall plants, with measurements ranging from 109.23 to 111.60 cm (Table 2). This indicates that late October to early December is an optimal period for sowing wheat if maximizing plant height is a priority. In contrast, during the second season, it was observed that the sowing date of November 20th produced the tallest plants, measuring 112.0 cm. This suggests that in this particular season, late

November might be the most favorable time for sowing wheat if aiming for maximum plant height.

Table (2). Mean values of wheat grain yield and its components, biological yield and the harvest index in 2021-2022 and 2022-2023 seasons as influenced by the sowing dates.

Sowing date	**PH (cm)**		**SL (cm)**		**No. of spikes per m^2**		**No. of grains per spike**		**1000-grain weight (g)**		**Grain yield (t ha^{-1})**		**Bio-yield (t ha^{-1})**		**HI (%)**	
	1st	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
30 Oct.	110.63	101.08	11.33	11.75	334.3	335.17	40.83	37.83	45.90	53.00	6.20	7.22	18.84	21.78	33.01	33.06
10 Nov.	111.60	103.17	11.68	12.09	408.3	394.17	41.50	33.83	54.38	44.71	7.17	7.36	22.22	23.84	32.33	30.88
20 Nov.	111.36	112.08	12.75	11.90	394.4	385.25	40.42	41.00	66.44	51.32	8.26	7.06	26.66	21.93	31.15	32.35
30 Nov.	105.23	100.42	12.29	13.00	368.5	371.83	34.50	38.17	56.58	53.23	7.36	6.93	23.47	22.10	31.48	31.48
10 Dec.	109.25	105.67	10.41	11.29	381.16	382.83	35.67	40.17	58.73	46.35	7.16	6.74	21.87	20.38	32.79	33.36
LSD	3.06	4.13	0.63	0.39	8.68	4.87	1.65	2.19	1.58	1.92	0.25	0.39	1.32	1.19	1.54	1.32

PH; plant height, SL; spike length, No. of spikes per square meter, Biological yield and HI; harvest index

The height of a crop is primarily determined by the genetic composition of a genotype, but it can also be influenced by environmental factors (Shahzad et al., 2007 and Shirinzadeh et al., 2017). One possible factor contributing to the differences in optimal sowing dates between seasons is temperature fluctuations. Temperature plays a crucial role in plant growth and development. Different seasons experience varying temperature patterns, which can significantly influence plant height.

In terms of spike length during the first season, the most noteworthy measurement was recorded when wheat was sown on November 20th and 30th, with respective values of 12.75 and 12.29 cm. Similarly, in the second season, the highest spike length was observed when sowing took place on November 30th, measuring 13.0 cm. In terms of the number of spikes per square meter, the highest values were observed during the first and second seasons in wheat sowed on November 20th, with recorded values of 408.3 and 394.17, respectively. In terms of the number of grains per spike, the most noteworthy results in the first season were obtained when sowing wheat on October 30th, November 10th, and November 20th, yielding values of 40.83, 41.50, and 40.42, respectively. Similarly, in the second season, the highest significant values were observed when sowing on November 20th and December 10th, resulting in values of 41.0 and 40.17, respectively.

Numerous researchers have extensively examined the significant influence of the sowing date of wheat on spike characteristics (Ahmed and Hassan, 2015; Ma et al., 2018 and Tahir et al., 2019). It is interesting to note that there was a slight decrease in spike length from the first season to the second season for wheat sown on November 20th, with a difference of 0.46 cm. However, the spike length increased when wheat was sown on November

30th in the second season, surpassing the spike length recorded in the first season. These findings suggest that the timing of wheat sowing can significantly impact both spike length and density. Sowing wheat earlier, specifically on November 20th, seems to result in longer spikes and a higher number of spikes per square meter.

The higher number of spikes per square meter resulting from early sowing is also significant. It suggests that by adjusting the timing of sowing, farmers can potentially achieve a denser crop canopy. A denser canopy has several advantages, including better weed suppression and improved water-use efficiency. Moreover, a dense canopy can help reduce soil erosion by providing better ground cover. Furthermore, an increased spike density can enhance pollination efficiency since there are more flowers available for pollinators. This may lead to improved fertilization rates and consequently higher grain set.

In terms of 1000-grain weight, the highest value during the first season was observed on November 20th, with a weight of 66.44 g. In the second season, the highest values were recorded on October 30th and November 30th, with weights of 53.0 and 53.23 g , respectively.

The grain yield data revealed that the first season exhibited the highest yield when wheat was sown on November 20th, reaching a value of 8.26 t ha^{-1}. This indicates that late November is an ideal time for sowing wheat in this particular region or under these specific conditions. Moving on to the second season, it was observed that the highest values were obtained when sowing took place on October 30th, November 10th, and November 20th, with corresponding yields of 7.22, 7.36, and 7.06 t ha^{-1}, respectively with no significant difference based on the given LSD value. It is worth mentioning that sowing wheat early in the first season, specifically on October 30th, as well as sowing it late in the second season, on November 30th and December 10th, led to a significant decrease in grain yield.

Research has shown that sowing date directly affects the development and growth stages of wheat, ultimately influencing its yield potential (Tahir et al., 2009; Ali et al., 2010 and Mukherjee, 2012). The sowing date determines the length and intensity of each growth phase, such as vegetative, reproductive, and grain-filling. A delay in sowing may result in a shortened vegetative phase which can negatively impact the wheat yield by devoting less resources to the reproductive growth, resulting in reduced grain formation. On the other hand, an early sowing date may delay crop development, which can be detrimental if the crop is exposed to frost or other cold stress events.

The data presented in Fig. (1) provide insights into the average temperature during March for two different seasons. The temperature recorded for the first season was 18.67°C, while for the second season, it was 21.93°C. It is worth noting that March is a crucial period for grain filling. Interestingly, the data suggests that the November 20 sowing date was more beneficial during this period. This is because the temperature during the second season was higher than the first season, resulting in earlier sowing dates leading to higher yields.

The highest biological yield in the first season was observed on November 20th, with a value of 26.66 t ha^{-1}. In the second season, the highest yield was achieved by sowing on November 10th, with a value of 23.84 t ha^{-1}. This implies that an earlier sowing date was more favorable for achieving maximum productivity during this particular season.

When considering the harvest index, the first season showed the highest values for sowing dates of October 30th, November 10th, and December 10th, ranging from 33.01 to 32.79%. Similarly, in the second season, the highest values were observed for sowing dates of October 30th, November 20th, and December 10th, ranging from 33.36 to 32.35%.

This contrasting trend between the two seasons suggests that the optimal timing for sowing may vary depending on various factors such as weather conditions. It is possible that in the first season, delaying the sowing process allowed for a longer growing period with favorable weather conditions, leading to increased biomass accumulation and ultimately higher yields. However, in the second season, sowing earlier on November 10th seemed to be more beneficial. This could be attributed to different weather patterns or changes in soil conditions that favored early sowing.

The impact of the sowing date on the wheat harvest index can be explained by the complex interaction between environmental factors and the crop's physiological processes (Alam et al., 2013; Moustafa and El-Sawi, 2014; Pathania et al., 2018 and Porker et al., 2020). The sowing date determines the timing of various phenological stages, such as flowering, grain filling, and maturity, which directly affect the grain yield. A delayed sowing date can lead to shorter growth periods, shorter grain filling stages, and increased exposure to adverse environmental conditions. Consequently, these factors may lead to reduced photosynthetic efficiency, limited nutrient uptake, and increased vulnerability to pests and diseases, ultimately resulting in a lower harvest index.

On the other hand, an early sowing date can contribute to a higher harvest index due to an extended growth period, increased rates of photosynthesis, enhanced nutrient uptake, and decreased pest and disease pressure. However, it is important to strike a balance, as exceedingly early sowing dates may also expose crops to environmental stresses. It is, therefore, crucial to consider regional climate patterns, soil suitability, and crop varieties to determine the optimal sowing date that would result in the highest harvest index, thus ensuring sustainable and profitable wheat production systems.

2. The Impact of Sowing Pattern on Wheat Performance

Table (3) presents a comprehensive analysis of the impact of various sowing methods on the growth parameters of wheat. The four techniques studied were broadcast, ridges, rows, and raised-beds. When considering plant height, it is noteworthy that the broadcast and raised-beds methods yielded the most significant results, with measurements of 111.49 and 111.14 cm, respectively. These techniques continued to demonstrate superior performance in the second season, with respective values of 106.93 and 105.40 cm.

Table (3). Mean values of wheat grain yield and its components, biological yield and the harvest index in 2021-2022 and 2022-2023 seasons as influenced by the sowing methods.

Sowing method	PH (cm)		SL (cm)		No. of spikes per m^2		No. of grains per spike		1000-grain weight (g)		Grain yield (t ha^{-1})		Bio-yield (t ha^{-1})		HI (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Broadcast	111.49	106.93	11.73	11.90	385.7	383.73	36.40	37.27	50.06	47.28	6.30	6.89	19.71	20.96	32.56	32.16
Ridges	106.52	102.47	11.5	11.79	385.2	382.53	37.07	35.93	55.90	52.17	7.07	6.88	21.92	21.54	33.36	32.38
Rows	109.30	103.13	11.05	11.80	366.5	370.47	37.40	38.13	57.07	49.27	7.42	7.09	23.42	21.91	33.26	31.86
Raisedbed	111.14	105.40	12.49	12.54	372	358.67	43.47	41.47	62.61	50.15	8.13	7.39	25.40	23.60	32.53	32.19
LSD	2.74	3.69	0.56	0.34	7.77	4.36	1.48	1.96	1.41	1.71	0.22	0.35	1.18	1.06	0.77	1.38

PH; plant height, SL; spike length, No. of spikes per square meter, Biological yield and HI; harvest index

In terms of spike length, the raised-beds sowing method proved to be the most effective, producing significant measurements of 12.49 cm in the first season and 12.54 cm in the second season. When examining the number of spikes per square meter, both the broadcast and ridges sowing methods exhibited the highest significant values. In the first season, these values were recorded as 385.7 and 385.2, while in the second season, they were 383.73 and 382.53, respectively. Furthermore, the raised-beds technique consistently yielded the highest significant values for the number of grains per spike in both seasons. Specifically, the first season saw a measurement of 43.47, while the second season recorded a value of 41.47.

Regarding the 1000-grain weight, the most noteworthy finding in the first season was that sowing in raised-beds resulted in a significant value of 62.61g . However, this changed in the second season, with sowing on ridges yielding a value of 52.17 g.

This unexpected shift in the highest value of the 1000-grain weight between the first and second seasons raises intriguing questions about the impact of different cultivation methods on crop yield. The initial finding that sowing in raised-beds resulted in a significantly higher 1000-grain weight of 62.61 g was undoubtedly promising, as it suggested that this method could potentially enhance grain production. However, the subsequent change in results during the second season, where sowing on ridges yielded the highest value of 52.17 g, challenges our understanding of optimal cultivation practices for maximizing grain weight. Sowing on ridges involves creating elevated rows or mounds for planting, which can help with water drainage and prevent waterlogging.

When it comes to grain yield, the highest significant yield in the first season was achieved through the raised-beds sowing method, with a value of 8.13 t ha^{-1}. On the other hand, the lowest yield was observed in the broadcasting technique, with a value of 6.30 t ha^{-1}. Moving on to the second season, the raised-beds technique once again produced the highest significant grain yield, reaching 7.39 t ha^{-1}. Interestingly, this yield was statistically comparable to the yield obtained through sowing in rows, which amounted to 7.09 t ha^{-1}. Conversely, the lowest yields in the second season were observed in both the broadcasting (6.89 t ha^{-1}) and ridges (6.88 t ha^{-1}) techniques.

These results highlight the consistent superiority of the raised-beds sowing method in terms of grain yield across both seasons. This technique seems to provide optimal conditions for seed germination and plant growth, resulting in higher productivity compared to other methods. On the contrary, the broadcasting technique consistently demonstrated lower yields in both seasons. This could be attributed to its inherent limitations, such as uneven seed distribution and lack of control over seed depth and spacing. These factors likely contribute to reduced plant establishment and subsequently yield.

The raised-beds sowing technique has gained significant attention in recent years due to its numerous advantages in wheat cultivation (Ahmad and Mahmood, 2005; Mollah et al., 2015; Rady et al., 2021 and Mohiy and Salous, 2022). Firstly, the enhanced drainage allows excess water to flow away quickly, preventing waterlogging and root rot. Secondly, the increased aeration facilitates better root respiration, leading to improved nutrient uptake and overall plant health. Lastly, the improved soil structure helps retain moisture during dry spells and enhances the efficiency of fertilizers. Consequently, the raised-beds sowing technique offers promising prospects for wheat cultivation, especially in areas with poor soil conditions or prone to waterlogging, contributing to higher yields and sustainable agricultural practices.

Regarding the biological yield, the raised-beds sowing technique consistently yielded the highest significant values in both seasons. In the first season, the value reached 25.40 t ha^{-1}, while in the second season, it amounted to 23.60 t ha^{-1}. It is worth noting that there were no discernible differences in the harvest index between the various sowing methods employed in both seasons. This suggests that the raised-beds sowing technique is highly effective in maximizing the overall yield of crops. The consistent and significantly higher values obtained in both seasons indicate that this method provides favorable conditions for plant growth and development. The first season's yield of 25.40 t ha^{-1} demonstrates the potential of the raised-beds technique to produce a substantial biological yield. This high yield can be attributed to various factors, such as improved soil drainage (Mascagni et al., 1995; Du et al., 2021 and Lin et al., 2023), enhanced root development (Kong et al., 2010), and better nutrient availability (Singh et al., 2010; Bhardwaj et al., 2010 and Osman et al., 2015). These factors contribute to optimal plant growth and ultimately result in a higher biological yield. Although there was a slight decrease in yield during the second season (23.60 t ha^{-1}), it is still noteworthy that the raised-beds sowing technique consistently outperformed other methods. This indicates that even under different environmental conditions or crop varieties, this technique remains highly effective in achieving significant yields.

3. The Interaction Effect Between Sowing Dates and Pattern on Wheat Performance

Tables (4 and 5) present the interaction effect between the sowing date and sowing method on various wheat parameters. In terms of plant height, the first season yielded the most noteworthy results. The treatments of broadcasting on November 20th demonstrated the highest significant values, reaching an impressive 121.73 cm. Following closely behind was sowing on ridges on November 10th, with a plant height of 118.0 cm. Broadcasting on October 30th and December 10th resulted in a plant height of 16.33 cm. Moving on to the second season, raised-beds cultivation on November 20th proved to be the most successful, with a significant value of 120 cm. Broadcasting on December 10th and raised-beds on December 10th followed suit, with plant heights of 115 and 113.33 cm, respectively.

In terms of number of spikes per square meter, the treatment of cultivation on raised-beds on November 20th yielded the highest significant value in the first season, measuring 459.67. Similarly, in the second season, the cultivation on ridges on November 10th resulted in the highest significant value, measuring 427.

When considering spike length, the cultivation on raised-beds on November 20th achieved the highest significant value in the first season, with a value of 15.33 cm. In the second season, several cultivation methods, including raised-beds on November 10th and 20th, broadcast on November 30th, rows on November 30th, and raised-beds on November 30th, showed statistically similar results.

In terms of the number of grains per spike, the cultivation on raised-beds on November 20th exhibited the highest significant value in the first season, with a count of 71.5. Additionally, cultivation in rows on November 20th showed a significant value of 69.43. In the second season, the cultivation on ridges and rows on November 30th yielded the highest number of grains per spike, with values of 59.83 and 59.40, respectively.

These findings highlight the impact of different cultivation methods and timing on spike length, number of spikes per square meter, and number of grains per spike. The results suggest that cultivation on raised-beds, particularly on November 20th, consistently leads to superior outcomes in terms of spike length and number of grains per spike. However, the second season revealed variations in the most effective cultivation methods for achieving a higher number of spikes per square meter.

In terms of 1000-grain weight, the most noteworthy results were observed when cultivating on ridges on November 10th, with a value of 52.67 g in the first season. Similarly, in the second season, raised-bed cultivation on November 20th yielded the highest significant value of 57.33 g.

When it comes to grain yield, the most significant values in the first season were achieved through cultivation in rows and raised-beds on November 20th, as well as raised-beds on December 10th, with yields of 8.84, 8.94, and 8.83 t ha^{-1}, respectively. In the second season, the highest significant values were obtained through raised-bed cultivation on October 30th, broadcast cultivation on November 10th, raised-beds on November 10th, and rows on November 20th, resulting in yields of 8.43, 8.25, 8.06, and 8.25 t ha^{-1}, respectively.

Table (4). Effect of sowing date × sowing method on wheat grain yield and its components, biological yield and the harvest index in 2021-2022 season.

Treatment (Sowing date × sowing method)	PH (cm)	No. of spikes per m^2	SL (cm)	No. of grains per spike	1000-grain weight (g)	Grain yield (t ha^{-1})	Bio-yield (t ha^{-1})	HI (%)
30 Oct.*Broadcast	116.33	345.00	12.00	39.53	36.00	4.67	14.06	33.17
30 Oct.*Ridges	105.47	348.00	11.47	48.37	35.00	6.41	19.42	32.96
30 Oct.*Rows	113.00	336.33	11.13	45.23	44.00	6.24	18.32	34.09
30 Oct.*Raisedbed	107.73	308.00	10.73	50.50	48.33	7.50	23.58	31.82
10 Nov.*Broadcast	103.00	425.00	10.60	46.93	42.00	6.43	19.93	32.29
10 Nov.*Ridges	118.00	437.00	12.40	53.20	52.67	6.97	21.92	31.92
10 Nov.*Rows	112.13	388.33	11.00	54.17	36.33	7.57	22.56	33.60
10 Nov.*Raisedbed	113.27	383.00	12.73	63.21	35.00	7.69	24.47	31.49
20 Nov.*Broadcast	121.73	384.00	13.33	63.27	42.33	7.71	25.71	30.13
20 Nov.*Ridges	102.27	356.00	11.87	61.57	39.00	7.56	22.92	33.06
20 Nov.*Rows	107.07	378.00	10.47	69.43	34.00	8.84	28.35	31.16
20 Nov.*Raisedbed	114.40	459.67	15.33	71.50	46.33	8.94	29.67	30.22
30 Nov.*Broadcast	100.07	389.33	13.40	48.30	36.33	6.62	20.30	32.70
30 Nov.*Ridges	104.87	413.00	10.77	59.37	24.00	7.77	25.19	30.92
30 Nov.*Rows	110.67	321.67	12.00	56.17	36.33	7.32	24.75	29.62
30 Nov.*Raisedbed	105.33	350.00	13.00	62.50	41.33	7.71	23.64	32.67
10 Dec.*Broadcast	116.33	385.33	9.33	52.27	25.33	6.03	18.57	32.52
10 Dec.*Ridges	102.00	372.00	11.00	57.00	34.67	6.63	20.13	33.04
10 Dec.*Rows	103.67	408.00	10.67	60.33	36.33	7.13	23.14	30.85
10 Dec.*Raisedbed	115.00	359.33	10.67	65.33	46.33	8.83	25.64	34.74
LSD at 0.05	6.12	17.37	1.26	3.16	3.30	0.50	2.63	3.08

PH; plant height, SL; spike length, No. of spikes per square meter, Biological yield and HI; harvest index

Table (5). Effect of sowing date × sowing method on wheat grain yield and its components, biological yield and the harvest index in 2022-2023 season.

Treatment (Sowing date × sowing method)	PH (cm)	No. of spikes per m^2	SL (cm)	No. of grains per spike	1000-grain weight (g)	Grain yield (t ha^{-1})	Bio-yield (t ha^{-1})	HI (%)
30 Oct.*Broadcast	108.33	341.67	12.43	54.83	42.67	6.38	19.94	31.97
30 Oct.*Ridges	100.33	341.33	11.63	53.30	31.33	6.93	20.82	33.31
30 Oct.*Rows	107.33	343.00	11.53	53.90	34.67	7.13	21.72	32.82
30 Oct.*Raisedbed	88.33	314.67	11.40	49.97	42.67	8.43	24.62	34.17
10 Nov.*Broadcast	96.67	411.67	11.13	43.70	25.00	8.25	25.89	31.87
10 Nov.*Ridges	103.33	427.00	13.03	46.53	34.67	6.35	21.01	30.23
10 Nov.*Rows	108.33	385.00	11.07	41.07	44.00	6.78	21.78	31.13
10 Nov.*Raisedbed	104.33	353.00	13.13	47.53	31.67	8.06	26.69	30.26
20 Nov.*Broadcast	114.00	390.67	12.53	47.27	32.33	6.41	19.32	33.19
20 Nov.*Ridges	107.00	362.67	10.27	55.17	36.67	6.96	21.09	33.09
20 Nov.*Rows	107.33	381.33	11.47	46.23	37.67	8.25	26.57	31.02
20 Nov.*Raisedbed	120.00	406.33	13.33	56.60	57.33	6.63	20.72	32.10
30 Nov.*Broadcast	100.67	389.33	13.07	45.37	42.67	6.70	20.78	32.37
30 Nov.*Ridges	105.67	406.33	12.37	59.83	34.33	7.61	25.21	30.27
30 Nov.*Rows	94.33	341.67	13.00	59.40	42.67	6.45	20.15	32.06
30 Nov.*Raisedbed	101.00	350.00	13.60	48.30	33.00	6.95	22.27	31.21
10 Dec.*Broadcast	115.00	385.33	10.33	45.23	43.67	6.70	18.88	35.57
10 Dec.*Ridges	96.00	375.33	11.67	46.03	42.67	6.56	19.57	33.57
10 Dec.*Rows	98.33	401.33	11.93	45.77	31.67	6.82	19.33	35.30
10 Dec.*Raisedbed	113.33	369.33	11.23	48.37	42.67	6.87	23.73	28.99
LSD at 0.05	8.26	9.74	0.77	3.83	4.39	0.78	2.38	2.65

PH; plant height, SL; spike length, No. of spikes per square meter, Biological yield and HI; harvest index

These findings highlight the importance of cultivation techniques and timing in achieving optimal 1000-grain weight and grain yield. By implementing ridge cultivation on November 10th and raised-bed cultivation on November 20th, farmers can expect to obtain higher 1000-grain weights. Similarly, for maximizing grain yield, cultivation in rows and raised-beds on November 20th, as well as raised-beds on December 10th, prove to be the most effective approaches in the first season. In the second season, raised-bed cultivation on October 30th, broadcast cultivation on November 10th, raised-beds on November 10th, and rows on November 20th are recommended for achieving the highest grain yields.

In the first season, the highest biological yield was achieved through cultivation in rows on November 20th, with a value of 28.35 t ha^{-1}. In the second season, various cultivation methods were tested, including raised-beds on October 30th, broadcast on November 20th, raised-beds on November 10th, and rows on November 20th. These methods resulted in significant yield values ranging from 26.69 to 24.62 t ha^{-1}.

It is worth noting that the cultivation in rows on November 20th consistently yielded the highest results in both seasons. However, the second season's findings indicate that alternative methods, such as raised-beds and broadcast cultivation, can also lead to substantial yields.

As a primary objective, a closer examination of grain yield reveals that the sowing method significantly influences the cultivated yield, whether it is done early or late. For instance, in the first season, when cultivation was carried out on October 30th, the broadcast, ridges, rows, and raised-beds cultivation methods resulted in grain yields of 4.67, 6.41, 6.24, and 7.50 t ha^{-1}, respectively. In the second season, these values increased to 6.38, 6.93, 7.13, and 8.43 t ha^{-1}, respectively. Conversely, when sowing was delayed until December 10th, the broadcast, ridges, rows, and raised-beds cultivation methods yielded 6.03, 6.63, 7.13, and 8.83 t ha^{-1}, respectively, in the first season. In the second season, these values decreased slightly to 6.7, 6.56, 6.82, and 6.87 t ha^{-1}, respectively. These findings highlight the significant impact of the sowing method on grain yield, with raised-beds cultivation consistently resulting in the highest yields across both seasons.

The study of wheat sowing method and sowing date interactions is of utmost importance in agricultural research and precision farming practices in the face of climate change, particularly in Kharga Oasis as a vulnerable environment. The efficiency and success of wheat cultivation heavily rely on understanding the intricate relationship between the sowing method employed and the appropriate sowing date. The results of the present study demonstrated this interaction clearly. In recent years, researchers have demonstrated that selecting the suitable sowing method can significantly impact wheat yield, soil quality, and production costs (Dagash et al., 2014; Farooq et al., 2015; Meleha et al., 2020 and Kawakita et al., 2021). Additionally, the timing of sowing has been shown to affect the rate of germination, crop establishment, diseases, and pest pressures (Tyagi et al., 2003; Coventry et al., 2011; Dubey et al., 2019; Poudel et al., 2020 and Sandhu et al., 2020). Consequently, studying the interactions between these two variables provides essential insights for optimizing wheat production systems, improving resource management, and ensuring sustainable agricultural practices in the face of changing climatic conditions. However, Further research and experimentation are recommended to explore additional variables that may impact yield, such as soil composition, irrigation techniques, and crop variety. By continuously refining our understanding of these factors, we can enhance agricultural practices and ensure sustainable food production for future generations.

4. DSSAT Model Testing

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 wheat, with NSE and R^2 values ≥ 0.8 (Fig. 2) in both seasons. The calibration results showed that the RMSE values were 0.406, 1.625 and 0.81 in the first season and 0.223, 1.125 and 0.999 in the second season for grain yield, total biomass and HI respectively, which showed good model performance for the total biomass and HI and excellent performance for the grain yield. This implies that the model was successfully calibrated for the two treatments of the experiment i.e., sowing date and patterns. Similar results were obtained by Andarzian et al. (2015), who concluded that the DSSAT model successfully simulated the wheat grain yield under different sowing dates in Iran with a coefficient of determination of 0.97 and 0.86 for grain yield and biomass respectively.

To sum up, the DSSAT model calculates the best sowing time of wheat by taking into account factors like thermal time, photoperiod, temperature, soil conditions, and the maturity length and growing season of the cultivar. This data assists farmers and researchers in maximizing yield and enhancing crop performance by optimizing wheat sowing dates (Yanan et al., 2021).

The DSSAT model can be used to simulate different crop management practices, including planting patterns like row spacing, and assess how they affect crop yield. The DSSAT model has been employed to simulate the influence of row spacing on crop yield for a variety of crops, such as cotton (Dhir et al., 2021). Ultimately, by simulating various row spacing scenarios and assessing their effects on crop yield, the DSSAT model can be a useful tool for enhancing crop productivity and optimizing crop management strategies.

CONCLUSION

The growth of wheat in Kharga Oasis is greatly affected by temperature, especially towards the end of the season. When the reproductive stages of the crop are exposed to high temperatures, there is a significant risk of yield loss. Through a comparison of different sowing dates, it was found that sowing wheat on the 20th of November in the first season and on the 10th of November in the second season resulted in the highest grain yield.

Additionally, the study revealed that raised-bed cultivation was the most effective sowing pattern in terms of grain yield and its attributes in both seasons. Therefore, it is recommended to cultivate wheat in early November using the raised-bed cultivation method in the Kharga Oasis. However, it is important to note that further research should be conducted to assess the impact of extended heat and drought stress on wheat cultivation in this region. This will provide a more comprehensive understanding of the challenges faced by farmers and help develop strategies to mitigate the negative effects. Furthermore, the raised-bed cultivation method should be thoroughly evaluated for its potential to conserve irrigation water in the Kharga Oasis, which is known for its scarcity of water resources. By exploring these aspects, it will be possible to optimize wheat production in this hyper-arid region and ensure sustainable agricultural practices.

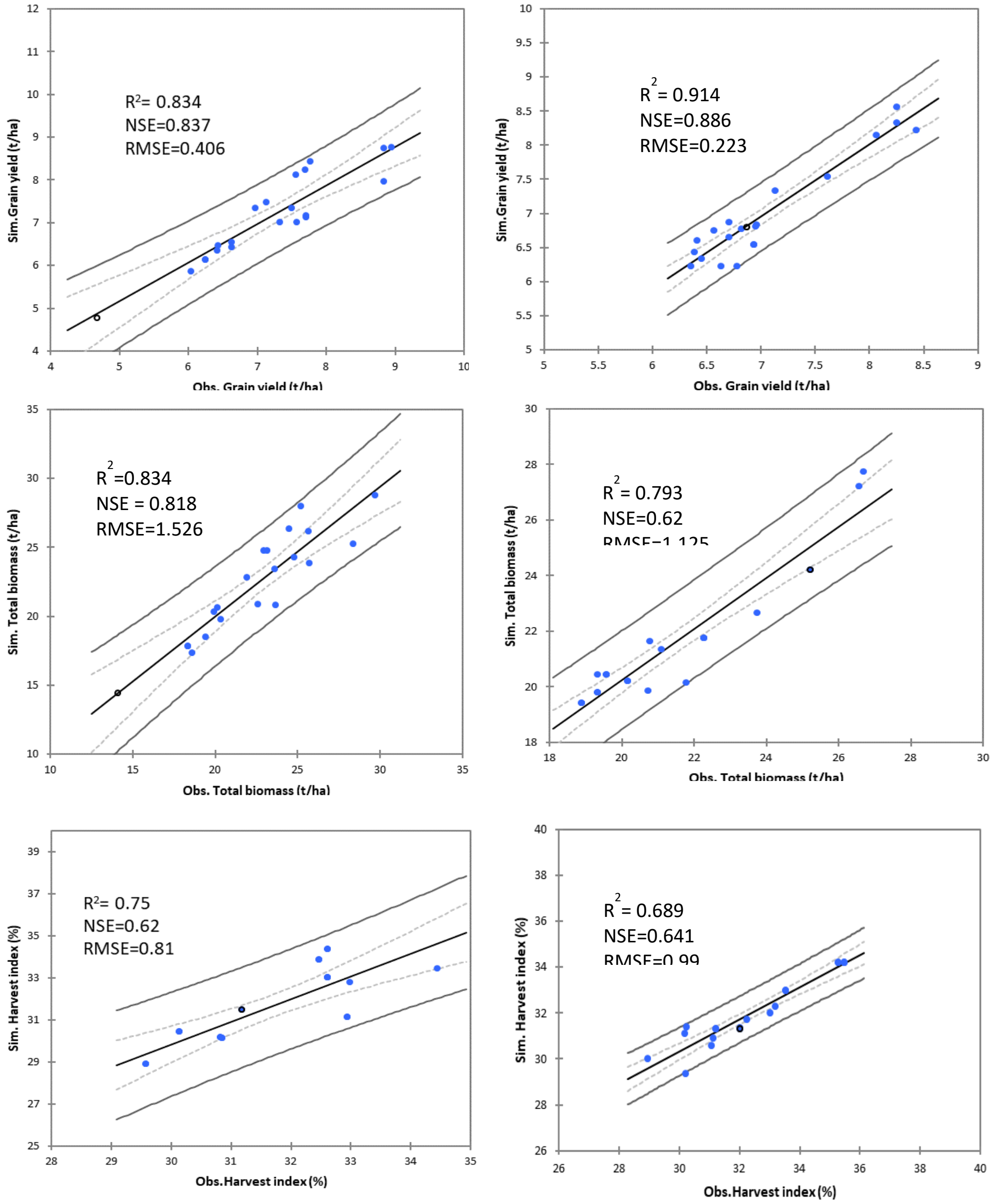

Fig. (2). Simulated vs. observed grain yield (t ha^{-1}), total biomass (t ha^{-1}) and harvest index (%) for the 2021/2022 (left) and 2022/2023 (right) seasons.

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تحسين إنتاجية القمح عن طريق تحديد ميعاد وطريقة الزراعة المثلى بإستخدام نموذج نمو المحصول بواحة الخارجة مصر

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يعد القمح المحصول الأكثر أهمية في مصر، لأنه مكون أساسي في النظام الغذائي التقليدي للسكان. أجريت تجربتان حقليتان خلال موسمين شتويين متتاليين ٢٠٢١-٢٢ و٢٠٢٢-٢٣ لدراسة تأثير خمسة مواعيد للزراعة (٣٠ أكتوبر، ١٠، ٢٠ و٣٠ نوفمبر و١٠ ديسمبر) تحت أربع طرق زراعة مختلفة (بدار وخطوط وصفوف ومصاطب) على إنتاجية صنف القمح (جيزة ١٧١). تم استخدام نموذج نمو المحصول (DSSAT) لمحاكاة نمو وإنتاجية محصول القمح المنزرع في واحة الخارجة. أظهرت النتائج أن مواعيد وطرق الزراعة أثرت بشكل كبير في قيم محصول الحبوب ومكوناته في الموسمين الزراعيين. كانت زراعة القمح في الموعد الأمثل (٢٠ نوفمبر) هي الأفضل لمحصول الحبوب في الموسم الأول، أما أعلى إنتاجية للحبوب في الموسم الثاني فقد تم الحصول عليها في تاريخ الزراعة ١٠ نوفمبر مع عدم وجود فرق معنوي مع كلًا من ميعادي الزراعة ٣٠ أكتوبر و٢٠ نوفمبر. أنتجت طريقة الزراعة على المصاطب أعلى القيم لمعظم الصفات المدروسة في الموسمين الزراعيين. قام نموذج DSSAT بمحاكاة إنتاجية محصول الحبوب والكتلة الحيوية الكلية ودليل الحصاد بشكل جيد مع قيم Nash-Sutcliff (NSE) أعلى من ٠.٧٥. كان لمواعيد وطرق الزراعة تأثير ملحوظ على محصول القمح ومكوناته، وقد نجح النموذج DSSAT في محاكاة تأثير هاتين الممارستين.