Agricultural Systems 165 (2018) 26–32

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Sowing date and mulch to improve water use and yield of wheat and barley in the Middle East environment

Ahmad Shams Aldien Shaaban[a], Ammar Wahbi[b], Thomas R. Sinclair[c,*]

[a] Department of Processing Data and Statistical Analysis, Center for Strategic Studies and Research, Aleppo University, Aleppo, Syria
[b] Soil and Water Management & Crop Nutrition Subprogramme, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency (IAEA), Vienna, Austria
[c] Crop and Soil Sciences Department, North Carolina State University, Raleigh, NC, USA

ARTICLE INFO

Keywords:
Barley
Mulch
Simulation
Sowing date
Wheat

ABSTRACT

Water is a critical limitation of crop yield in Middle East environments. Cereal production is limited to the winter months when rains occur. Options to increase the effective use of the available water to increase yield could be of direct benefit. This simulation study was undertaken for four locations in Syria that encompassed the wetter climate for wheat production in the north and the drier climate for barley production in the middle and south. Simulations were done for four sowing dates along with either the absence or presence of mulch on the soil surface. These simulations showed that sowing in early November for both barley and wheat resulted in the highest average yields among the simulated sowing dates. Surprisingly, the retention of straw mulch on the soil surface had only a small impact on yield. In most cases, yield increases were fairly modest in the range of about 4 to 9%. Since management practices to retain straw mulch in place in the field are challenging in the Syrian environment, these simulations do not indicate priority be given to developing this management practice solely for water retention.

1. Introduction

Precipitation commonly limits crop yields. This is certainly true in the Middle East where rainfall occurs in the winter months with no rain in the summer months. Farmers commonly cultivate their lands in late spring or early summer before seeds are sown around 1 December. Due to the high demand for grain production, land management no longer includes a fallow rotation. Hence, the intense tillage of the land can results in severe soil erosion.

Wheat and barley are the two cereals of greatest importance due to their value as human food and animal feed, particularly in the Middle East region. However, the high variability in timing and amount of rainfall events across growing seasons and locations in the Middle East makes it difficult to develop management recommendations. One of the more important management considerations is sowing date. Sowing date of wheat and barley is now generally based on tradition and the experience of the farmer, and on access to irrigation. However, the sensitivity and variability in yield across growing seasons as a result of sowing date has not been closely analyzed for this region. That is, what sowing date for rainfed crops will result in the greatest average yield across seasons? Also importantly, what sowing date will offer the lowest variability in yield, and hence, yield stability for farmers?

Since the weather is highly variable over locations and seasons in the Mediterranean climate of the Middle East, simulation models are needed to evaluate the range of conditions over many years to fully answer the above questions. Such model analysis has been done for wheat but the application to the diversity of weather in these environments has not been fully explored. Sommer et al. (2012) used the calibrated CropSyst model to assess the influence of sowing date on wheat yields grown at the single location of Tel Hadya, northern Syria. The calibration of the model causes the model to be empirical and may limit its ability to simulate the full scope of response to variable weather conditions. In fact, the simulation results across 30 years showed no significant impact on wheat yield between an early and late sowing date, or as a result of retention of crop residue.

Further, indications of the impact of sowing date on wheat yield can be gained from simulations done in Australia which also experiences a Mediterranean climate. Kirkegaard and Hunt (2010) found in simulations with the APSIM model at the single location of Kerang, Victoria that earlier sowing by one month resulted in more than a doubling of mean yield. Also in Australia, early sowing of wheat at Kingsthorpe, Queensland was simulated with the DSSAT (Cammarano et al., 2012). These simulations showed a modest yield increase of 28% in going from late sowing to early sowing under non-irrigated conditions. In

---

* Corresponding author.
E-mail address: trsincla@ncsu.edu (T.R. Sinclair).

https://doi.org/10.1016/j.agsy.2018.05.011
Received 15 December 2017; Received in revised form 17 April 2018; Accepted 21 May 2018

simulations with the APSIM model at seven locations in Western Australia, early sowing using a 'dry sowing' management generally resulted in yield increases although in wetter seasons and locations early sowing resulted in yield decreases (Fletcher et al., 2015). The results from this latter study support the need for simulation assessments across many seasons to fully consider weather variations on yield response at any particular location.

Most recently, Schoppach et al. (2017) used the SSM model to simulate wheat and barley yields across the Middle East using 30 years of generated weather data. The simulation results for the western Middle East showed optimum sowing date was roughly mid November. However, both the low spatial resolution (1° × 1°) and timing of sowing (one month intervals) did not allow full resolution of optimum sowing date. Importantly, Schoppach et al. (2017) offered no analysis of the crop water budget and the critical impact of the transpiration and soil evaporation on the soil water budget and their impact on crop yield.

In addition to altered sowing date, another possible management scheme for yield increase is the retention of straw mulch on the soil surface to decrease soil evaporation. Simulations of wheat in the Levant region with straw mulch showed an increase in both yield and the transpiration:evapotranspiration ratio in all growing seasons (Sinclair and Amir, 1996). However, in this case the major benefit of the straw mulch system was wetter soil that inhibited cereal cyst nematode development so that continuous wheat production was possible (Amir and Sinclair, 1996). Kirkegaard and Hunt (2010) included a stubble retention management in their simulations of wheat at the one location in Australia. They found a surprisingly small yield increase (15%) as a result of the stubble management. In the Sommer et al. (2012) analysis of wheat at one location in Syria, no significant change in yield was found due to mulch.

To explore further the possibility of improving barley and wheat yields by altering sowing date or use of straw mulch, we examined production across the diversity of climates in the Syrian Middle East from wetter locations in which wheat is grown to drier locations in which barley is grown. The current study used the mechanistic, non-calibrated Simple Simulation Model (SSM; Soltani and Sinclair, 2012). This model has been shown to be robust in simulating grain yield of wheat in the Levant region across a wide range of rainfall conditions with no yield difference between simulated and observed yields greater than 260 kg ha^{-2} (Amir and Sinclair, 1991) and for barley across four locations in Syria with R^2 of 0.89 (Wahbi and Sinclair, 2005). In the study of Wahbi and Sinclair (2005), it was found that the difference between the two species in duration of development events in their life cycle was important in determining the relative yield advantage of each species. Barley had a shorter season than wheat and held an advantage in drier growing seasons. The objective of the current study was to examine the interactive consequences of sowing date and straw mulch on barley and wheat in crop water use, yield, and yield stability.

2. Materials and methods

2.1. Model

The SSM model is fully described by Soltani and Sinclair (2012). Daily weather data input required by the model are minimum and maximum temperature, solar radiation, and precipitation. The major mechanistic components of the model are: plant development as a function of temperature, growth as function of light interception, and transpiration as a function of growth. Importantly, each of these processes is restricted at low soil water content. The input parameters to the model are mechanistic and can be directly observed for each crop species / genotype. Hence, there is no "calibration" of the entire model, which is critical in enhanced model transparency (Soltani and Sinclair, 2015) and extrapolation to new conditions.

Wahbi and Sinclair (2005) previously published the descriptive parameters for wheat and barley and these were used directly in the current simulations as given in Table 1. The parameters defining plant development were based on cumulative temperature units, which was calculated using base temperature of 0 °C. Crop development was also accelerated somewhat under water-deficit conditions by adding 6° C to the cumulative temperature units each day when fraction transpirable soil water (described later) was less than 0.2. Daily crop growth was based on radiation use efficiency of 1.1 g MJ^{-1} solar radiation for both crop species. During seed fill, daily seed growth was calculated based on a constant daily increase in grain harvest index. Seed growth progressed more rapidly in barley with a daily harvest increase of 0.015 d^{-1} as compared to 0.011 d^{-1} for wheat. All development parameters reflected more rapid development by barely as compared to wheat.

Table 1
Parameters for barley and wheat (Simple Simulation Model SSM).

Parameter	Wheat	Barley
Plant density (plants m^{-2})	300	250
Base temperature (°C)	0	0
Radiation Use Efficiency (g MJ^{-1})	1.1	1.1
Phyllochron (°C leaf^{-1})	115	103
Duration from termination of leaf development to anthesis (°C)	370	330
Duration from anthesis to seed fill (°C)	90	70
Duration of seed fill (C)	550	480
Daily increase in harvest index (d^{-1})	0.011	0.015

SSM does a daily accounting of water added to the soil by precipitation and removal as a result of soil evaporation and crop transpiration. The amount of water is tracked in both the top 150 mm of the soil, which supports soil evaporation, and the entire soil volume that is occupied by roots. The simulations were initiated in all cases on 1 September well before the rains began so the soil was assumed to be initially devoid of extractable soil water. Therefore, the early initiation date for the simulations allowed the model to calculate daily the soil water balance prior to sowing and therefore, calculate in each simulation soil water conditions at sowing.

Soil evaporation was calculated assuming two stages in evaporation depending on the presence or absence of water in the top soil layer (Ritchie, 1972). When available water exists in the top soil layer, soil evaporation was calculated by energy balance at the soil surface. When there was no available water in the top soil layer, it was assumed water originates deeper in the soil profile by diffusion to the soil surface. In this stage, soil evaporation is calculated as a decreasing function based on the square root of the cumulative duration of this dry phase (Ritchie, 1972).

Daily transpiration rate was calculated from daily crop growth based on the mechanistically defined transpiration coefficient given by Tanner and Sinclair (1983). The value of the transpiration coefficient from the derivation of Tanner and Sinclair (1983) was assumed equal for barley and wheat with a value of 5.8 Pa. Since soil drying results in decreased growth, this outcome also meant that transpiration decreased with soil drying. These calculations were done based on the fraction of transpiration soil water (FTSW), which is the ratio of current amount of soil water divided by the total capacity for stored transpirable water store in the soil. In these simulations, crop growth (and transpiration) decreased as a function of FTSW using the same logistic function for barley and wheat (Amir and Sinclair, 1991). Decreases in crop growth occurred at FTSW less than about 0.3 down to no growth at FTSW equal to zero. Total capacity for transpirable soil water storage (mm) was calculated as 0.13 × water extraction depth. For these simulations, maximum extraction depth at all locations was assumed to by 700 mm as discussed by Wahbi and Sinclair (2005).

Simulation of the impact of mulch on soil evaporate was done by decreasing soil evaporation in both the wet and dry phase by a constant fraction. Adams et al. (1976) showed that the fractional decrease in transpiration was closely correlated with the mass of finely chopped straw mulch on the soil surface. In the simulations presented here, it