Journal of Agribusiness and Rural Development

IMPACT OF RAINFALL VARIABILITY ON MAIZE YIELD IN THE KWAZULU-NATAL, NORTH-WEST AND FREE STATE PROVINCES OF SOUTH AFRICA (1987–2017)

Phrasia Mapfumo[1✉], Clarietta Chagwiza[2], Michael Antwi[1]

[1]University of South Africa, South Africa
[2]University of Pretoria, South Africa

Abstract. Climate change has caused drought, increased temperatures and decreased crop yield in many places, including South Africa's North-West province. This study investigated the impact of rainfall variability on maize yield (1987–2017). The objectives were to investigate the impact of rainfall variability on maize yield for the Kwazulu-Natal, North-West, and Free State provinces of South Africa, as well as to assess the differences in the impact of rainfall variability on maize yield between the three provinces. Rainfall and maize yield data were obtained from South Africa Weather Services (SAWS) and the Department of Agriculture, Forestry, and Fisheries (DAFF), respectively. A Pearson Correlation Analysis revealed a weak negative correlation between rainfall and maize in the KwaZulu-Natal and Free State provinces. However, there was also a weak positive correlation between maize yield and rainfall in the North-West province. While rainfall determines yield, it becomes detrimental to yield if it is excessive. Rainfall variability negatively affected maize yield, rainfall exceeding maize's requirements was not beneficial to crop yield, and drought reduced yield as well. ANOVA results revealed that the group mean yield of the provinces was different, with KwaZulu-Natal having the highest mean yield. The impact of rainfall variability on maize varied between provinces; KwaZulu-Natal was the least affected while the North-West province was the most negatively affected due to droughts causing reduced maize yield.

Keywords: climate change, rainfall, mean maize yield, correlation, ANOVA, South Africa

INTRODUCTION

Climate change is evident and has been increasing over the past few years (Srivastava et al., 2018). Currently, it is not only a cause for concern for humanity, but it is also a threat to life on Earth due to the increasing frequency of droughts, increased temperatures and global warming (Hirich et al., 2016). It is a universal issue because it affects all countries in the world. Meteorological changes caused by climate change inevitably affect crops as well (Bazzaz and Sombroek, 1996). Climate change can affect food quality and compromise its availability and accessibility (Brown et al., 2013). The greenhouse effect caused by climate change results in an increased concentration of carbon dioxide in the atmosphere, which affects the growth rate of crops and other plants. Changes in carbon-dioxide concentration may alter rainfall, sunshine and temperature levels, which can impact crop and livestock production (Mahato, 2014). Climate change is bound to negatively impact maize yield in Southern Africa, reducing it by an average of 18 per cent (Zinyengere et al., 2013). A reduction in maize yield will aggravate food insecurity in the region as well.

As much as 70 per cent of Africans work in agriculture (African Agriculture Climate, 2002; Haggblade

✉Phrasia Mapfumo, University of South Africa, Science Campus, Florida 1709, e-mail: mapphrasia03@gmail.com; https://orcid.org/0000-0002-6429-5210

et al., 2002). About 80 per cent of rural people rely on agriculture to support themselves; those living in urban also rely on agriculture to raise their status (Haggblade et al., 2002). Even though agriculture is a vital sector for people of Africa, their production is rain-fed and sustenance-oriented (African Agriculture Climate, 2002). Very few farmers use irrigation for production purposes. Hence, any climate changes would severely harm crop production in this region.

The African continent is also experiencing a rise in temperatures and the data available indicates that temperatures have been increasing by 0.05°C per decade since the 20th century (United Nations Environmental Program, 2002). The rainfall patterns have been changing in southern Malawi, South Africa, Zimbabwe, western Mozambique, and Zambia both throughout the 20th century and in the 21st century; a trend of increased drought has been noticed as well (KNMI, 2006). By 2100, the extremely low rainfall conditions in Southern Africa will become 50 per cent more prevalent, as well as about 30 per cent more prevalent over the Kalahari desert (KNMI, 2006). Water harvesting systems should be put in place to improve water availability and crop yields alike.

Since the early 21st Century, Sub-Saharan Africa (SSA) has been unable to keep up with the pace of development of the rest of the world; this has resulted in 330 million people living in abject poverty. Most SSA countries' industries are under-developed, with others closing down – especially in Zimbabwe. This poses many challenges to the majority of these countries due to the climate change affecting their agriculture-based economies. Crop production is bound to decrease, leading to job loss due to the poor functioning of this sector. The livelihoods of more than 180 million people depend on agriculture, and as such, agriculture is a vital sector for these countries as well (IIASA, 2002).

Currently, South Africa`s agricultural production uses 50 per cent of the water resources available (Benhin, 2006), with only 672 822 ha being certified for irrigation in 2008 (Van Der Stoep and Tlyocoat, 2014). Today its agricultural industry is facing many challenges, including fluctuating rainfall, limited access to capital, infrastructure, markets and technology, land reform unpredictability, as well as HIV/AIDS and other negative factors (Adger, 2003). The one that limits agricultural production to the highest extent is water availability; South Africa's high-risk meteorological setting results in

an uneven and varying distribution of rainfall and other climate-related extremes (Johnston et al., 2012). Since the majority of South Africa's arable land is rain-fed, the livelihood of people who practise rain-fed agriculture will be at risk and the number of people facing hunger and malnourishment may rise due to the predicted increasing weather fluctuations caused by climate change (Johnston et al., 2012).

In South Africa, maize is both a vital animal feed and staple food, as well as an export product, with an average of 25 per cent being exported to the neighbouring countries (Greyling and Pardey, 2019). South Africa is the breadbasket of the Southern Africa region, with maize being produced by commercial and non-commercial farmers alike, including the non-commercial farmers from the northern Kwazulu-Natal, Mpumalanga, Eastern Cape and Limpopo provinces (DAFF, 2016). However, it is necessary to quickly find ways of improving South Africa's maize yield to effectively support the needs of both its own population, as well as its neighbouring countries whenever such a need arises.

Maize is the chief staple food for people of Southern Africa and the Republic of South Africa produces 50 per cent of the region's total maize output (Akpalu et al., 2008). South Africa produces 3.8 t/ha while Zambia produces 2.1t/ha (MAMID, 2015). Approximately 70 per cent of grains produced in South Africa are maize and 60 per cent of its cropping area is devoted to maize alone. Free State, North-West, and Mpumalanga provinces produce maize commercially, accounting for 72 per cent of the country's total maize production (Nortje, 2017). Maize contributes 47 per cent of the total field crop value, with other contributors being sugarcane (13.2 per cent), wheat (9.7 per cent), as well as soya beans and hay, which contribute 7.4 per cent (DAFF, 2016). In 2015/16, the gross value of maize was R 26,506 million (DAFF, 2017). These figures show the economic importance of maize in South Africa. Hence, the relationship between maize yield and climate change in South Africa`s three major maize producing regions warrants attention. The objectives of this study were two-fold: i) to investigate the impact of rainfall variability on maize yield in South Africa's KwaZulu-Natal, Free State and the North-West provinces in the 1987–2017 period; and ii) to assess the difference in the impact of rainfall variability on maize yield between the KwaZulu-Natal, Free State and North-West provinces in South Africa in the 1987–2017 period.

MATERIALS AND METHODS

Study area

This study was carried out in three provinces of the Republic of South Africa, i.e. KwaZulu-Natal, North-West and Free State. The average rainfall in the KwaZulu-Natal province ranges between 600 mm and 2,000 mm. Agriculture is socially and economically significant for the province (Ngcobo and Dladla, 2002). The average annual rainfall in the North-West province is 539 mm. The North-West province produces the highest volume of cereals, contributing 34.19 per cent to the nation's maize production (Masigo and Matshego, 2002). Lastly, the average rainfall in the Free State province is 600 to 750 mm in the case of its eastern areas, however, it drops to 250 mm in the south-western ones. The province produces up to 33 per cent of South Africa's maize and 45 per cent of its wheat (Maphalla and Salman, 2002). The three provinces were selected because they produce the highest volumes of maize in the Republic of South Africa. This study's findings may help enhance maize productivity in both these and other maize-producing provinces, which receive either more or less annual rainfall or prepare mitigation and adaption plans to address the impact of climate change on maize production.

Data sources and analysis

Climate data

The data used for this study included archival data on rainfall (in millimetres) and maize yield (in tonnes). The data on annual maize yield (t) for a period of 31 years (1987–2017) was obtained from DAFF. The mean yield was derived by dividing the total yield for each year by the land area cultivated. The total cropping area for both white and yellow maize and the total yield for the 1987–2017 period were provided as well. The cultivar planted was not considered.

Climate data (rainfall) for a period of 31 years (1987–2017) was obtained from South Africa Weather Services (SAWS). Choosing such a period is in line with the convention of using 30 years' weather data in characterising an area's climate, as adopted by the World Meteorological Organisation. The climate variable selected for this study was rainfall. This is because it is the one variable in the case of which farmers can find ways to optimise the cultivation process to produce optimal yield.

After its collection, the data was cleaned and synthesized and descriptive statistics were prepared. A Pearson correlation analysis was used to correlate rainfall with maize yield. Annual rainfall was chosen as the independent climate variable to determine the impact of rainfall variability on maize yield. The Pearson correlation analysis was used to determine the correlation strength between average annual rainfall and average maize yield. Both were computed and run in the Pearson Correlation Analysis.

To determine the differences in the impact of rainfall variability on yield between the three provinces, ANOVA was used to analyse the mean maize yield data. The average maize yield was computed and run in a weighted one-way ANOVA to determine the difference in the impact of climate change on the mean maize yield between the KwaZulu-Natal, North-West, and Free State provinces in the 1987–2017 period. The null hypothesis was that the mean maize yield in the KwaZulu-Natal, North-West, and Free State provinces was not the same (1987–2017). However, the alternative hypothesis stated that the mean yield was the same across all three provinces.

RESULTS

This section presents the study findings. The impact of rainfall variability on maize yield is reported for all three provinces, followed by an assessment of the differences between the impact of climate change on maize yield in the KwaZulu-Natal, Free State, and North-West provinces.

The impact of climate change (rainfall) on maize yield

The first objective of the study was to investigate the impact of climate change on maize yield in the KwaZulu-Natal, North-West, and Free State provinces of the Republic of South Africa (1987–2017). Since South Africa had four provinces before 1986, the 1980-1986 period was excluded from the study. The three provinces produce both yellow and white maize, hence the results were reported for both maize varieties. The strength of the relationship between rainfall and maize yield was analyzed using Pearson's correlation analysis for both yellow and white maize. Table 1 shows the results.

Table 1 above shows the results of the Pearson correlation analysis, which revealed a weak negative correlation between maize yield and rainfall for white and yellow maize in the KwaZulu-Natal and Free State provinces. There was a weak positive correlation between

Table 1. Result of the rainfall – maize yield correlation analysis

Province	R	r^2	P-value
		White maize	
KwaZulu-Natal	−0.1522	0.0232	0.2067
North-West	0.2458	0.0604	0.0906
Free State	−0.0643	0.0041	0.3644
N	31		
		Yellow maize	
KwaZulu-Natal	−0.1999	0.0400	0.1402
North-West	0.2045	0.0418	0.1339
Free State	−0.2748	0.0755	0.0672
N	31		

Source: own computation using research data.

Table 2. Results of the ANOVA analysis of the mean maize yield

Variable	Free State province	KwaZulu-Natal province	North-West province
White maize mean yield	3.25*	4.59*	2.56**
Yellow maize mean yield	3.12*	4.56*	2.60

*Significance at $p < 0.01$; **significance at $p < 0.05$ (if using Tukey's comparison test).
Source: own computations using research data.

maize yield and rainfall in the case of the North-West province. The r^2 determination coefficient for white maize was 2.32, 6.04, and 0.41 per cent of rainfall of the total variance influencing maize yield in the past 31 years in the KwaZulu-Natal, North-West, and Free State provinces, respectively. This means that the remaining 97.68, 93.06, and 99.59 per cent of the white maize yield variations could be attributed to other factors. In the case of yellow maize, there was a weak negative correlation between maize yield and rainfall in the KwaZulu-Natal and Free State provinces and a weak positive correlation between maize yield and rainfall in the North-West province. The r^2 determination coefficient for yellow maize was 4, 4.18, and 7.55 per cent of rainfall of the total variance influencing maize yield in the past 31 years in the KwaZulu-Natal, North-West, and Free State provinces, respectively. The remaining 96, 93.82, and 92.45 per cent of the yellow maize yield variations could be attributed to other factors.

Assessing differences in the impact of climate change in mean maize yield between the provinces

The second objective of the study to assess the differences in the impact of climate change on maize yield in the KwaZulu-Natal province, Free State province, and North-West provinces of the Republic of South Africa in the 1987–2017 period. To do this, the average maize yield data per province were analysed using a one-way weighted ANOVA for independent samples. There were two categories of maize, i.e. the white and yellow maize grown in all provinces. As such, the analysis was performed separately for both white and yellow maize. Table 2 shows the inferential statistics.

The Free State province had a significantly different mean yield of both white and yellow maize with $p < 0.01$, 3.25 t, and 3.12 t, respectively. The KwaZulu-Natal province had a significantly different mean yield of both white and yellow maize with $p < 0.01$, 4.69 t, and 4.56 t, respectively. The North-West province's mean yield of white maize was significantly different with $p < 0.05$ (2.56 t). However, the mean yield of yellow maize in the North-West province was insignificantly different (2.60 t).

DISCUSSION

The main purpose of the study was to investigate the impact of climate change on maize output in the KwaZulu-Natal, North-West, and Free State provinces of South Africa (1987–2017). An additional objective was to assess the difference in the impact of climate change on maize yield in the KwaZulu-Natal, North-West, and Free State provinces of the Republic of South Africa in the 1987–2017 period. As such, the discussion of the findings is primarily focused on these two aspects.

Correlation between average maize yield and average annual rainfall (mm)

The results for the KwaZulu-Natal and Free State provinces revealed a weak negative correlation between average maize yield and average annual rainfall for both yellow and white maize. It translates into an increase

in rainfall showing a corresponding decrease in maize output (Table 1). This was different than in the case of the North-West province, where the correlation between maize output and annual rainfall was positive but weak, and an increase in rainfall resulted in a corresponding increase in maize yield for both yellow and white maize (Table 1).

The correlations between maize yield and average annual rainfall were insignificant, at $p < 0.05$, for all provinces. The lack of significance shows that while notable correlations exist between rainfall and maize output, it is impossible to state with certainty whether the differences are real. The results reveal a contrasting perspective on the findings of studies by Adamgbe and Ujoh (2013) and Omoyo et al. (2015). Nonetheless, the results are in line with those in other studies. There is a slowly decreasing water efficiency trend as the cyclic rainfall quantity rises (HarvestChoice, 2010). Crop water use efficiency is a simple way of approximating the crop's water use by dividing the crop output by the quantity of water used (crop per dribble) (HarvestChoice, 2010). In the case of this study, it was prominently evident in 1987 when KwaZulu-Natal received an annual rainfall of 1465.1 mm but maize yield was only around 3 tonnes. As rainfall increased, maize yield decreased. The decrease of maize yield when the rainfall received exceeds the optimal volume required could be attributed to the soil becoming waterlogged, as well as the leaching of nutrients.

A maize plant needs 450–600 mm of water per growing season, which is mostly soil moisture reserve. Any amount above that can lead to a lower yield per hectare if the crop is not well managed. A farm's total output is determined by the soil and weather conditions, which may be considered the farm's yield possibility. Approximately 10–16 kg of grain is produced for every millimetre of water used (Du Plessis, 2003). The results showed poor water productivity in KwaZulu-Natal and Free State, which can be attributed to the lack of such materials as fertiliser, as well as pests, diseases and the use of cheap or untreated maize seeds. Nutrient leaching occurs whenever there is increased rainfall; for maximum yield, split fertiliser application is recommended to ensure that crops have all the required nutrients throughout all growth stages. It is also important to note that yield is dependent on the cultivar, including its adaptability and yield potential.

Plants exhibit increased sensitivity to moisture stress in some growth stages, which can affect maize yield regardless of how much more rainfall is received per annum. The degree of sensitivity to water shortage varies based on the specific crop growth stages; low water accessibility during a critical stage can have a higher impact on yield than other factors (HarvestChoice, 2010). Maize plants are extremely sensitive to water shortage during a particular, critical time, i.e. between anthesis and the start of the grain-filling stage (Bergamaschi et al., 2004; Bergonci et al., 2001). Their highest water requirements occur during another critical period – when the leaf area index is at maximum integrates with the maximal demand for evaporation (Bergamaschi et al., 2001; Radin et al., 2003). Maize is sensitive to water shortage during these critical times because of high evapotranspiration and great physiological stress, which determines the major output elements such as the number of ears on a plant and the number of kernels on them. Maize plants are also highly sensitive to water shortage during the time between anthesis and the start of the grain-filling stage. Just a month of inadequate rainfall during the tasseling stage can lead to a severe decline in maize output (Ojo, 2000).

After 1987, the KwaZulu-Natal province never received rainfall exceeding 1400 mm per annum, but the yield improved nonetheless. This could be attributed to better cultivars and improved crop management practices. Insect-resistant maize was first grown in the Republic of South Africa in 1998 and the statistics for 2012/2013 revealed that 86 per cent of maize grown in South Africa was genetically-modified (GM) maize (SAASTA, 2014). Maize yield is also affected by pests and diseases, which were not considered in this study. While the yield improved when the GM maize was introduced and adopted, it was not to an extent that would create a positive correlation between maize yield and annual rainfall in KwaZulu-Natal and Free State.

Rainfall availability is one of the major critical aspects affecting crop productivity in rain-fed agriculture. Rainfall variability between one season and another significantly affects the volume of soil water available to crops (Jat et al., 2016). This means that if the previous season's rainfall lasted longer than usual, it is likely that the soil water content will be at a better level and reaching one suitable for the seeds to germinate will only take a little bit of rainfall. Thus, the growing season will resume early. However, since most farmers do not have

the technology to test the soil water content, they either plant their crops too early or too late, leading to crop failure. Rainfall has three significant characteristics, i.e. quantity, prevalence, and severity, which differ depending on the place, day, month and year (Jat et al., 2016). Hence, rainfall amount is not the only factor that affects maize crop yield, and as such, the results for the KwaZulu-Natal and Free State provinces showed a weak negative correlation. Too much rainfall (intensity) at a given point in time will lead to excessive water saturation of the soil, and consequently, waterlogging that causes plant lodging. Rain frequency also affects maize yield; it is not beneficial unless it is evenly distributed throughout the maize's lifespan. Additionally, it leads to a negative correlation between maize output and rainfall quantity because it is not beneficial unless it is available during the critical stages of the maize's life, effectively leading to low output. The knowledge of rainfall characteristics is essential for planning the use of rainfall in crop production (Omoyo et al., 2015).

Expecting stronger correlations between maize output and rainfall volume in dry seasons rather than in rainy ones is prudent. This explains the positive correlation between average annual rainfall and average maize output/ha in the North-West province despite weak rainfall. Unlike sugarcane, maize does not require a lot of rainfall. If distributed evenly throughout maize's life, a rainfall amount of 450–600 mm results in better yields, provided that all other factors remain the same. The average maize yield in the KwaZulu-Natal and Free State provinces was affected by too much rainfall – as rainfall increased, the yield decreased. Variations in the annual rainy days and annual rainfall amounts account for most of the annual maize yield variations (Adamgbe and Ujoh, 2013; Paul and Oluwasina, 2011). The rainfall variability between seasons affects the type of cultivars that farmers have to plant, hence the reason for low yield or the negative association between the average maize output and the average annual amount of rainfall in the two provinces. Farmers may plant medium maturity maize cultivars but receive more rainfall that would be better suited for long- or late-maturing ones, which may cause maize cobs to rot while the plants are still in the field. Conversely, farmers may plant late-maturing varieties, expecting more rainfall like in the previous season, only to get rainfall that is insufficient to support the crops through all their growth stages, effectively leading to low yield.

In 1987, KwaZulu-Natal had an extreme climate event where it received a record-high volume of rainfall – amounting to 1,400 mm – however, the maize yield was too low (negative correlation). Flooding at an early vegetative stage (36 days after planting) results in lower plant canopy height, as well as a decreased production of dry matter and lower grain yield (Mukhtar et al., 1990). Climate change also brings about extreme events like drought and flooding, both of which have a similar effect on maize yield. The agricultural constraints caused by climate change range from the pronounced seasonality of rainfall to severe and recurrent droughts (Omoyo et al., 2015). All three provinces experienced droughts in 1992, 1995, 2005 and 2015. A significant decrease in rainfall results in undesirably low yields (Lal, 1973). Reduced yield made maize scarce and expensive. These droughts also affected other countries in Southern Africa; people had to eat yellow maize and sorghum as their staple food – white maize – was unavailable.

Mean maize yield variability in the KwaZulu-Natal, Free State and North-West provinces of South Africa

The second objective of this study was to examine the differences in the impact of climate change on maize yield in the KwaZulu-Natal, Free State and North-West provinces of the Republic of South Africa in the 1987–2017 period. The null hypothesis was that the mean maize yield was the same for all the provinces while the alternative hypothesis was that the mean maize yield was not the same for all groups. Since the farmers cultivated two types of maize, the yield of both yellow and white maize for both groups was considered. Table 2 shows the results of a one-way ANOVA analysis for both white and yellow maize for the three provinces (1987–2017). The results for yellow maize showed that the mean maize yield was significantly different in the Free State and KwaZulu-Natal provinces, with a p-value < 0.01. As for the significance, the results for white maize were the same as for yellow maize, however, the mean yield was different in the Free State and KwaZulu-Natal provinces, with a p-value < 0.01. Yet, the mean yield in the North-West province was significantly different with a $p < 0.05$. The null hypothesis, which stated that the mean maize yield was the same for all provinces, was rejected and the alternative hypothesis – that the mean maize yield was not the same for all groups – was accepted.

Climate change influenced the three provinces differently – the amount of rainfall in the KwaZulu-Natal province was higher than in the other provinces. The North-West province was more prone to drought and received less rainfall. In 1987, KwaZulu-Natal received 1465.1 mm of rainfall; however, maize yield was 3.04 t. Receiving excessive rainfall that is not useful for maize crops is a negative consequence of climate change. In 1992, North-West had the lowest yield of just 0.37 tons due to drought. The KwaZulu-Natal and Free State provinces also suffered drought but it did not affect maize yield to such an extent as in North-West. Rainfall exceeding 500 mm seemed not to increase maize yield.

About 500 mm of rainfall throughout the crops' developmental stages resulted in a yield of around 1.5 tonnes/ha in Ethiopia's East Shewa whilst that in South Africa's Kroonstad was about 10 tonnes/ha (HarvestChoice, 2010). This shows that even if the three provinces received the same amount of rainfall, their average maize yield would not be the same since other factors like soil characteristics, temperature and crop management systems were different. The type of cultivars grown also determines the yield per hectare. In this study, the three provinces received different amounts of rainfall; the KwaZulu-Natal province received the highest amount of rainfall compared to the North-West and the Free State provinces. KwaZulu-Natal also had the highest maize mean yield per hectare. Farmers who cultivated their crops using conservation farming methods had a reasonably higher output compared to their colleagues who cultivated their crops using conventional farming methods (Martinsen et al., 2014). Depending on the farming and cropping system utilised, their yield may differ even with the same amount of rainfall received. Maize yield potential depends on the variety, expected rainfall and crop management practices.

CONCLUSIONS AND POLICY RECOMMENDATIONS

The study has shown that rainfall variability does not significantly influence maize yield on its own. This was confirmed by the negative correlations between maize yield and annual rainfall. KwaZulu-Natal received a considerably high rainfall amount; however, maize yield did not positively correlate with the rainfall received. Therefore, it is important to note that while rainfall is crucial for crop growth, development and yield,

other factors like pests, diseases and temperature affect maize yield as well. These other factors need to be considered to determine how climate change affects maize yield. Rainfall variability affected maize yield in the Free State, KwaZulu-Natal and North-West provinces. Since KwaZulu-Natal recorded the highest mean yield for both yellow and white maize, it had a smaller impact on maize yield in this province. On the other hand, the North-West province was severely affected by rainfall variability, leading to reduced maize yield.

Based on the results of this study, several recommendations have been proposed. Farmers should be educated on how to produce maize effectively in their provinces based on the amount of rainfall received through extension and advisory services supported by the government. The use of drought-tolerant and early-maturing maize cultivars is recommended in the case of the North-West province. While the government should intensify general irrigation efforts, it should focus primarily on investing in drip irrigation, which is a water-efficient irrigation system that can be used in any terrain. Using conservation agriculture (CA) is highly encouraged for all three provinces, however, the CA practices adopted are bound to vary based on the amount of rainfall received by the given province. The extension and advisory services ought to disseminate weather information on time to improve their decision-making process on planting dates. Plant breeders are encouraged to develop maize germplasm that would provide high yield in the rainfall pattern conditions of the given province.

ACKNOWLEDGEMENTS

REFERENCES

Adamgbe, E.M., Ujoh, F. (2013). Effect of variability in rainfall characteristics on maize yield in Gboko, Nigeria. J. Env. Prot., 4(9), 881–887.

Adger, W.N. (2003). Social aspects of adaptive capacity. In: Huq, S., Klein, R.J.T., Smith, J.B. (ed.), Climate change, adaptive capacity and development (pp. 29–49). London: Imperial College Press.

African Agriculture Climate (2002). Climate Change and Agriculture in Africa. Retrieved from: http://www.ceepa. co.za/Climate_Change

Akpalu, W., Hassan, R.M., Ringler, C. (2008). Climate variability and maize yield in South Africa. Environment and Production Technology Division. IFPRI Paper, 843.

Bazzaz, F.A., Sombroek, W.G. (1996). Global climate change and agricultural production: direct and indirect effects of changing hydrological, pedological, and plant physiological processes. Food & Agriculture Org.

Benhin, J.K. (2006). Climate change and South African agriculture: Impacts and adaptation options. CEEPA Discussion Paper, 21.

Bergamaschi, H., Dalmago, G., Bergonci, J., Bianchi, C., Muller, A., Comiran, F., Heckler, B. (2004). Water supply in the critical period of maize and the grain production. Pesq. Agropec. Bras., 39(9), 831–839.

Bergamaschi, H., Radin, B., Rosa, L. M. G., Bergonci, J. I., Aragonés, R., Santos, A.O., França, S., Langensiepen, M. (2001). Estimating maize water requirements using agrometeorological data. Rev. Arg. Agromet., 1(1), 23-27.

Bergonci, J.I. (2001). Irrigation efficiency on grain yield and dry matter of maize crop. Pesq. Agro. Brasil., 36(7), 949–956.

Bergonci, J.I., Bergamaschi, H., Santos, A.O., França, S., Radin, B. (2001). Eficiência da irrigação em rendimento de grãos e matéria seca de milho. Pesq. Agro. Brasil., 36(7), 949–956. Retrieved from: https://doi.org/10.1590/S0100-204X2001000700004

Brown, C.J., Saunders, M.I., Possingham, H.P., Richardson, A.J. (2013). Managing for interactions between local and global stressors of ecosystems. PloS one, 8(6), e65765.

DAFF (2016). Trends in the Agricultural Sector Retrieved from: www.media.senwes.co.za.

DAFF (2017). Trends in the Agricultural Sector. Retrieved from: www.media.senwes.co.za

Du Plessis, J. (2003). Maize production. Department of Agriculture Fisheries and Forestry. Republic of South Africa.

Greyling, J.C., Pardey, P.G. (2019). Measuring Maize in South Africa: the shifting structure of production during the Twentieth Century, 1904–2015. Agrekon, 58(1), 21–41.

Haggblade, S., Hazell, P.B., Reardon, T. (2002). Strategies for stimulating poverty-alleviating growth in the rural nonfarm economy in developing countries. EPTD DISCUSSION PAPER, 92. Retrieved from: https://www.ifpri.org/publication/strategies-stimulating-poverty-alleviating-growth-rural-nonfarm-economy-developing

HarvestChoice (2010). Assessing the Impact of Rainfall Variability on Maize Yield Potential in Sub-Saharan Africa.

Hirich, A., Fatnassi, H., Ragab, R., Choukr-Allah, R. (2016). Prediction of climate change impact on corn grown in the south of Morocco using the Saltmed model. Irrig. Drain., 65(1), 9–18.

IIASA (International Institute for Applied Systems Analysis). (2002). Climate change puts Agriculture at great risk. Press Release on Climate Change and Agricultural Vulnerability. Media Briefing, Press Conference Room, Press Center, Sandton Convention Centre, WSSD Johannesburg.

Jat, M.L., Dagar, J.C., Sapkota, T.B., Yadvinder-Singh, Govaerts, B., Ridaura, S.L., Saharawat, Y.S., Sharma, R.K., Tetarwal, J.P., Jat, R.K., Hobbs, H., Stirling, C. (2016). Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. Adv. Agron., 137, 127–235.

Johnston et al. (2012). Modelling impacts of climate change on selected South African crop farming systems. WRC Report No' 1882/1/16. Retrieved from: www.wrc.org.za

KNMI (Koninklijk Nederlands Meteorologisch Instituut). (2006). Changes in extreme weather in Africa under global warming. Design and Production Studies.

Lal, R. (1973). Effects of seed bed preparation and time of planting on maize (Zea mays) in Western Nigeria. Exp. Agr., 9(4), 303–313.

Mahato, A. (2014). Climate change and its impact on agriculture. Int. J. Sci. Res. Pub., 4(4), 1–6.

Maphalla, L.T., Salman, M.V. (2002). Provincial report on Education and Training for Agriculture and Rural Development. Free State Province. Retrieved from: www.nda.agric.za

Martinsen, V., Mulder, J., Shitumbanuma, V., Sparrevik, M., Børresen, T., Cornelissen, G. (2014). Farmer-led maize biochar trials: Effect on crop yield and soil nutrients under conservation farming. J. Plant Nutr. Soil Sci., 177(5), 681–695.

Masigo, A., Matshego, C. (2002). Provincial report on Education and Training for Agriculture and Rural Development in North West Province. Department of Agriculture. Retrieved from: www.nda.agric.za

MAMID (Ministry of Agriculture Mechanization and Irrigation Development). (2015). Crop and Livestock Report, Zimbabwe.

Mukhtar, S., Baker, J., Kanwar, R. (1990). Corn growth as affected by excess soil water. Trans. ASAE, 33(2), 437–442.

Ngcobo, H., Dladla, B. (2002). Provincial report on Education and Training for Agriculture and Rural Development in KwaZulu-Natal Province. Kwazulu-Natal Department of Agriculture. Retrieved from: www.nda.agric.za

Nortje, J. (2017). Quality overview of imported and local maize. GrainSA. Retrieved from: www.grainsa.co.za/qualityoverview-of-imported-and-local-maize

Ojo, S. (2000). Factor Productivity in Maize Production in Ondo-State, Nigeria. Appl. Tropic. Agric., 15(1), 57–63.

Nyandiko, N.O., Wakhungu, J., Otengi, S. (2015). Effects of climate variability on maize yield in the arid and semi arid lands of lower Eastern Kenya. Agric. Food Sec., 4(1).

Paul, I.I., Oluwasina, O. (2011). Rainfall characteristics and maize yield in Kwara State, Nigeria. Ind. J. Fund. Appl. Life Sci., 1(3), 60–65.

Radin, B., Bergamaschi, H., Santos, A.O., Bergonci, J.I., França, S. (2003). Evapotranspiração da cultura do milho em função da demanda evaporativa atmosférica e do crescimento das plantas [Evapotranspiration of corn crop as a function of atmospheric evaporative demand and plant growth]. Pesq. Agr. Gaucha, 9(1/2), 7–16.

SAASTA (2014). Public understanding of Biotechnology.

Srivastava, A.K., Mboh, C.M., Zhao, G., Gaiser, T., Ewert, F. (2018). Climate change impact under alternate realizations of climate scenarios on maize yield and biomass in Ghana. Agric. Sys., 159, 157–174.

United Nations Environmental Program (2002). Vital Climate Graphics Africa. Evidence of Climate Change and adverse impacts in Africa.

Van Der Stoep, Tlyocoat (2014). South African Irrigation Statistics – An analysis of the 2014 Registration Management (WARMS). Data Presentation during the SANCID 2014 Symposium, GlenburneLodge.Muldersdrift. In: Inter-Agency Assessments, Rome: FAO.

Zinyengere, N., Crespo, O., Hachigonta, S. (2013). Crop response to climate change in southern Africa: A comprehensive review. Glob. Planet. Change, 111, 118–126.