Agricultural and Forest Meteorology 214–215 (2015) 208–218

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Sowing rules for estimating rainfed yield potential of sorghum and maize in Burkina Faso

J. Wolf[a,*], K. Ouattara[b], I. Supit[c]

[a] Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[b] Institut de l'Environment en de Recherches agricoles (INERA), Ouagadougou, Burkina Faso
[c] Earth System Science and Climate Adaptive Land Management, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 6 January 2015
Received in revised form 20 August 2015
Accepted 21 August 2015

Keywords:
Crop modelling
Maize
Sorghum
Sowing
WOFOST
Yield potential

ABSTRACT

To reduce the dependence on local expert knowledge, which is important for large-scale crop modelling studies, we analyzed sowing dates and rules for maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.)) at three locations in Burkina Faso with strongly decreasing rainfall amounts from south to north. We tested in total 22 methods to derive optimal sowing dates that result in highest water-limited yields and lowest yield variation in a reproducible and objective way. The WOFOST crop growth simulation model was used.

We found that sowing dates that are based on local expert knowledge, may work quite well for Burkina Faso and for West Africa in general. However, when no a priori information is available, maize should be sown between Julian days 160 and 200, with application of the following criteria: (a) cumulative rainfall in the sowing window is ≥3 cm or available soil moisture content is >2 cm in the moderately dry central part of Burkina Faso, (b) cumulative rainfall in this period is ≥2 cm or available soil moisture content is >1 cm in the more humid regions in the southern part of Burkina Faso. Sorghum should also be sown between Julian days 160 and 200 with application of the following criteria: (a) in the dry northern part of Burkina Faso the long duration sorghum variety should be sown when cumulative rainfall is ≥2 cm in the sowing window, and the short duration sorghum variety should be sown later when cumulative rainfall is ≥3 cm, (b) in central Burkina Faso sowing should start when cumulative rainfall in this period is ≥2 cm or when available soil moisture content is >1 cm.

Sowing date rules are shown to be generally crop and location specific and are not generic for West Africa. However, the required precision of the sowing rules appears to rapidly decrease with increasing duration and intensity of the rainy season. Sowing delay as a result of, for example, labour constraints, has a disastrous effect on rainfed maize and sorghum yields, particularly in the northern part of West Africa with low rainfall.

Optimization of sowing dates can also be done by simulating crop yields in a time window of two months around a predefined sowing date. Using these optimized dates appears to result in a good estimate of the maximal mean rainfed yield level.

1. Introduction

For many African countries it is unclear if the future food demand of the rapidly growing population can be met by increasing domestic food production (Alexandratos and Bruinsma, 2012; Nelson et al., 2010). Especially, in the semi-arid regions of Africa where agriculture is based on small-scale, climatically vulnerable systems (Challinor et al., 2007), increasing food production will be a challenge. Rainfall in West Africa shows high spatial and temporal variability (Graef and Haigis, 2001). Both the start and length of the rainy season, as well as the rainfall distribution over time strongly vary from year to year (Sivakumar, 1990). Consequently, rainfed agricultural production is highly variable and optimal timing of farm operations is very important. Based on their experience, farmers should adapt the periods for land preparation and sowing to the start of the rainy season, trying to avoid dry spells after the first rainfall events (Marteau et al., 2011; Wang et al., 2008). On the other hand, they can also not wait too long with land preparation to avoid drought periods at the end of the crop's growth period.

Approaches have been developed and crop models have been applied for optimizing sowing dates for maize in Burkina Faso

* Corresponding author. Tel.: +31 317 483078.
E-mail address: joost.wolf@wur.nl (J. Wolf).

http://dx.doi.org/10.1016/j.agrformet.2015.08.262
0168-1923/

(Waongo et al., 2014) and Nigeria (Kamara et al., 2009), and millet in Niger (Soler et al., 2008; Sultan et al., 2005). Also, analyses of dry spell occurrence after different sowing dates (Sivakumar, 1992) and evaluation of different methods to determine the onset of the growing season (Ati et al., 2002; Stern et al., 1981; Marteau et al., 2011) at different locations in West Africa have been performed. The implementation of such approaches could indicate the high risk periods for sowing and could help to attain higher yields and to reduce risk of severe yield reduction or complete crop failure due to drought stress at the beginning or end of the crop's growth period. Crop modelling studies have also been used to estimate climate change impacts on cropping systems and yields and yield variations over Africa (Challinor et al., 2007; Thornton et al., 2011) and at the global scale (Rosenzweig et al., 2014; Parry et al., 2004), and to assess the adaptive capacity of farming systems (e.g. through optimization of sowing dates) to future conditions. Challenges of such impact and adaptation studies were reviewed by Challinor et al. (2009).

Simulated yield levels of rainfed grain crops in semi-arid regions strongly depend on the sowing date (Soler et al., 2008; Kamara et al., 2009). For crop growth simulations of maize and sorghum in West Africa, often sowing dates were based on local expert knowledge of farmer's practices (e.g. the approach used in the Global yield gap atlas project, see http://www.yieldgap.org/web/guest/methods-overview) or on the generic crop calendar data from FAO (see http://www.fao.org/agriculture/seed/cropcalendar/welcome.do). Such approaches have some limitations, such as: (a) the same sowing date is used for each year independent of the inter-annual variation in rainfall pattern, (b) the same sowing date is used for short and long duration varieties, and (c) the compiled sowing dates for all region – crop combinations per country are rather subjective, as they are dependent on the local expert knowledge of farmer's practices. Particularly for large-scale modelling studies on, for example, yield potential and yield gaps of the main grain crops, food security and climate change impacts on yields and food production over Africa, good estimates of the mean sowing date per crop per region or climate zone are essential, but are not available with sufficient precision from the two approaches mentioned above.

The main objective of this study which is related to the type of modelling analyses mentioned in the previous paragraph, is to solve this sowing date-problem for large-scale studies. Therefore we tested methods for deriving optimal sowing dates that result in highest water-limited yields and lowest yield variation for the main grain crop-region combinations in Burkina Faso (as an example for the range of environmental conditions over West Africa). These methods are reproducible and objective, and reduce the dependence on local expert knowledge. We performed model analyses for different sowing dates and rules for both maize (*Zea mays L.*) and sorghum (*Sorghum bicolor* (*L.*)) at three locations in Burkina Faso with a strongly decreasing rainfall gradient from south to north.

2. Materials and methods

Yield levels for the two main grain crops in Burkina Faso, i.e. sorghum and maize, were modelled using management information per climate zone (Van Wart et al., 2013) and per crop variety. In the following sections we discuss in more detail how this information was obtained and to what purpose it was used.

2.1. WOFOST model and the simulated yields

We used WOFOST version 7.1.3 (release March 2011) to simulate the rainfed crop yields for maize and sorghum (Supit et al., 1994, 2012; Wolf et al., 2011; Boogaard et al., 2013; see for further information http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra/Facilities-Products/Software-and-models/WOFOST.htm). The basic processes simulated by WOFOST are phenological development, biomass growth, its partitioning over plant organs, and root growth, as determined by the defined crop's characteristics, and the soil water balance and its main components (e.g. influx from rainfall, soil evaporation and crop transpiration). The most important external drivers are daily weather data such as solar radiation, temperature, and rainfall. Yield estimates are established for water limited (i.e. rainfed) growing conditions, assuming optimal nutrient availability and optimal crop management. This means that crop growth is not hampered by nutrient shortage and yield losses due to pests and diseases do not occur. Consequently, the simulated water limited yields are much higher (3–4 times) than occur in reality. However, since the nutrient levels have a very limited effect on the quest for the optimal sowing dates to attain highest yields, these simulated water limited yields provide a useful indicator for the sowing date analysis.

Simulated crop emergence occurs after a certain temperature threshold in degree days is reached after sowing. Yield failures that occurred in our study, were mainly caused by drought stress, either during crop development directly after emergence or during grain filling.

2.2. Model calibration and input data

2.2.1. Model calibration

We used the standard crop parameter sets of WOFOST for maize and sorghum as compiled by Van Heemst (1988) and Boons-Prins et al. (1993) as base to start from. Next, we compiled data from literature and local experts concerning the crop characteristics for short and long duration maize and sorghum varieties commonly grown in Burkina Faso (Table 1). These characteristics can be considered representative for optimal (i.e. no water and no nutrient limitation and optimal crop management and protection) growing conditions in Burkina Faso. Table 2 presents the optimal crop calendars for both short- and long-duration sorghum and maize

Table 1
Main crop characteristics for grain maize and sorghum in Burkina Faso used to calibrate the WOFOST model parameters; these characteristics are representative for high-yield varieties growing under optimal conditions with respect to water and nutrient supply and optimal management.[a]

Crop, Zones in Burkina Faso	Period from emergence to maturity (days)	Period fractions from emergence to flowering and from flowering to maturity (%)	LAI-max ($m^2\ m^{-2}$)	Total biomass above-ground[b] (kg dry matter ha^{-1})	Yield[b] (kg dry matter ha^{-1})	Harvest index[c]
Grain maize, all zones	80–120	50% – 50%	3–7	10,000–20,000	5000–10,000	0.45–0.55
Sorghum, all zones	75–120	55% – 45%	3–7	8000–18,000	3200–7200	0.35–0.45

[a] Crop characteristics are based on crop data, expert knowledge and experimental information for Burkina Faso, as reported by Stoop (1987), Mando et al. (2005), Ouedraogo et al. (2007), Muleba (1999), Olaoye et al. (2009), and are based on experimental information from Ghana (i.e. Kpongor, 2007; Morris et al., 1999; Adjei-Nsiah, 2012; DTMaize bulletin, 2013 and MacCarthy et al., 2009) for total biomass production and crop yields.
[b] The growth duration may vary strongly between short- and long-duration varieties which causes the considerable variation in total amount of above-ground biomass and in yield.
[c] Yield/Total biomass above ground.