Field Crops Research 219 (2018) 1–13

Contents lists available at ScienceDirect

Field Crops Research

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

Exploring adaptations of groundnut cropping to prevailing climate variability and extremes in Limpopo Province, South Africa

Munir P. Hoffmann[a,*], Jude J.O. Odhiambo[b], Marian Koch[a], Kingsley K. Ayisi[c], Gang Zhao[d], Alejandra S. Soler[a], Reimund P. Rötter[a,e]

[a] University of Göttingen, Tropical Plant Production and Agrosystems Modelling (TROPAGS), Grisebachstraße 6, 37077 Göttingen, Germany
[b] Department of Soil Science, School of Agriculture, University of Venda, South Africa
[c] Risk and Vulnerability Science Center, University of Limpopo, South Africa
[d] INRES, University of Bonn, Katzenburgweg 5, Bonn 53115, Germany
[e] University of Göttingen, Center of Biodiversity and Sustainable Land Use (CBL), Büsgenweg 1, 37077 Göttingen, Germany

ARTICLE INFO

Keywords:
APSIM
Arachis hypogaea L.
Climatic variability
Drought
El Niño
Planting date

ABSTRACT

Adapting groundnut production to the high climatic variability and extremes prevailing in Limpopo (South Africa) requires season- and site-specific exploitation of genotype x environment x management interactions. Notably, the El Niño-Southern Oscillation phenomenon (ENSO) causes distinctive seasonal rainfall anomalies in the province: Weather records over the period 1955–2010, showed El Niño years with an average of 296 mm growing season rainfall, neutral years with 349 mm and La Niña with 434 mm. We hypothesized that (i) early planting date is crucial for ensuring high productivity of groundnut and (ii) early maturing cultivars can ensure satisfactory production even in El Niño years, both options aiming at escaping prolonged periods of drought. To evaluate our hypotheses, we conducted a three year on-station trial with three planting dates and two cultivars, a one year trial at two sites comparing the two cultivars, tested crop model APSIM against field trial data, and, finally, performed long-term gridded crop model simulation runs for all cultivated land (i.e. 14,739 grid cells at a resolution 0.01°) in Limpopo exploring the effect of the cultivars and planting dates on groundnut yield. Field trials showed that early planting was superior to later plantings, irrespective of the weather year. Even in the very dry El Niño year 2016, yields of more than 1000 kg/ha were achieved with early planting, while planting later was not possible due to severe soil water deficits. Cultivar ICGV 03796 performed slightly better than ICGV 99257 due to faster ground cover closure, but no difference in phenology was observed. After evaluation of the model against the field trial data was found satisfactory, APSIM simulations showed that highest yields were achieved in La Niña years (median 996 kg/ha across all grids) and smallest in El Niño years (654 kg/ha across all grids). However, as in the field trials, we observed on average over all grid cells higher grain yields for early planting for all weather years as effective rainfall captured was higher than for later plantings. Longer growth duration by cultivar ICGV 03796 appeared to be more productive than an earlier maturing cultivar that we added into the simulation analysis as a third cultivar. However, a closer look at the spatial pattern of the simulation analysis revealed that for the generally drier regions of Limpopo, this cultivar with shorter growth duration would indeed be more productive in El Niño years. It showed that such season-specific adaptation would increase yields only by 2.9% for Limpopo province in total, but yield gains of more than 10% could be obtained for 11.3% of the grid cells in El Niño years. Hence, this study demonstrated that management recommendations at provincial scale explicitly need to consider in more detail a site- and season-specific approach.

1. Introduction

Groundnut (*Arachis hypogaea* L.) has been an important cash crop for smallholder as well as for commercial farming systems in South Africa in the 1960ies and 70ies with average annual production of 300,000 tons (FAOSTAT, 2017). However, since then groundnut production declined to roughly 50,000 tons, in the 2010s. The lowest figure was reached in 2016 with an estimated production of 20,000 tons. This turned South Africa into an importer of 30,000–50,000 tons to fulfil the country's demand. While the high demand for labor and lack of improved genetic material are perceived as long-term reasons for the decline in production, in many parts of South Africa, and

* Corresponding author.
E-mail address: mhoffma@gwdg.de (M.P. Hoffmann).

https://doi.org/10.1016/j.fcr.2018.01.019
Received 10 September 2017; Received in revised form 15 January 2018; Accepted 17 January 2018

especially in Limpopo province, adaptation to climate variability is a major challenge for successful groundnut farming (Conway et al., 2015). In particular, the already high rainfall variability might even get exacerbated under climate change (Conway et al., 2015). The low production in 2016 was driven by the El Niño-Southern Oscillation (ENSO) phenomenon, which in certain years has caused severe dry spells in the region. Such climate extreme events, triggered by ENSO, can be predicted for the next season with a fairly high confidence for this region (Malherbe et al., 2014).

However, groundnut management needs to be well adapted to such variable conditions; i.e. it requires an efficient exploitation of season- and site-specific environment x management x genotype (G x M x E) interactions to revitalize growth in production. Keeping groundnut in crop rotations would have additional benefits apart from the production aspect, which are nitrogen fixation (and increased soil fertility), and diversification of the narrow range of crops found in the predominating maize-based systems of the region. Hence, these are some good reasons why agronomists currently focus on identification of promising legume genotypes and their management, fitting well to local soil and climate conditions (Farrow et al., 2016).

While carrying out field trials is a classic tool for agronomists to understand crop performance for a given environment, they are expensive and resource demanding. Thus, it is hardly possible to run such trials for several years and sites, which are required to develop season and site specific recommendations for a wide range of G x M x E. Process-based crop modelling has evolved as an additional option to identify production limitations and adapted cropping practices. For instance, Hoffmann et al. (2017) used the model APSIM (Agricultural Production System sIMulator) to demonstrate the benefits of zone and season specific fertilizer management in low rainfall south-east Australia by analyzing soil-weather-plant interactions. Models like APSIM simulate on a daily basis crop growth in dependence of available resources light, water, temperature and nitrogen (Holzworth et al., 2014). While this makes it data demanding (climate & soil) in terms of running, it enables it at the same time to investigate G x M x E interactions at a relatively detailed level, including in-season rainfall distribution, which is crucial for understanding growth patterns in the highly variable climate of Limpopo. Key requirement for crop model application is prior model evaluation for the region. This has been done for many crop models intensively for Europe, America, Asia and Australia (for instance: Holzworth et al., 2014; Jones et al., 2003), but there are few tested models for southern Africa. APSIM is an exception, having its roots in East Africa, but also used intensively in southern Africa (for an overview, see Whitbread et al., 2010). However, the usage of crop models cannot replace field trials. On the contrary, in recent years there is growing awareness, especially in the crop modelling community, that good field trials have become scarce, but are crucial to improve and test the models (Rötter et al., 2011). In addition, crop models are not well prepared yet to deal with all yield-constraining factors, which farmers face, notably the lack of capability to simulate pest and diseases. Having this in mind, we combined on-station field trials with crop modelling to test two management options across Limpopo, the most vulnerable province of South Africa in terms of climate variability and food security (Conway et al., 2015; De Cock et al., 2013). We hypothesized that (i) early planting date is crucial to ensure high productivity of groundnut and (ii) short-term cultivars ensure satisfying production even in El Niño years. Both options are based on the idea to escape prolonged periods of drought by earlier harvesting – and among the frequently proposed options as an adaptation strategy to terminal drought in Africa. However, MacCarthy et al. (2017) showed for northern Ghana a much more complex response to shifting planting date, indicating that this might not be the case in every region. Nevertheless, for southern Africa Shumba et al. (1992) showed that for maize one day delay in planting of maize in Harare region (Zimbabwe) during the period of 5-October to mid of December resulted in 1.35% lower yields. This is in line for other regions in southern Africa (MacColl, 1990). Similarly, sunflower yields have been shown to be reduced in South Africa due to late planting (Ma'ali, 2017). Consequently, also the recommendation for groundnut in South Africa is to plant early. Besides planting date, also cultivar choice is seen as an important adaptation to the local climate conditions. Makaudze (2014) found early maturing cultivars in maize beneficial in El Nino years in Zimbabwe. The information from these crops served as basis for developing our hypotheses.

To evaluate our hypotheses we went through the following steps: (i) we conducted a three year on-station trial with three planting dates and two cultivars, (ii) carried out a one year trial at two sites comparing the two cultivars, (iii) evaluated APSIM against the trial data, and finally (iv) performed long-term grid-based crop model simulation runs for all arable land in Limpopo investigating the performance of cultivars and the effect of planting date across the province. This combination of methods should build the basis for arriving at improved management recommendations to better adapt groundnut production to climate variability and extremes.

2. Material & methods

The study took place in the Limpopo province, South Africa. It borders Mozambique, Zimbabwe and Botswana. Overall climate conditions differ spatially in the province and ranges from warm-desert climate (BWh according to Koeppen classification) in the West, to warm-semi-arid (BSh) to humid subtropical climate (Cwa) in the East of the province (Engelbrecht and Engelbrecht, 2016). Rainy season occurs during summer (October–April) (see Supplement Fig. A–C). The winter period is characterized by extended dry spells. The average growing rainfall differs substantially in the province, from 320 mm growing season to more than 600 mm over the period 1955–2010 (Kalnay et al., 1996; Sheffield et al., 2006). In addition to the strong spatial variability, a strong difference between seasons exists in the region (Fig. 1), which is caused a.o. by ENSO (Moeletsi et al., 2011; Reason et al., 2005). The categorization of the years into El Niño, La Niña and neutral is usually based on the Oceanic Niño Index (ONI) (NOAA, 2017). Running 3-month mean ONI values for the months December, January, and February representing the core months of the cropping season were used in our case to capture the core period of the growing season. If value was above one, it was classified as El Niño, if below minus one as La Niña, and in-between as neutral years. This resulted for the period from 1955 to 2010 in eight El Niño years and seven La Niña years (see Supplement Fig. D). Indeed, rainfall during the growing season (October-to April) was different as expected; El Niño (296 mm), neutral years (349 mm), and La Niña (434 mm) when aggregated over the whole province.

Soil water holding capacity varies widely across the province from 20 to 140 mm, but remains overall low (Fig. 2). Limpopo is economically the least developed province of South Africa and has also a high share of smallholder farms in comparison to commercial farms (Schoeman et al., 2013).

2.1. Field trials

2.1.1. Time of planting x crop cultivar trials

The trials were carried out in the cropping seasons 2013/14, 2014/15 and 2015/16 at the experimental farm of the University of Venda (Univen) in Thohoyandou (Fig. 1). The soil is clay with a low soil organic carbon content of 0.4–0.7% in the top soil. The experiment was laid out using a randomised complete block design in factorial arrangement with three replicates: treatments were planting date (early, mid and late) and cultivar. In the first year, planting dates were 09/12/2013 (early), 15/01/2014 (mid) and 09/02/2014 (late), in the second year 02/12/2014 and 03/01/2015 and in the third year 5/12/2015 and 30/01/2016. For third planting date, sowing was not possible in the seasons 2014/15 and 2015/16 due to severe drought. Two cultivars