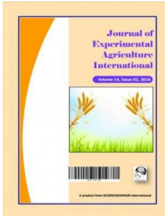

Journal of Experimental Agriculture International
14(4): XX-XX, 2016, Article no.JEAI.29056
Previously known as American Journal of Experimental Agriculture
ISSN: 2231-0606

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Maize Production under Climate Change in a Savannah Region in DR-Congo

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Authors' contributions

This work was carried out in collaboration among all authors. Author MML designed the experiment, collected and analyzed the data. Author RVK supervised field experimentation, data collection and analysis. Author KKN coordinated the research program, co-supervised data analysis and wrote the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2016/29056
Editor(s):
(1).
(2).
Reviewers:
(1).
(2).
Complete Peer review History:

Original Research Article

Received 20th August 2016
Accepted 10th October 2016
Published 5th November 2016

ABSTRACT

Climate change is a serious threat to poverty alleviation in developing countries as it can sweep several decades of development efforts. It is one of the constraints to achieving potential crop yields, and it is a factor that is often not considered in agriculture development project. The objective of this paper is to evaluate farmer's perception on climate change and to document changes in rainfalls, temperatures, and maize grain yields during the last 30 years in a savannah region of Gandajika in the DR-Congo. A survey of 131 families of small farmers scattered within 20 Km of the agronomic research station (INERA) was carried out in 2009 on the effects of climate changes based on farmer's perception. Data on rainfall and temperature were collected at two weather stations over a period of 31 years (1980 to 2010) in the District of Gandajika (Eastern Kasai, DR-Congo). Maize grain yield was compiled for the same region and period. Agricultural practices are traditional and farmers are not using any inputs. Sixty-seven percent feel the effects of climate change. The number of rainy days per year decreases significantly from 139 during the

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first decade (1980 to 1990) to 97 in the last (third) decade (2000-2010). However, annual rainfalls did not significantly change during these three decades (P-value > 0.05). A significant variation in temperature was observed in the last decade with an increase from 24℃ to 27℃. In the meantime, maize grain yield declined gradually over time. The average yield decreased from 1.6 t ha^{-1} in 1999 to 1.4 t ha^{-1} in 2002, 1.2 t ha^{-1} in 2003, and 0.75 t ha^{-1} in 2004.

Keywords: Climate changes; rainfalls; temperature variation; crop yield; farmer's knowledge; Sub-Saharan Africa.

1. INTRODUCTION

Climate change is a serious threat to poverty alleviation in developing countries as it can sweep several decades of development efforts. It is currently one of the main constraints to achieving potential crop yields [1-4]. As emphasized in the Johannesburg Declaration on Sustainable Development, "the adverse effects of climate change are already evident. Natural disasters are becoming more frequent and devastating, making developing countries more vulnerable". Climate change is indeed a global phenomenon, but its adverse effects are more acutely felt by people in poor countries. They are especially vulnerable because of their high dependence on natural resources as well as their limited ability to cope with climate variability and extreme weather events [1,5].

Globally, many changes are already being felt, and others are in sight. The physical and economic environments are dynamic and affect economic and environmental systems such as agriculture. The diagnosis of loss of potential crop yields revealed that socio-economic and climatic constraints are directly associated with crop production [6-8]. Diagnostic studies of yield loss are based on crop mathematical models that facilitate our good understanding of the agro-ecological systems. These tools also provide a framework for studying changes at global levels [9].

DR-Congo has a National Action Plan for Adaptation to Climate Change (PANA), with a component on Agricultural Sector Adaptation (PANA-ASA), which performs simulations of climate change across the country and implements coping mechanisms for rural populations [10]. Projected evapotranspiration, green water and water stress signals are based on the Dynamic Global Vegetation Model (DGVM) LPJ- ml forced by bias corrected projections of global climate model ECHAM, following two types of scenarios, "strong" and "weak" Green Gas emissions. Simulations take into account the region of the Congo Basin, which was divided into five climatic zones. Gandajika region is in zone 5 (6° to 14° South latitude and 21.5 East longitude 32°). The results of this simulation predict an increase in precipitation (0-10%) and a slight decrease in evapotranspiration in 2050. It also forecasts a decline in yield if the production systems and the current agricultural techniques are maintained [10].

Maize is the dominant crop in the farming systems in Kasai. It is the main staple food in Eastern Kasai and an important source of income for local farmers who can sale the surplus production. In general, local production does not meet the region demand and imports from neighboring provinces are required to meet the food security needs of Eastern Kasai [11].

According to Parry [12], maize has been one of the primary crops for which climate change impact assessments have been conducted. Typical responses of this crop to climate change conditions are acceleration of the rate of development and reduction of grain number and weight. Several studies have addressed the reduction of maize yields due to climate change through applications of mitigation strategies [13-14]. The effects of climate change on plant diseases are summarized in Boland et al. [15]. Typically, the two most important environmental factors in the development of plant disease epidemics are temperature and moisture [16]. In many areas including Gandajika, maize mildew occurrence is a serious plague whose emergence coincides with the sensitive stage of maize development which is devastating for susceptible varieties and a major obstacle for maize production for small farmers. In fact, downy mildew, a fungal-borne disease, causes significant damage to maize crop, leading to losses of up to 100% of grain yield in affected areas [17].

The objective of this paper is to evaluate farmer's perception on climate change and to document changes in rainfalls, temperatures, and maize grain yields during the last 30 years in a savannah region of Gandajika in the DR-Congo.

2. MATERIALS AND METHODS

2.1 Characterization of Study Site

The study was conducted in Gandajika region in Eastern Kasaï (Democratic Republic of Congo) located at 6°45’ south latitude and 23°57’east longitude, and at altitude of 792 m. This region is 90 km from the main city of Mbuji-Mayi (Fig. 1). The region falls within the Aw4 climate type according to Köppen classification characterized with 4 months of dry season (from mid-May to august) coupled with eight months of rainy season, sometimes interrupted by a short dry season in January/ February [18]. Daily temperature averages 24°C and annual rainfall is close to 1,500 mm. Gandajika soils consist of a collection of sandy on clay sediment more often based on a shallow lateritic old slab. The adsorption complex is fairly well saturated and there are still some weatherable minerals [19,20].

(a)

(b)

Fig. 1. Location of experimental sites a) Democratic Republic of Congo (orange); b) Details on the map of Democratic Republic of Congo. The arrow indicates the site (Gandajika) where the study was conducted

Adapted from Google Map, accessed in June 2016

2.2 Data Collection

A survey was carried within 20 Km around the agronomic researcher station (INERA). A total of 131 famer's family filled out a questionnaire to report agro-ecological changes they attribute to climate variation. Sampling was randomized and covers north, south, east, and west areas of the INERA station. The survey consisted in assessing famer's knowledge and interpretation of climate change and its impact on maize yield in Gandajika.

The rainfall and temperature data were compiled from two weather stations (INERA and MPOYI) over a period of 31 years (1980 to 2010) and maize grain yields were provided by the Ministry of agriculture.

2.3 Data Analysis

An analysis of variance was conducted using R package to compare the means for temperatures, rainfalls, numbers of rainy days, and maize grain yields. The Honest Tukey test was used to determine significant differences among means at $P \leq 0.05$ and 0.01.

3. RESULTS

3.1 Maize Production in Gandajika

The total area available is 1.34 ha per household, of which on average 0.74 ha is sown. Eighty- four percent of the land are on plains, 12% are on slopes and 4% in the shallows. About 93% of farmers grow maize without any fertilization. Seventy-six percent of the population grows maize in crop mixture (92% of them associate maize with cassava and others with legumes) and 24% in pure culture. This last portion of the population is more exposed to climate hazards due to the fragility of the monoculture. Genetically Improved varieties are rarely used because they are expensive to produce. Hence, ninety-two percent of the population use the local variety, 2% grow genetically improved varieties (Salongo-2 and Mus-1) and 6% combined in the same field local and improved varieties. Eighty-seven percent of the population practice continued cropping on the same land with no rotation, which increases the degradation of soil fertility, while 9.1% restore soil fertility by practicing crop rotation.

3.2 Farmers's Perception on Climate Change

Farmers's perception data are described in Fig. 2. Overall, 67% of farmers in the present study perceived that climate change is a serious threat to crop production in Gandajika. This is less than the 94% reported by the PANA-DR-Congo project on climate change supported by the United Nations Development Project Program (UNDP). About 55.6% of farmers associated current droughts resulting in late rains in the growing season and longer dry seasons with climate changes. This value is also less than 83% reported by the PANA project from a national study. The main effects of climate changes reported by farmers within the region include a poor rainfall distribution (82%) and an increase in overall rainfalls (64%). These changes have resulted in delay in growth (5.6%), increase in plant diseases (19.4%), and disruption of the schedule of agricultural activities (30.6%). As a mitigation strategy for these climate change effects, farmers plants gradually throughout the growing seasons.

3.3 Variation in Temperature and Rainfalls in Last Three Decades

Farmer's perceptions were supported by collected agro-ecological and meteorological data. Three decade were considered: the first from 1980 to 1989; the second from 1990 to 1999 and the third from 2000 to 2009. The averages number of rainy days have significantly decreased (1st decade: 139±15; 2nd decade: 110 ±13; 3rd decade: 97±12). Results from temperature and rainfalls analyses revealed an increase of temperature from 24°C to 27°C during the last 30 years, with a sharp change in the last five years (Fig. 3). However, annual rainfalls did not significantly change during these three decades ($P > 0.05$). Overall, no significant difference among the three decades was observed but a hike of 3°C in temperature was observed in the last 5 years. Details on variation in temperatures, rainfalls, and number of rainy days are described in Figs. 4 and 5. There is a significant decrease of number of rainy days in the third decade (2000-2009) compared to the first one (1980- 1989) (Fig. 5).

3.4 Evolution of Maize Grain Yield

Fig. 3 shows that maize grain yield at Gandajika has declined gradually over time. The average yield decreased from 1.6 t ha^{-1} in 1999 to 1.4 t ha^{-1} in 2002 and 1.2 t ha^{-1} in 2003 to 0.75 t ha^{-1} in 2004. The sharp decrease of grain yield is significantly correlated with an abrupt increase of average temperatures (Fig. 6).

The decrease in rainfalls and variations in temperatures required adaptive measures such as changing agricultural calendar and practices. The main growing season (Season A) (from august 15 to January 15) starts now in mid-September with usually a decline in the rainfalls in October. The second growing season (season B), that started in mid-January and ends in mid-May is also affected by weather disturbances in March and the dry season beginning in early May. We also observed that the cycle and frequency of downy mildew in maize remained constant with occurrence in mid-October for season A despite the late start of rains in the season.

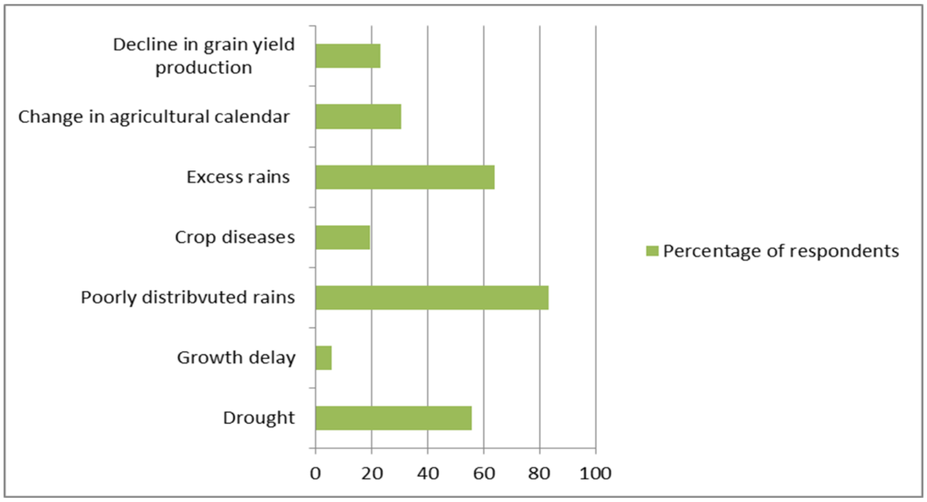


Fig. 2. Effects of climate changes based on farmer's perception in Gandajika

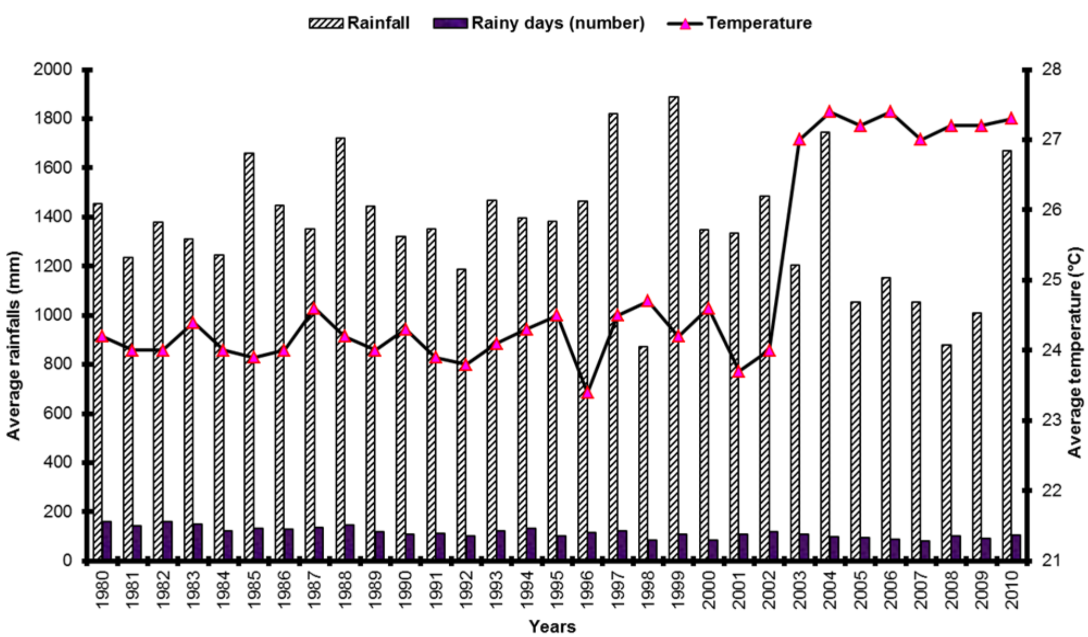
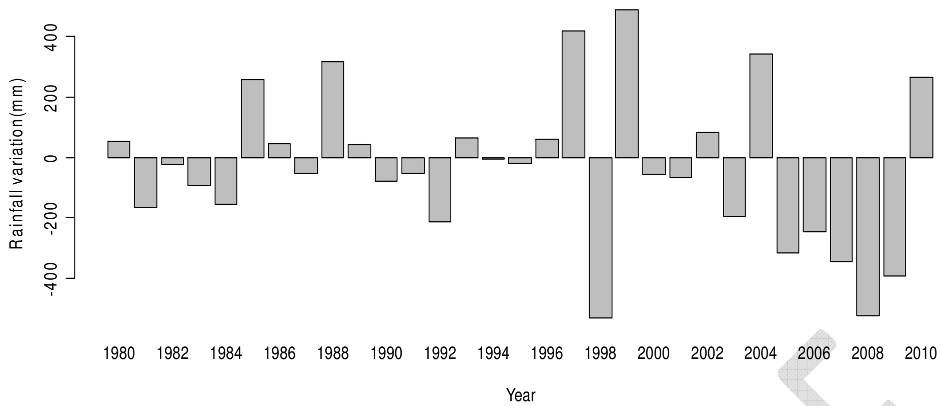
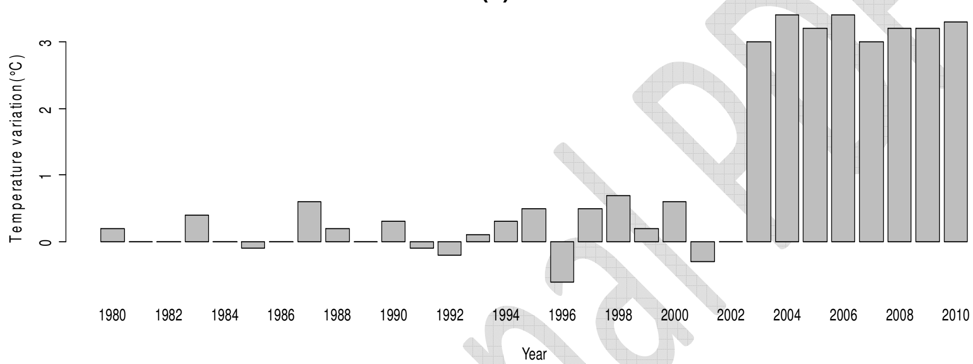


Fig. 3. Annual average temperatures, rainfalls and numbers of rainy days over 30 years in Gandajika

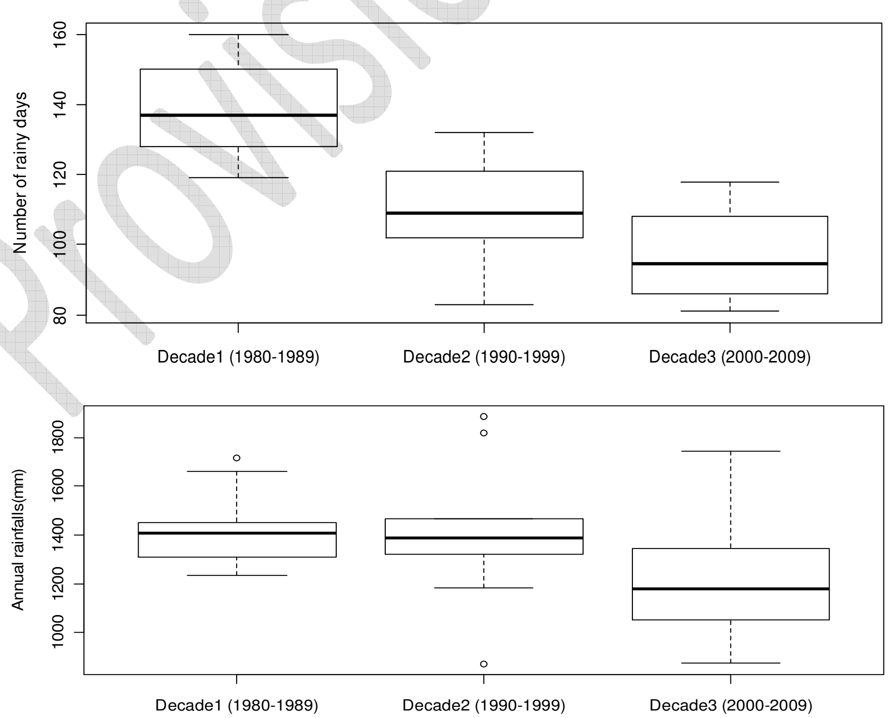


(a)



(b)

Fig. 4. Meteorological variations from the annual average of 1.500 mm and 24°C of rainfalls and temperature, respectively



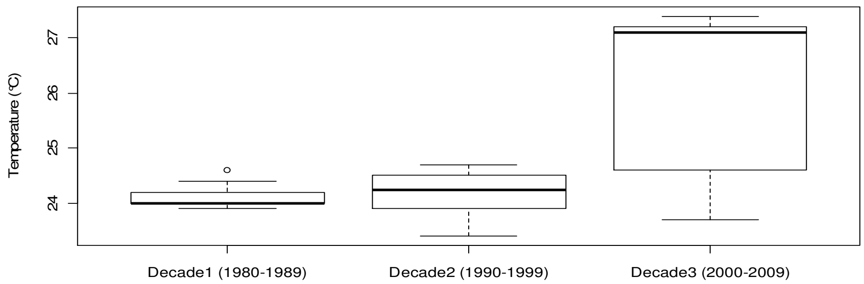


Fig. 5. Mean numbers of rainy days, annual rainfalls, and temperaturte for the last three decades in Gandajika

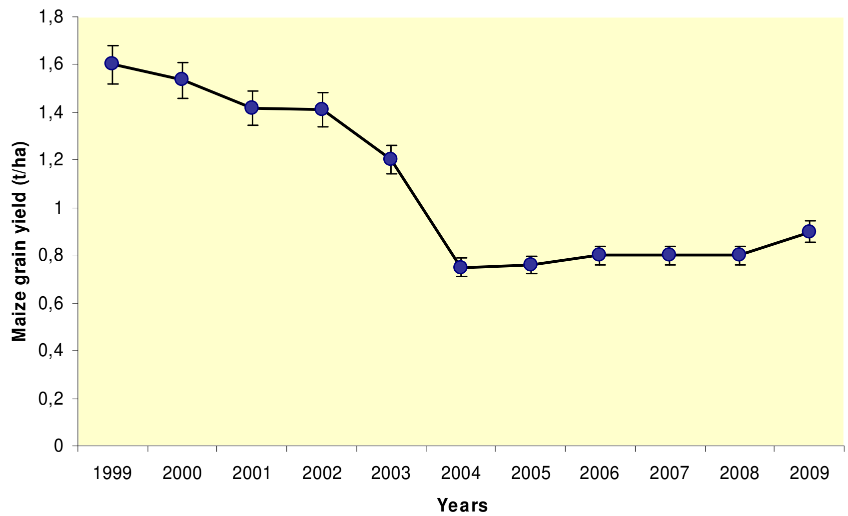


Fig. 6. Evolution of maize grain yields in the last 10 years
(Source: Ministry of Agriculture, Gandajika Territory)

Data on soil fertility has been discussed in [19, 20]. In Gandajika most farmers practice restitution of crop residues season after season and crop fallow system to maintain soil fertility. Interestingly, recent analysis of soil chemistry revealed no significant depletion of soil fertility or increase of soil acidification over the last two decades [19,20].

4. DISCUSSION

A significant proportion of the population (67%) is aware of the climate change and its effects on crop production. This awareness is important to facilitate the implementation and adoption of mitigations techniques. IPCC [2] provides a broad assessment of changes expected by 2100 in Africa for all climate scenarios, and predicts that the warming is very likely to be above the global average in all seasons. In addition, the annual rainfall is likely to decrease in Mediterranean Africa, Northern Sahara, Southern Africa, but increase in East Africa [2,21-23]. For West Africa, Patricola and Cook [23] project about 50% increase in rainfall in spring and drying in early summer (June and July). These projections are consistent with those in other regional climate studies. The same trend is observed in other regions with wetter conditions over eastern Central Africa (i.e. Cameroon, Central African Republic, Congo, and Democratic Republic of Congo) in June, but drying during August through September, and drying over East Africa in later summer, but wetter in October.

The climatic data collected in Gandajika are consistent with PANA-ASA predictions. The increase in the average temperature from 24 to 27°C, with daily peaks up to 32 to 33°C, and prolonged lack of rainfall can cause serious physiological disorders to plants and affect the growth and production. Hulme et al. [4] and

Desanker and Magadza [24] indicate that warming across the African continent is expected to be between 0.2℃ to 0.5℃ per decade. This suggests that the hike of 3℃ in annual temperature observed in Gandajika in recent years might not be a permanent trend. It should be pointed out that in the present study, no significant differences in annual rainfalls among the three decades was observed, but a decrease in the number of rainy days per year, from 139 days for the first decade to 97 days for the 3rd decade was statistically significant (p- value < 0.05). This has resulted to more heavy rains that damages crops. High temperatures coupled with high humidity leads to pest and disease proliferation with downy mildew being the main threat.

In several studies, impacts of climate change are expressed as absolute or relative changes in crop productivity, water uptake and resource use (mainly nitrogen). Researchers have identified adaptation strategies closely related to current management practices (i.e. changes in fertilizer use, sowing dates, plant density, cultivars with longer or shorter growing periods, etc.), but have not attempted other mechanisms of adaptation especially if environmental conditions change in a way that alters growing seasons characteristics. There is a need to incorporate longer maturing hybrids to counterbalance the effect of accelerated phenology due to warmer temperatures [13,25]. Several studies assessed phenological stages of maize [26-31]. In Gandajika conditions, phenological stage of maize has been assessed by Lufuluabo et al. [32] and Lukombo et al. [33]. Early sowing dates have been also suggested as an effective measure to cope with climate change in maize production [14,26]. In Mexico, fertilization is proposed as a measure of adaptation to climate change, although this alternative may not be effective in all regions [34]. Curculeanu et al. [13] evaluated changes in fertilization levels and plant densities and found that a combination of several alternatives instead of a single one is the most efficient way to minimize the negative effects of climate change.

Most nutrients in Oxisol ecosystems such as in Gandajika, are contained in the standing vegetation and decomposing plant material. High levels of management can result in ecologically stable oxisols with sustainable productivity. The long term effect of crop residue on cereal and legume productions in different tropical soil types are well documented [35]. The decline in maize production in Gandajika appeared not to be linked to the level of soil fertility but likely the effect of climate variation. Farmers in the targeted region are being advised by local agricultural extension services to plant late in the growing season A. However, the late planting of maize will promote the onset of mildew. In fact, maize plants are more susceptible 2 to 6 weeks after sowing. Planting maize in mid-october would lead to the synchronization of phase of maize susceptibility with the emergence of *Peronosclerospora sorghi* (mildew causing agent) [19,20]. This means that the onset of downy mildew coincides with the phase during which maize is highly susceptible to mildew. The genetically improved varieties released in the region are the most affected. This explain in part why local varieties that are resistant to mildew are more used than improved varieties by small farmers across the region.

5. CONCLUSION

Climate change is *evident* in the targeted region (Gandajika) in DR-Congo based on physical climatic data collected over many years. The main growing season which typically runs from mid-August through mid-January 15 has been delayed to mid-September and it is affected by a short dry period in October. An increase of temperature from 24℃ to 27℃ has been observed during the last 30 years. The averages annual number of rainy days has significantly decreased. This sharp change in meteorological data is significantly associated with a decrease in maize grain yield.

ACKNOWLEDGEMENTS

This research was conducted through a partnership between Laurentian University (Ontario, Canada), DR-Congo universities, and Caritas Congo. We are grateful to the Canadian International Development agency (CIDA), Laurentian University (Canada), CARITAS Congo and INERA-DR-Congo for financial support and in- kind contributions. Thanks to PRODI (Ditunga Project), the local agricultural Inspector (Mr. Kambowa), and INERA researchers in Gandajika for data collection.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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