1    *Type of the Paper (Article)*

2    **Effect of rainfall variability on the maize varieties grown in a changing climate:**
3    **a case of smallholder farming in Hwedza, Zimbabwe**

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10

11    **Abstract:** Rain-fed maize production has significantly declined in Zimbabwe especially in semi-arid
12    and arid areas causing food insecurity. Erratic rainfall received associated with mid-season dry spells
13    largely contribute to low and variable maize yields. This study involved a survey of current farmers'
14    cropping practices, analyses of climatic data (daily rainfall and daily minimum and maximum
15    temperature) of Hwedza station and simulation of maize yield response to climate change using
16    DSSAT CERES crop growth simulation model. The climatic and maize yield data was analysed using
17    mean correlation and regression analyses to establish relationships between rainfall characteristics
18    and maize yield in the study area. Survey results showed that maize was the staple food grown by
19    100% of the farming households while 8.7% also grew sorghum. The survey concludes that 56.2% of
20    the farmers grew short season varieties, 40.2% medium season varieties and 3.6% long season
21    varieties. The result of the correlation analysis of climatic data and maize yield showed that number
22    of rain days had strong positive relationship (r = 0.7) with maize yield. Non-significant yield
23    differences (p > 0.05) between maize cultivar and planting date criteria were obtained. Highest yields
24    were obtained under the combination of medium season maize cultivar and the DEPTH criterion in
25    all simulations. The range of simulated district average yields of 0.4 t/ha to 1.8 t/ha formed the basis
26    for the development of an operational decision support tool (cropping calendar).

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29     KEYWORDS
30    Crop Modelling, DSSAT, Climate variability, Survey, Maize, Crop guidelines/Cropping calendar

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## 1.0 Introduction

In Zimbabwe, agriculture is one of the key sectors of the economy (Matutu, 2014), with an estimated 80% of the population directly dependent on agriculture. Over 65% of farmers practice rain-fed farming for their livelihood (Johnson and Chivandi, 2010; Mapfumo, 2013).Agriculture sector contributes 20.1% to the gross domestic product (GDP)(Crop, 2013). It is apparent that an agricultural production crisis is developing in Zimbabwe due to a steep decline in agricultural production(Mapfumo, 2013). This conclusion is based on declining income derived from agriculture as compared with non-agricultural sectors and the fact that the growth rate of agriculture has deteriorated relative to the population growth rate. In addition the status of the country as, "the food basket of the Sothern Development Community (SADC)" is gradually dwindling largely due to several factors and amongst them are climate related factors. Zimbabwe's climate is changing with the rate of change seemingly faster than what is normally expected(Asseng, 2015; Geerts and Raes, 2012; Hertel and Lantz C. Baldos, 2016; Sithole and Murewi, 2009). As a result, the climate of Zimbabwe is now characterized by many extreme events such as severe storms, floods and droughts, strong winds, hail, frost and heat waves (Sithole and Murewi, 2009; Zinyengere et al., 2014).

Low agriculture production in Zimbabwe may be attributed to several factors such as market forces that are disincentives, lack of irrigation facilities, inability of the farmers to access inputs in time, conservative attitudes towards extension services, field operations, timing of planting, and superimposed on these is the lack of use of adequate climate information (Conway et al., 2008). Climate change and variability have become topical issues in recent time because of their largely detrimental impacts on natural and human systems(Mugalavai et al., 2008; Phillips et al., 1998). The most frequently cited activities or operations likely to be affected by climate change are agriculture, forestry, hydrology and fisheries especially in semi-arid regions (Laura, 2017).Within the agriculture sector, an extreme event like drought is arguably the most important climatic challenge and has major impacts on rain-fed cereal yields (Chimonyo et al., 2016; Kosgei, 2009; Mabhaudhi et al., 2018; Mendelsohn, 2008).

Use of agro-climatic information can improve rain-fed production but there is a general lack of readily available useable information accessible to farmers to achieve this (Keating et al., 2003; Mhizha et al., 2014). In agriculture, decision support tools for making choices such as crop variety selection, planting dates and timing of fertilizer application can contribute to increased yields under rain-fed conditions (Geerts and Raes, 2012; Hsiao et al., 2009; Vanuytrecht et al., 2014). However these decision support guidelines for rain-fed farming systems are not available to resource-poor farming communities such as subsistence farmers in Zimbabwe(Mhizha et al., 2014; Mupangwa et al., 2011; Raes et al., 2004; Zinyengere et al., 2014). Optimum management practices, such as planting criteria and cultivar selection can be accessed through validated models such as DSSAT for making seasonal or within-season decisions (Pickering, 1996; Vanuytrecht et al., 2014).One tool which can fill this gap is a crop calendar. A crop calendar is a tool that provides timely climate related information about crops and varieties to promote local crop production. It contains information on planting dates, sowing and harvesting periods of locally adapted crops in specific agro-ecological zones (Mendelsohn et al., 2006).

85    Previous attempts to study effects of rainfall on crop yield in Zimbabwe (Alumira and Rusike, 2014;
86    Crop et al., 2012a; Mhizha, 2010; Mhizha et al., 2014; Mupangwa et al., 2011; Raes et al., 2004;
87    Zinyengere et al., 2011) were based on some rainfall characteristics such as dates of onset and end of
88    rainy season, and temperature. Though these studies were comprehensive, farmers' practices and
89    important rainfall characteristics, like rain days that are also vital to crops were not considered. It is
90    against this backdrop that this study focuses on examining the length of growing seasons and
91    matching them with crop growth cycles in Hwedza district of Zimbabwe. Planting windows, best
92    planting combination and variety selection were developed into a maize crop calendar that will guide
93    farmers on planting dates, dry spell probability during critical stages of the crop growth cycle and
94    rainfall cessation. In addition, current common farmers' practices were investigated through a
95    sampling survey. Historical climate was characterized from observed daily temperature and rainfall
96    data and a crop growth simulation model DSSAT (Decision Support System for Agro-technology
97    Transfer) version 4.5 was used to explore implications of observed changes in daily rainfall records
98    on district maize average yield.
99
100   **2.0 Materials and Methods**
101   **2.1 The study area**
102   The study was carried out in Hwedza district of Zimbabwe, (Figure 1). The geographic position for
103   Hwedza climate station is: latitude -18°, longitude 31° and altitude 1 425 m. The average total annual
104   rainfall for Hwedza is 807 mm. The rainy season starts in November and tails off in April. Ther is
105   wide spatial and temporal variation in rainfall. The mean annual temperature ranges from 18-19 °C
106   at about 1400 m above sea level. Maximum temperatures are low in the winter months (June-July)
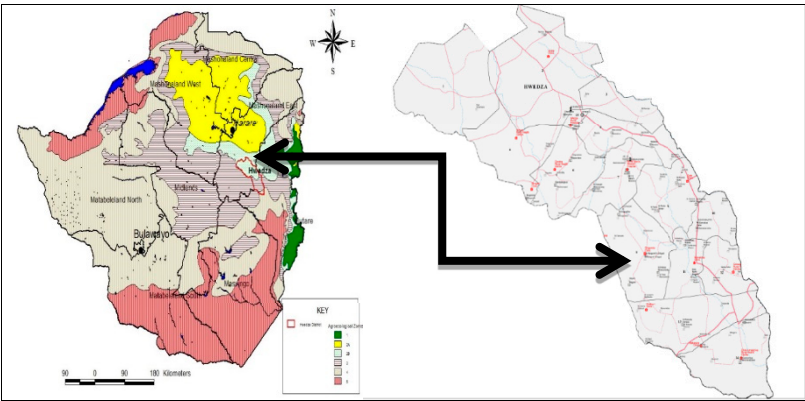107   and highest in the month of October (Crop et al., 2012b).
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112   **Figure 1:** Map of Zimbabwe showing agro ecological zones and Hwedza district
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114   Hwedza livelihoods are mainly crop production based, with mixed crop- livestock systems hinged
115   on maize production, as well as groundnut, soya bean and cowpea.
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**2.2 Importance of socio-economic surveys in agriculture**

In research farmers experience and practice are the backbone of research questions. One of collecting data is through surveys. Survey research involves the collection of information from a sample of individuals through their responses to questions. Survey research owes its continuing popularity to its versatility, efficiency, and generalizability (Quantity and Marsh, 2017). Surveys are efficient in that many variables can be measured without substantially increasing the time or cost(Bank and Change, 2018; World and Annual, 2008).For a survey to succeed, it must minimize the risk of two types of error: poor measurement of cases that are surveyed (errors of observation) and omission of cases that should be surveyed (errors of non-observation) (Division and Banda, 2003; Peytchev et al., 2011) . Potential problems that can lead to errors of observation stem from the way agro-meteorological questions are written, the characteristics of the farmers who answer the questions, the way questions are presented in questionnaires, and the interviewers used to ask the questions.

**2.2.1 Sampling design**

A stratified two stage random sampling design was used for the survey. The sample size was based on central limit theorem and sample size calculation formula was based on the assumption of normal Approximation, (Davis et al., 2016; Division and Banda, 2003).

**2.3 Agroclimatic characterization**

**2.3.1 Meteorological data**

One meteorological station was selected for this study; the station was selected based on availability of meteorological data. Forty nine years of daily rainfall data of Hwedza station for the period 1963 to 2012 was collected from Meteorological Service Department (MSD). The choice of this length of period is in line with the convention of using 30 years' weather data in characterizing the climate of an area, as adopted by the World meteorological Organization (Scafetta and B. J. West, 2009).

**2.3.2 Rainfall**

The following definitions were used during weather characterizations.

- agricultural rain (wet) day: when an area receives 4.95 mm or more of rainfall
- rain day: when an area receives 2.95 mm or more of rainfall
- dry day: any day that accumulates less than 2.95 mm of rain
- water logging rains: At least 100 mm of rain within five consecutive days

The season was considered to have started if an area receives effective planting rains. In the study, INSTAT "Climatic Events" menu options was used to define events of interest (start of season, dry spell, water balance)(Gallagher and Stern, 2015). Then sowing dates were based on the following definitions commonly agreed upon with the farmers,

1.  **AREX criterion**, first date from 1st October when an area receives more than 25 mm in 7 days with the condition that there is no 10 day dry spell or longer within the next 20 days.
2.  **MET criterion**, first date from 1st October when an area receives at least 40 mm in 15 days, with the condition that there is no 10 day dry spell or longer within the next 20 days.
3.  **Depth criterion**, first date from 1st October when an area receives at least 40 mm in 4 days (Mugalavai et al., 2008).

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161     **2.4 Climate impact scenario assessment with DSSAT and Simulation procedure**

162     In this study the DSSAT model was calibrated and validated using the district average observed data.

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164     **2.4.1 Weather data**

165     The three main weather parameters required for use by the DSSAT model are: daily rainfall (mm),

166     daily minimum temperatures (T°C) maximum temperature (T°C) and daily solar radiation (MJ/m$^{-2}$).

167

168     **2.4.2 Soil characteristics**

169

170     The soil texture characteristics at Hwedza were considered to be in Group G5- felsic igneous and

171     metamorphic rocks, moderately deep coarse loam (Mtambanengwe and Mapfumo, 2005). The field

172     capacity and wilting point for textural classes of Zimbabwe are found at -10 kPa and -1500 kPa suction

173     pressures respectively (Journal, 1983; Mtambanengwe and Mapfumo, 2005) (Table 1).

174

175     **Table 1.** Physical characteristics of the soils used in crop simulations (Nyamangara et al., 2000)

| Depth (cm) | 0-15 | 25-40 | 50-65 | 90-105 |
|---|---|---|---|---|
| DM % | 99.7 | 99.2 | 98.8 | 98.2 |
| Texture | mLS | mSal | cSaCl | cSaC |
| Gravel % | 1 | 3 | 6 | 9 |
| Course sand % | 17 | 17 | 20 | 20 |
| MediumSand % | 32 | 26 | 22 | 16 |
| Fine Sand % | 38 | 31 | 24 | 20 |
| Silt % | 8 | 8 | 5 | 5 |
| Clay % | 4 | 18 | 29 | 39 |
| pH (CaCl$_2$) | 4.0 | 4.2 | 5.0 | 5.2 |
| Carbonates | 0 | 0 | 0 | 0 |
| EX Ca (me %) | 0.7 | 1.1 | 1.8 | 1.5 |
| EX Mg (me %) | 0.1 | 0.2 | 0.6 | 0.7 |
| EX Na (me %) | 0.02 | 0.02 | 0.02 | 0.02 |
| EX K (me %) | 0.24 | 0.12 | 0.24 | 0.14 |
| TEB (me % ) | 0.9 | 1.5 | 2.7 | 2.3 |
| CEC (me %) | 0.9 | 2.0 | 3.1 | 4.1 |
| Base Sat % | 100 | 75 | 87 | 57 |
| E/C | 21.3 | 11.4 | 10.6 | 10.6 |
| S/C | 21.3 | 8.5 | 9.2 | 6.0 |
| ESP | 2.1 | 1.0 | 0.7 | 0.5 |
| EKP | 25.6 | 6.1 | 8.0 | 3.5 |
| Org Carbon % | 0.29 | 0.19 | 0.14 | 0.17 |

176

177     **2.4.3 Management and Experiment Data**

178     **Planting dates** The planting dates used for the study were based on the optimal plantings commonly

179     used in Zimbabwe. In this study, method applied are the Depth criterion, MET criterion and AREX

180     criterion dates (Raes et al., 2004).

181     **Fertilizer management**

182     Two levels of fertilizer application were used: a ´optimal´ level and a lower level more representative

183     of resource poor farming communities in Hwedza.

184     Model calibration and validation

185     The DSSAT model was calibrated by continuously adjusting the maize genotypic input parameters

186     so as to mimic observed average district grain yield. The model was calibrated using the observed

187     average district grain yield data collected from 1999 to 2008.

188     The CERES groups of models require a set of parameters describing the crop environment

189     interactions, termed genetic coefficients. To use the CERES maize models in Zimbabwe, the genetic

190     coefficients of the widely grown varieties were obtained from CIMMYT, (CAO et al., 2012; Jones et

191     al., 2003) (Table 2).

192     **Table 2.** Genetic coefficients of Zimbabwe maize varieties

| Maize cultivar | P1 | P2 | P5 | G2 | G3 | PHINT |
|---|---|---|---|---|---|---|
| **Short Cultivar** | 110 | 0.30 | 680 | 820 | 6.6 | 38.9 |
| **Medium** | 200 | 0.30 | 800 | 700 | 8.5 | 38.9 |
| **Long Cultivar** | 320 | 0.52 | 940 | 620 | 6.0 | 38.9 |

193     *P1: length of the juvenile period (degree days above 8 ᵒC*

194     *P2: Factor to account for delay in development when day length is less than the optimum*

195     *P5: Time in degree days from silking to maturity*

196     *G2: Maximum kernels per plant*

197     *G3: Kernel filling rate (mg/day) during grain filling under optimum conditions*

198     *PHINT: Phyloochron interval (time in degree days between successive leaf tip appearance)*

199     **2.5 Model validation**

200     Validation of the model was done by use of the root mean square error (RMSE). The RMSE is a

201     measure of the difference between the simulated predicted outcomes.

202     **3.0 Results and Discussion**

203     **3.1 Survey Results**

204     **3.1.1 Gender**

205     Out of 438 sampled farming household, 34.9% were females farming households while 65.1 % were

206     males. In Hwedza there fewer females who are household heads.

207     **3.1.2 Cropping information**

208     The descriptive statistics from SPSS, showed that 100% of farming households in Hwedza grew maize

209     because it is a strategic and staple grain food in Zimbabwe. Sorghum is a drought tolerant cereal crop

210     but is grown by only 8.7% of farming household in Hwedza district, especially in communal area and

211     small scale sectors.

212     **3.1.3 Start of season from the survey**

213     In Hwedza, the start of the season varies depending on farmers location micro climates . Out of 438

214     farmers interviewed (Table 3) the start of season is very variable. There is no consistent of start of

215    season. The inconsistent of start of season might attributed to climate variability in Zimbabwe
216    (Zinyengere et al., 2015) .

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218

219    **Table 3**. Start of season in Hwedza district

| Month | October | | | November | | | December |
|---|---|---|---|---|---|---|---|
| **Dekad** | 1 | 2 | 3 | 1 | 2 | 3 | 1 |
| **Respondent as %** | 2.1% | 22.1% | 18.7% | 7.5% | 18.0% | 31.4% | 0.2% |

220

221    **3.2.2 Analyzed start season from historical data using INSTAT**
222    Three criteria for determining the start of season were analyzed using INSTAT. According to the
223    AREX criterion, the season often starts on the 2nd dekad of November (11 November), while it starts
224    on 2nd dekad of November (16 November) based on the MET criterion with the Depth criterion giving
225    a common start of season on the 3rd of November (day 148) of the Julian calendar starting from 1 July.
226    The *t*-tests of correlations (at the 5% level of significance) (figure2) exposed that there was no
227    significant trend in the planting dates computed by any of the three criteria over the past 49 years
228    (Fiwa et al., 2014). From the analysis of Depth criterion with less risk of crop failure after the start of
229    there is evidence that the climate variability (Sithole and Murewi, 2009) is significantly affecting the
230    onset of the cropping season (figure 2). The variability of onset dates with time on a station further
231    proves a well-known point that rainfall pattern and distribution from one station cannot be used as
232    representative enough to give operational guidelines of the whole district. There are different micro-
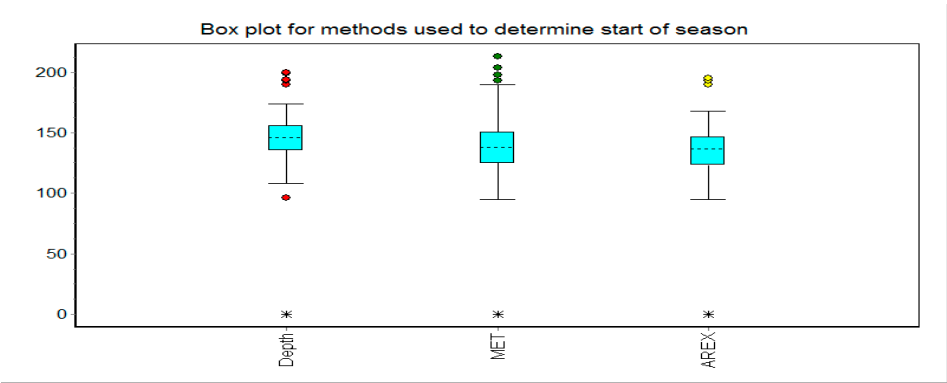233    climates in Hwedza district which was proved by the survey results.

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236    **Figure 2.** Vertical boxplot showing criteria used to determine start of season

237    **3.2.3 Occurrence of dry spells**

238

239    The probability and occurrence interannual fluctuations in precipitation-dry spells were reported in
240    Hwedza (Table 4). Dry spells cause water stress in maize. Water is one of the main yield reducing
241    factors in maize production. Availability of adequate moisture at rootzone is essential for maize
242    development. Scarcity of water (drought stress) at critical stages (anthesis and grain filling) of maize
243    cause yield loss(Basir et al., 2018). Potential yield can be reduced by 10-50% if dry spells occurs at 8-
244    16 leaf stage of maize phenology. Water stress during this period will reduce ear size and potential

245   yield(A Ahmed et al., 2018). With high chances of having dry spells greater 14 days (17% chance)
246   (Table 4) in January and 14 days (15% in February) maize potential yield is reduced.
247
248   **Table 4.** Risk of 14 day, 21 day and 28 days dry spells in a season at Hwedza station

|  | **Percent chance of occurrence of dry spells of duration not less than:** | | |
|---|---|---|---|
| **Month** | 14 days | 21 days | 28 days |
| **November** | 40% | 16% | 8% |
| **December** | 10% | 0% | 0% |
| **January** | 17% | 0% | 0% |
| **February** | 15% | 7.7% | 7.6% |
| **March** | 26% | 10.5% | 0% |

249
250   Results from survey and analysis of historical data (Table 4) rainfed maize anthesis period in Hwedza
251   takes place between January and February. The critical maize growth stages (silking and grain filling)
252   often coincide with mid-season dry-spells. Silking stage is the most sensitive stage for water stress.
253   Water stress during silking coupled with high temperatures can result in 100 percent loss (Fiwa,
254   Resources and Raes, 2014; Zinyengere *et al.*, 2015; A Ahmed *et al.*, 2018; Basir *et al.*, 2018). This explains
255   the importance of growing varieties which match with length of growing period. Dry weather that
256   starts early and covers several growth periods will have a compounding effect with severe reductions
257   in maize and sorghum yields. False starts of the rainy season cause replanting and increase cost of
258   production of rain fed crops in Zimbabwe, therefore starts of season need to be monitored to reduce
259   risk of crop failure (Mupangwa et al., 2011).
260

261   **3.2.4 Agricultural seasonal rainfall characteristics and maize phenology**
262   There is a marked decrease in total amount rainfall received in January and February for 49 years
263   analyzed (Figure 3a). A marked decrease in total rainfall received in January and February signify
264   characteristics of climate change. There is a gradual decrease in total rain received in month of
265   January from selected 10 year period (1992, 2002 and 2012) which is a sign of climate change in
266   Hwedza (Sithole and Murewi, 2009). In rainfed maize production January and February months are
267   critical because the dates usually correspond with critical stages of cereal crop growth.
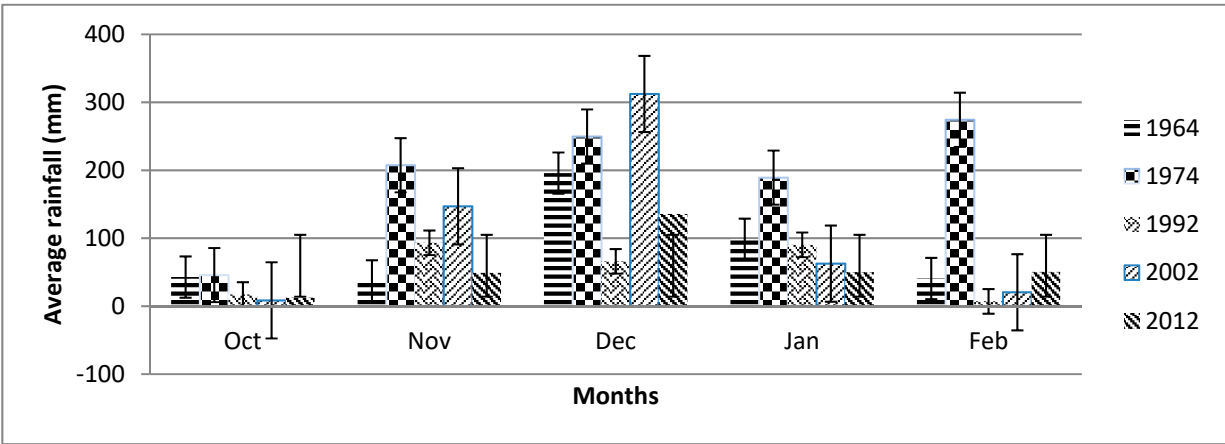


268

269   **Figure 3.** Hwedza monthly rainfall changes. *Error bars show mean deviation*

270    The average seasonal rainfall showed a significant increase (Figure 3). A significant increase of total
271    seasonal precipitation is not important in rainfed maize production. What matters in crop phenology
272    development is the rainfall distribution (Geerts and Raes, 2012). Analyzed climatic data of Hwedza
273    station there is a marked decrease in number of rain days in a season (Figure 4). Two definitions were
274    used to define the agricultural rain day: (a) any day when an area receives 4.95 mm or more of rainfall,
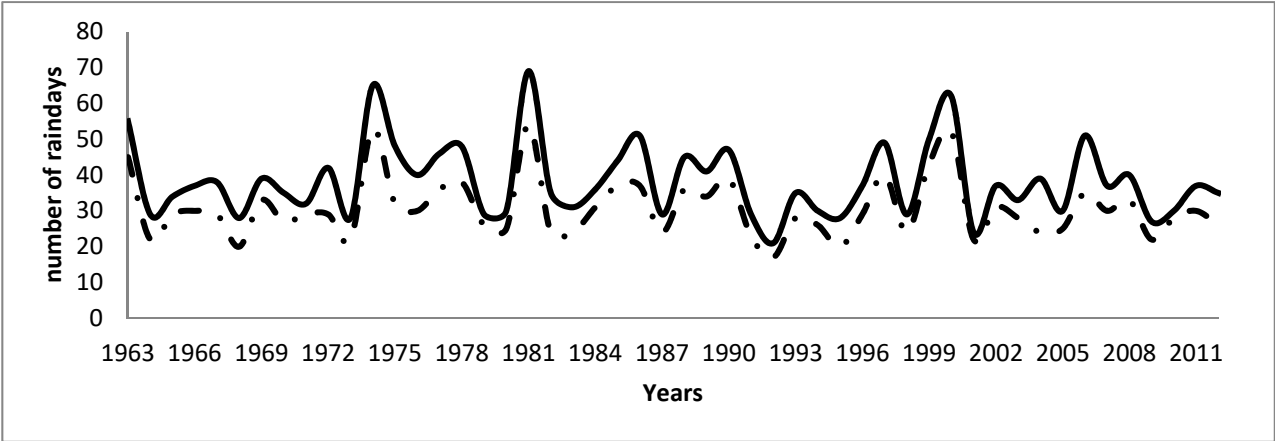275    (b) any day when an area receives 2.95 mm or more of rainfall.



276

277    **Figure 4**. Number of rain days in a season (dashed line = rain days> 2.95; continuous line = rain days>
278    4.95 mm)

279

280    **3.3 Modelling results**

281    **3.3.1 Grain yield calibration**

282    Comparison of simulated grain yield cultivar and observed data was done only for period of 2000-
283    2008 due to lack of long term maize grain district average and temperature data during simulation
284    (Table 5).

285    **Table 5.** Average district observed yields and simulated grain yields

| Year | District Observed Yields (T/Ha) | Simulated Yields (T/Ha) | | |
|------|------|------|------|------|
| | | Short Varieties | Medium Varieties | Long Varieties |
| **2000** | 0.5 | 1.5 | 1.3 | 0.4 |
| **2001** | 1.4 | 0.9 | 1.6 | 0.6 |
| **2002** | 0.6 | 1.0 | 1.1 | 0.4 |
| **2003** | 1.0 | 0.5 | 0.6 | 0.4 |
| **2004** | 1.4 | 0.5 | 0.5 | 0.6 |
| **2005** | 0.6 | 0.5 | 0.4 | 0.4 |
| **2007** | 1.1 | 0.6 | 1.0 | 0.5 |
| **2008** | 0.9 | 0.7 | 0.9 | 0.6 |

286

287    Crop model application assumption indicated specifically that the model simulates the processes
288    happening in the farming system (Geerts and Raes, 2012; Zinyengere *et al.*, 2014;Chisanga, Phiri and
289    Chinene, 2017; Ndawayo *et al.*, 2017).Calibration of district grain yield simulation was done by
290    assessing the goodness of fit of simulated against grain yield and also two sample t-test at 95 %
291    confidence interval. During calibration the model initially failed to correctly simulate crop yields and

292    the RMSE was greater than 30% which was considered to be a poor simulation result(Chisanga et al.,

293    2017; Geerts and Raes, 2012; Zinyengere et al., 2015). This was due to the missing yields which were

294    experienced in 1991/1992 in (Table 6). The missing yields were attributed to the drought which was

295    experienced in the 1991/1992 season (Unganai and Kogan, 1993; Kuri *et al.*, 2014; Mutowo *et al.*, 2014;

296    Asseng, 2015).

297    **Table 6.** Simulated average yields in (Tonnes-T) from 1981-2008

| Cultivar | Short Varieties | | | Medium Varieties | | | Long Varieties | | |
|---|---|---|---|---|---|---|---|---|---|
| Planting Criteria | Depth | MET | AREX | Depth | MET | AREX | Depth | MET | AREX |
| Year | Yield(T) | Yield(T) | Yield(T) | Yield(T) | Yield(T) | Yield(T) | Yield(T) | Yield(T) | Yield(T) |
| 1981 | 1.3 | 1.4 | 0.7 | 2.4 | 2.8 | 2.8 | 0.7 | 0.7 | 0.7 |
| 1982 | 1.2 | 1.2 | 2 | 2 | 2 | 2 | 0.8 | 0.8 | 0.8 |
| 1983 | 1.1 | 1.0 | 1 | 2.6 | 2.4 | 2.4 | 0.6 | 0.7 | 0.7 |
| 1984 | 1.4 | 1.4 | 1.4 | 2.4 | 2.4 | 2.4 | 0.6 | 0.6 | 0.6 |
| 1985 | 1.6 | 1.4 | 1.4 | 2.3 | 2.5 | 2.3 | 0.7 | 0.7 | 0.7 |
| 1986 | 1.1 | 1.5 | 1.5 | 1.7 | 2.4 | 2.4 | 0.6 | 0.6 | 0.6 |
| 1988 | 1.2 | 1.4 | 1.4 | 2.2 | 1.9 | 1.9 | 0.7 | 0.6 | 0.6 |
| 1989 | 1.3 | 1.3 | 1.3 | 2.4 | 2.4 | 2.4 | 0.6 | 0.6 | 0.6 |
| 1990 | 1.2 | 1.2 | 1.2 | 2.6 | 2.6 | 2.6 | 0.5 | 0.5 | 0.5 |
| 1991 | 1.5 | 1.1 | 1.1 | 2.2 | 1.5 | 1.5 | 0.4 | 0.4 | 0.4 |
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1993 | 1.3 | 1.5 | 1.5 | 2.9 | 2 | 2 | 0.5 | 0.5 | 0.5 |
| 1994 | 1.1 | 1.3 | 1.3 | 2.9 | 2.7 | 2.7 | 0.7 | 0.7 | 0.7 |
| 1995 | 0.8 | 1 | 1 | 1.8 | 2.8 | 2.8 | 0.6 | 0.5 | 0.5 |
| 1996 | 1.1 | 1.4 | 1.4 | 2.1 | 2.3 | 2.3 | 1 | 0.9 | 0.9 |
| 1997 | 0.9 | 0.9 | 0.9 | 2 | 2 | 2 | 0.5 | 0.5 | 0.5 |
| 1998 | 1.5 | 1.5 | 1.5 | 3 | 3 | 3 | 0.5 | 0.5 | 0.5 |
| 1999 | 1.2 | 1.3 | 1.3 | 2.4 | 2.6 | 2.6 | 0.8 | 0.8 | 0.8 |
| 2000 | 1.5 | 1.5 | 1.5 | 1.3 | 1.3 | 1.3 | 0.4 | 0.4 | 0.4 |
| 2001 | 0.9 | 0.9 | 0.9 | 2.1 | 2.1 | 0.6 | 0.6 | 0.6 | 0.6 |
| 2002 | 1.1 | 0.9 | 0.9 | 1.1 | 1.1 | 1.1 | 0.4 | 0.4 | 0.4 |
| 2003 | 0.6 | 0.4 | 0.4 | 0.5 | 0.6 | 0.6 | 0.3 | 0.4 | 0.4 |
| 2004 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 | 0.5 | 0.6 |
| 2005 | 0.6 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 2007 | 0.6 | 0.6 | 0.5 | 1.1 | 0.9 | 0.9 | 0.5 | 0.5 | 0.5 |
| 2008 | 0.6 | 0.7 | 0.7 | 0.9 | 1 | 0.9 | 0.6 | 0.6 | 0.6 |

298

299    The long season cultivar which requires greater than 150 days to mature gave lowest yields (0.3 t/ha)

300    (Table 6) when planted late because the average length of growing season is 139 days therefore the

301    cultivar failed to reach physiological maturity. Maize is a C4 plant; its optimum photosynthesis rate

302    is at optimum at (28-35 °C), which is around January to February. Around this period the probability

303    of experiencing dry spells greater than 14 days is very high. Water stress at anthesis period and grain

304    filling reduce yield drastically.

305

306    **3.3.2: Validation of simulated results**

307    By using GenStat, the separation of the mean was carried out to find which varieties are most suitable

308    in Hwedza and were compared with results from observed maize district average yields. The

309    simulated results for medium season and short season varieties showed no significant difference

310    from the observed maize district average yield, P = 0.6 and P = 0.16, respectively while significantly

311    difference were obtained between simulated results for long season varieties and district average, P

312    = 0.004 (Fiwa et al., 2014; Zinyengere et al., 2015). The results from the survey farmers who grew long

313    term varieties were 3.6 %, medium term varieties 40.2 % and short-term varieties 56.2 %. In research,

314    finding farmers experiences and practices of farmers are important in crop modelling and in

315    development of cropping guidelines. Farmers perceptions make calibration and validation of model

316    easy. In science of modelling garbage in garbage out scenarios are common(K. L. MACKERRON,

317    1999; Mukhtar, 2012). During fine tuning a model it's important to compare simulated results and

318    data from baseline surveys.

319    **3.3.3 Evaluating planting criteria and maize cultivar**

320    STATA version 15.0 was used to evaluate the effects of planting criteria and maize cultivar (Figure

321    5). The variance ratio for planting criteria to maize varieties was not significant as illustrated by

322    standard mean errors bars (Figure 5). The combination of AREX criterion and maize varieties

323    produced highest yields followed by MET criterion and lastly, the depth criterion. The results show

324    less significant differences in yield obtained from simulation with different combination of planting

325    criteria. The combination of depth criterion and medium season cultivar is recommended because

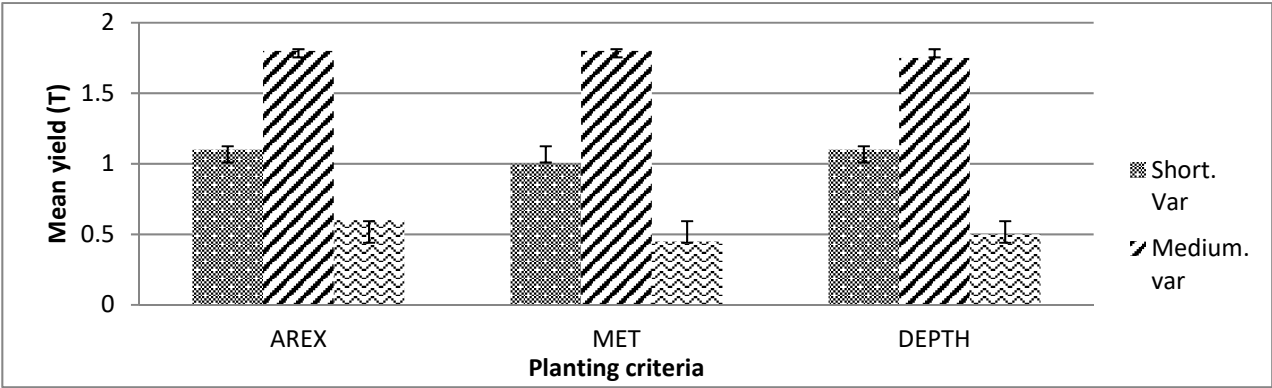326    depth criterion has less risk of crop failure (Raes et al., 2004).



327

328    **Figure 5. Combination of planting Criteria and cultivar (AREX, MET, DEPTH criterion) effects on**

329    **yield**

330

331    By planting late, farmers avoid the potential false starts which may occur early in the season. This

332    ensures that crops do not suffer moisture stress in the initial and crucial stages of

333    development(Chivenge et al., 2015). The medium and short varieties obtain better yields when

334    planted late and early. The maize yield of short and medium varieties was insignificantly affected by

335    time of planting (Figure 5).

336

337 **3.3.4: Cultivar optimization for maize crop calendar**

338 Testing of null hypothesis that mean of medium, short and long-term varieties were equal to mean

339 of observed yields (Table 7). Medium and short varieties (P=0.6333 and P=0.169) respectively

340 (Table 7) there's no difference between the means and conclude that a significant difference does

341 exist.

342

343 **Table 7.** Varieties optimization

| Sample | Mean (T/Ha) | Variance | Standard deviation | Standard error of mean | P. Value |
|--------|-------------|----------|--------------------|------------------------|----------|
| Baseline yields | *1.022* | *0.168* | *0.410* | *0.137* | |
| Medium. Variety | 0.925 | 0.169 | 0.412 | 0.146 | 0.633 |
| Short. Variety | 0.750 | 0.130 | 0.361 | 0.128 | 0.169 |
| Long. Variety | 0.479 | 0.009 | 0.099 | 0.035 | 0.004 |

344

345 The results (Table 7) are consistent with observation by(Mhizha et al., 2014; Phillips et al., 2006) that

346 medium-term varieties are dominant in agro-ecological region IIb and III in Zimbabwe, while in drier

347 zones the more drought-tolerant crops, pearl millet (*Pennisetum glaucum.* L) and sorghum (*sorghum*

348 *bicolor.*L) are recommended. Some farmers are risk takers they grow long varieties (P value < 0.05)

349 (Table 7) where there's difference between the means and conclude that a significant difference

350 exist. Climate variability confuse farmers to extent of choosing maize varieties which don't match

351 with crop varieties water requirements. In some LaNina years farmers benefits from well distributed

352 rains which favors better yields from long maize variety.

353

354 **3.3.5 Relationship between total seasonal rainfall, simulated yield and observed yields**

355 The simulated results showed that DSSAT is sensitive to moisture stress, it failed to simulate 1992

356 yields because of the drought experienced in that season (Figure 6), shows that in years where total

357 seasonal rainfall was greater than 700 mm simulated and observed yields were greater than 1 tonne.

358 Not all years with totals seasonal rainfall greater than 700 mm had good yields, this proves that

359 rainfall distribution (rain days) is more important than seasonal totals. In a season, if severe mid-

360 season dry-spells greater than 14 days occur at anthesis and grain filling stages, final maize yields are

361 affected. Maize requires about 600 mm of rainfall of even distribution to reach physiological maturity.

362 In case of low seasonal total rainfall (less than 600 mm) and few rain days (erratic rainfall distribution)

363 growing of small grains is highly recommended. In Hwedza only 7.8 % of farmers grew sorghum (or

364 other small grains) which implies that farmers are advised to grow both maize and sorghum to reduce

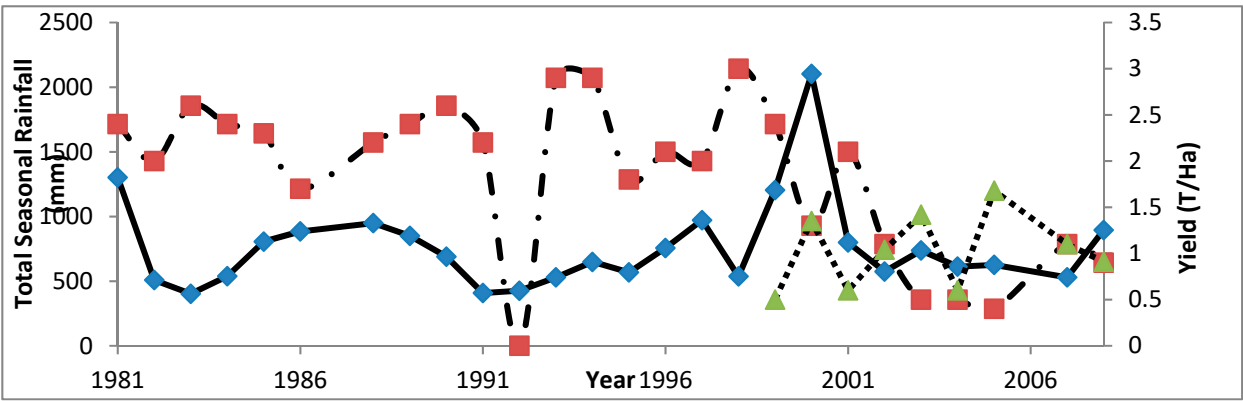365 the negative impact of climate variability on yields.

366



367

**Figure 6.** Relationship of total seasonal, simulated1981-2008) and observed yields 1999-2008 *(dashed striped line = total seasonal rainfall; continuous line = simulated yield (T), dashed with stars observed yields)*

The correlation (r = 0.7) between rainfall characteristics and maize yield shows that annual number of the rain days had strong (significant) positive correlation with maize yield; while dates of onset (r = 0.003) had weak correlations with maize yield (Table 8). This implies that variations in annual rain days and annual rainfall amounts account for most for the annual variations in maize yield. This confirms the findings by (Geerts and Raes, 2012; Mhizha et al., 2014; Raes et al., 2004; Zinyengere et al., 2014) who reported that annual rain days and annual amount had the greatest effect on maize yield. Thus, the higher the amount of rainfall spread over the number of rain days in a year, the greater the maize yields.

With the seasonal length varying from 90-139 days, the results show that the length of growing period is not very reliable to maize production but very suitable for drought tolerant crops like sorghum and finger millet. Seed companies in Zimbabwe have a range of sorghum varieties which can be grown throughout the country but particularly in areas where maize is a high-risk crop. In these areas where the higher drought tolerance of sorghum is so important it is more likely to produce a crop in years with less than average rainfall.

**Table 8.** ANOVA for regression of observed average yield on number of rain days

| Source | df | SS | MS | F value | Prob>F |
|--------|----|----|----|---------|--------|
| **Regression** | 1 | 0.957656 | 0.95766 | 16.42 | 0.0049 |
| **Residual** | 7 | 0.408231 | 0.05832 | | |
| **Total** | 8 | 1.36589 | | | |
| **R-squared = 0.7011 (adjusted = 0.6584)** | | | | | |

In rain-fed maize production, low yield experienced in marginal areas in Zimbabwe are attributed to lack of moisture, soil fertility, lack of know-how- agronomic management and lack of resources. It is clear that the typical average yields experienced in marginal areas of Zimbabwe (0.4 to 1 t/ha) are common when few rain days and poor fertilizer application experienced despite other agro-meteorological factors (Mhizha et al., 2014; Mugalavai et al., 2008; Raes et al., 2004). Number of rain-days are strongly correlated (r = 0.7) to district maize average yield. The more the rain days the more the more the water availability in the root zone.

393

394    **3.3.7 Maize (Crop Calendar) in Hwedza (Decision support tool)**

395    The decision support tool for maize production was developed for Hwedza district (Figure 7). The

396    tool was developed based on triangulation of the survey results, analysis of 49 years' historic climatic

397    data for Hwedza climate station and simulation results by DSSAT model. The tool is meant to help

398    maize producers, to make decisions for maize production management based on the climate

399    variability in Hwedza.

400
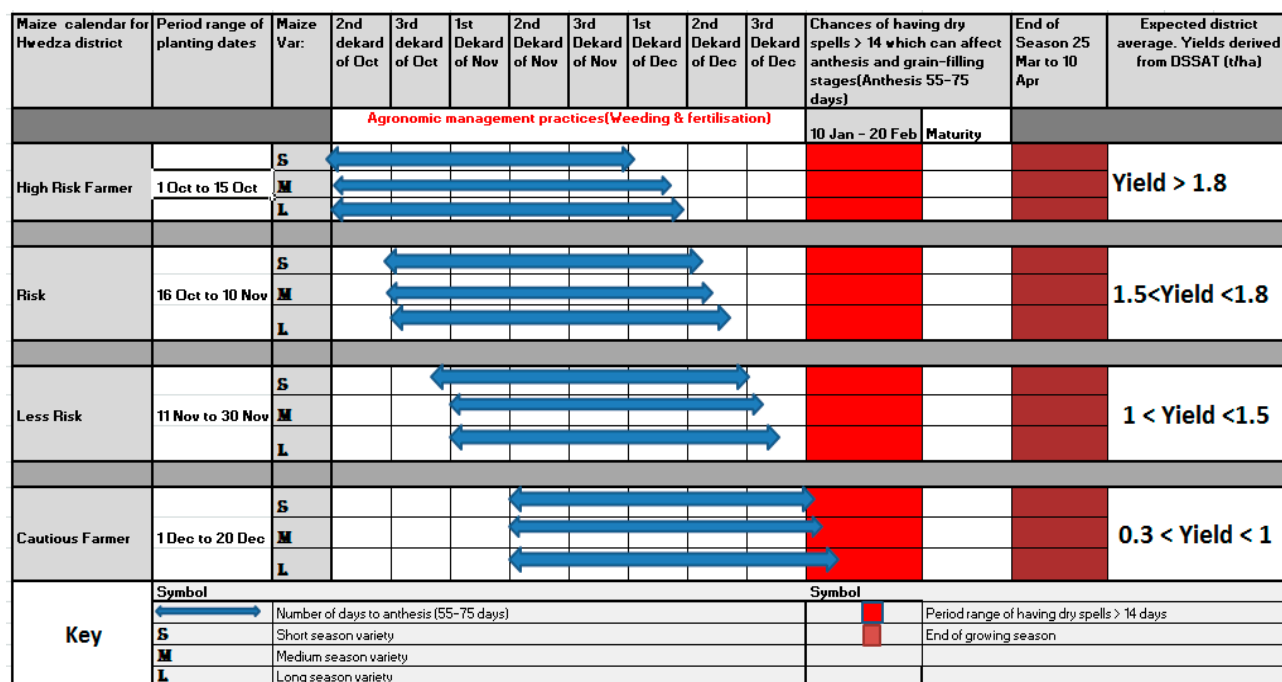


401    **Figure 7.** Maize crop calendar for Hwedza District

402    In applying the decision support tool, farmers, it should be noted that when they plant early the

403    district average yields as high as 1.8 t can be attained if the long, medium and short varieties are

404    planted between 1 October to 10 November) with their current fertilizer application.

405    In general , highest maize yields in the crop calendar are obtained after averaging few success years

406    with October plantings due to favorable heat units for hybrid maize growth (Geerts and Raes, 2012;

407    Mhizha et al., 2014; Zinyengere et al., 2014), but these can usually only be sustained with irrigation.

408    However, plantings in October may be feasible on vleis or when there are good early rains (over 40

409    mm). Early planting in October in figure 3.7 has fewer chances of successes in crop establishment due

410    to dry spells which often occurs after early plantings.

411    The red color represents the chances of having mid-season dry spells, which are greater than 14 days.

412    Planting in December produce low yields and is very risky because the crop may suffer from water

413    stress at the end of season, while pests like stalk borer and disease (maize streak virus are more

414    prevalent to late planted maize crop.

415    The blue lines represent period from planting to anthesis stage. The brown strip represents the

416    common end of season. It is clear that with the use of DSSAT model, the length and the quality of the

417    growing period can be assessed for its suitability to rainfed production of maize varieties (Chisanga

418    et al., 2017; Chivenge et al., 2015; Ndawayo et al., 2017; Zinyengere et al., 2015). As a result, a crop

419    calendar that can be used to indicate whether to grow maize varieties of particular length of growth

420    cycle was developed for Hwedza district.

421

### 4. Conclusions

The maize cropping calendar (guidelines) was successfully developed as a general guide applicable to the study area.

The survey helped to find agro-meteorological challenges which are affecting maize production in Hwedza district of Zimbabwe. Results of this study indicate that rain fed maize farming in Hwedza is constrained by inadequate precipitation. The survey results showed that the start of the season was very variable generally ranging from the 1st dekad of October to the 1st dekad of December. The survey concludes that 56.2 % of the farmers grew short season varieties, 40.2 % medium season varieties and 3.6% long season varieties.

The study has established that there is high variability in rainfall characteristics (start of season, number of rain days and dry spell length) which translates into high variability in maize yield per hectare. The result also reveals that the number of rain days the strongest influence on maize yield per hectare in the study area (r = 0.7) while start of season has less effect on district average maize yield (r = 0.003).

Use of one station based climatic data for the study area does not represent the whole study area, therefore use spatial data might help to come up with cropping guidelines.

The validated DSSAT model was applied together with an optimization to select the best combination of planting criteria and maize cultivar. The study showed that maize cultivar and planting date affect maize yields considerably. The DEPTH criterion and medium season cultivar produced the highest district average yield of 0.9 t/ha.
Though crop modelling approach can be used to develop cropping guidelines, this study reveals that dedicated local knowledge is necessary to calibrate and validate models.

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