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Full Length Research Paper

Impact of climate variability on tomato production in Limpopo Province, South Africa

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The relationship between tomato production, monthly average temperature and seasonal average temperature in Limpopo province, South Africa during the period of 1971 - 2006 were investigated using statistical regression analysis methods. The motivation for selecting Limpopo in this study lies in the 66% tomato contribution to the tomato industry in South Africa. The results showed yearly peak values of tomato in the range of 200 000 - 228 000 tons from year 2000 to 2006. In this study, we analyzed the correlation of tomato records in Limpopo with climatic variables in order to assess the climate change effects of tomato production and food security in South Africa. Our results show that tomato yield increased by a factor of two from 1971 to 2006. Particularly, during autumn, spring, summer and winter, tomato yield increased by a factor of two respectively. It is noteworthy that the majority of months registered positive trends in tomato production, except February and June. These could be attributed to the application of robust farming practices and improved technology over the same period. However, from the trend analysis, results demonstrate that there are possible negative impacts of climate change on crop yield, especially on farmers without advanced technology and good modern agricultural practices.

Key words: Climate variability, climate change, temperature, tomato production, Limpopo, South Africa.

INTRODUCTION

Climate is a primary determinant of agricultural productivity and as such, it influences the types of vegetation that can grow in a given location (Box, 1981; Woodward, 1987). In this context, agriculture is a complex sector involving different driving parameters (such as physical, environmental, economic and social). It is now well recognized that crop production is very sensitive to climate change (McCarthy et al., 2001), with different effects according to region. According to the intergovernmental panel of climate change (IPPC), the analysis on climate change impact shows that there is a general reduction of potential crop yields and a decrease in water availability for agriculture and population in many parts of the developing world (IPCC, 2001). The main drivers of agricultural responses to climate change are biophysical effects and socioeconomic factors. There is a biophysical effect on crop production by changing the meteorological variables, including rising temperatures, changing precipitation regimes and increasing levels of atmospheric carbon dioxide (McCarthy et al., 2001). Biophysical effects of climate change on agricultural production depend on the region as well as the agricultural system, and the effects vary over time (Adams, 1998). In fact, the increase of temperature limits crop yield by accelerating the plant development, affecting the floral organs and fruit formation and the functioning of the photosynthetic apparatus.

On the geographical locality of our study site, Limpopo Province is situated in the Northern Province of South Africa, which is a tropical region. According to Mendelsohn and Dinar (1999), the tropical regions in the developing world are particularly vulnerable to potential damage from environmental changes because large areas of these regions are covered by poor soils, which have already made much of the land unusable for

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agriculture. Small-scale farmers, predominant in the Province, who have little capital, will not be able to pursue the new strategies that will be required to adapt to the change in climate.

Tomato is a major vegetable crop and commonly grown by both poor and rich farmers in South Africa. It is used worldwide as a fresh vegetable or as a spice in food preparation. Currently, it is one of the main vegetables used for hawking by small-scale entrepreneurs in the informal sector. The crop is also grown commercially and provides a large number of jobs in South Africa. For instance, in 1998, about 5 465 ha of tomatoes were planted in South Africa, creating a direct employment opportunity for 16 395 people (Anonymous, 1999).

Generally, agriculture in South Africa has traditionally been the largest employer in the economy (Meyer, 1998). However, the contribution of agriculture to total employment has declined from 30% in 1971 to 13% of the economically active population in South Africa in 2000 (Abstract of Agricultural Statistics) (AAS, 2002). According to the National Department of Agriculture (NDA, 2000), the commercial farms provide livelihoods and housing to about six million family members of about one million employees and provide for their educational needs. There are also 240, 000 small farmers who provide a livelihood to more than one million of their family members and occasional employment to another 500, 000 people. In South Africa, the important tomato producing areas are situated in Onderberg (Mpumalanga), Pongola and Nkwalini (KwaZulu-Natal) and Trichardts and Limpopo provinces (Pietersen 1999, unpublished). The aim of the study was to identify the contribution of one of the environmental variables such as climate variables, particularly temperature, which is one factor influencing tomato yield. The regression statistical analysis methodology is used to evaluate the response of tomato production to various climatic conditions.

Study area

Limpopo is one of the developing provinces in South Africa and is particularly vulnerable to climate change impact, partly because of their exposure to extreme weather events and sensitive economies. Limpopo province also has the high number of rural dwellers dependent on natural resources, though communities in Limpopo region may have a greater ability to adapt to long term changes in climate, such as increased seasonal temperature and altered patterns of precipitation. Sometimes dams in Limpopo gets so full because of heavy rainfall in such a way that they flow to the farmers and destroy the plants of the farmers and in that way, the economy gets low (Thomas et al., 2005).

Limpopo province is a main tomato growing area in South Africa, producing 66% of the total annual tonnage of tomatoes (NDA, 2009). The main production areas are Letaba, which is producing on 3259 ha around Mooketsi and Musina, which is producing on about 859 ha. Tomatoes are also planted in smaller areas in Giyani, Polokwane and Mokopane districts. The total annual production of tomatoes is about 227,990 tons of the total South African production which is 345,440 tons, that is two thirds of the national tomato production (NDA, 2009). However, most of this production comes from the Mooketsi area where Bertie van Zyl farm is the dominant grower in the northern parts of the province. This local company is in Mooketsi region and it produces and transports approximately 150 000 tons of tomatoes to various markets in the country.

DATA AND METHODOLOGY

The monthly regional market tomato data were obtained from the National Department of Agriculture in 2009. According to the government statistics, Limpopo province contributes 66% of tomato to the South Africa fresh produce market (NDA, 2009). Due to the imperfection and lack of documentation from the tomato farms in South Africa, the monthly average tomato market data (these were used as an indicator of tomato production) were calculated by weighting the total number of tomatoes distributed monthly in the South African tomato fresh markets, by 2/3 as expressed in Equation 1.

$$\mathrm{P}\{(\theta,\phi);T\} = \mathrm{P}_0\{(\theta,\phi);T\} \times \frac{66}{100} \qquad (1)$$

Here, $\mathrm{P}\{(\theta,\phi);T\}$ and $\mathrm{P}_0\{(\theta,\phi);T\}$ is the spatial-temporal (where $\{\theta;\phi\,\&\,T\}$ are the longitude, latitude and time epoch) average production of tomato in Limpopo and South Africa, respectively. The 2/3 weighting factor used here is based on the NDA definition of the spatial distribution of tomatoes in South Africa.

Climatic variables that were considered were the 36-year averaged observed temperature obtained from the Climate Research Unit (CRU) for the period of 1971 - 2006. The data were obtained from the monthly mean climate fields of 0.5 º × 0.5 º grid resolutions in Limpopo province of South Africa. The mean climate surfaces were constructed from a 36 year (1971-2006) station observation fields, which were then interpolated on the climate grid surfaces. In this study, the mean monthly temperature values were calculated to derive seasonal averages. The autumn season commences from March to May (MAM); winter, from June to August (JJA); spring, from September to November (SON) and summer, from December to February (DJF). Additionally, the statistica software were used to estimate the factor of climate in the current yield trends by applying the regression models to observe trends in climate variables for a period of 36 years from 1971-2006.

To assess the relationship between the time series of tomato production and climate change proxies, the first-difference time series methodology was employed. The first-difference time series considered here is the difference in values from one year to another as described in Lobell et al. (2005) and Nicholls (1997). Furthermore, a multiple linear regression analysis (here, the first difference in yield is considered the response variable, while the first differences of average temperature, minimum average temperature and average maximum temperature are considered as the second variable) was used. Additionally, the spatial and temporal patterns of the significant correlation values were used to

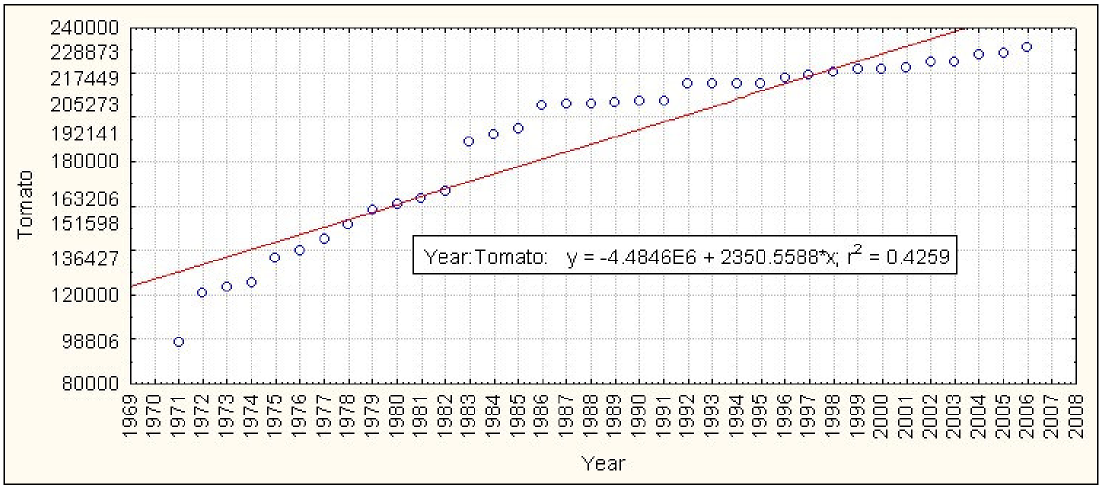

Figure 1. Trend of tomato production in Limpopo Province (1971 - 2006).

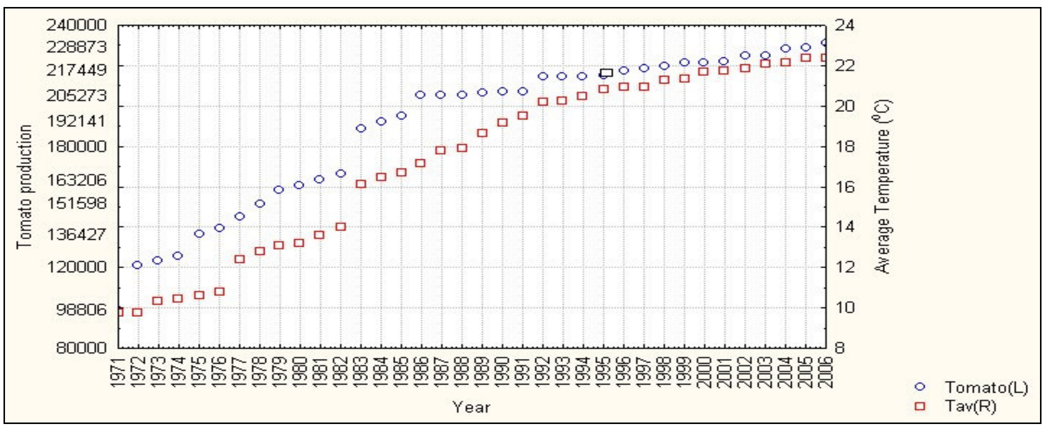

Figure 2. Trend of average annual maximum temperature and tomato production in Limpopo province (1971-2006).

determine relationships between the tomato production and average temperature in Limpopo during the various month and seasons. Composites of temperature and tomato yield were presented in the form of scattered plot in order to study the characteristics of the extremes temperature and weather events and dependency.

RESULTS AND ANALYSES

Trend in tomato production in Limpopo Province (1971 - 2006)

The results (Figure 1) indicate that there is an increase of tomato production in Limpopo for certain years and there are some decrease of production in certain period because of the sensitivity of the tomato crop to climate change and variability. The reduction in tomato production in some of the years was mainly due to droughts experienced in the region. The tomato yield during 1971 to 2006 had a range of 98 806 tons to 228 873 tons. Figure 1 shows the trend of tomato production in Limpopo where tomato yield increased by a factor of two from 1971 to 2006. Thus the response of tomato during that period of 36 years was more favorable. Figure 1 displays year patterns of computed tomato yield. This shows that the largest values during tomato yield (in which temperatures were increased) were concentrated over the last decades.

Relationship between tomato production average temperatures during 1971 to 2006

Figure 2 shows the trend of average annual maximum temperature and tomato production in Limpopo. It shows more erratic pattern of temperature and tomato yield in the

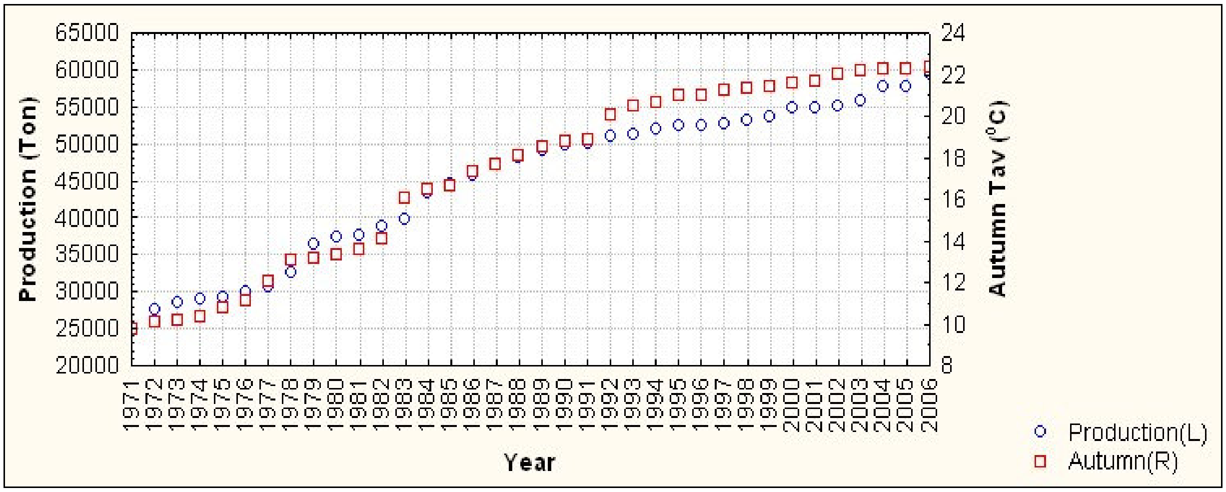

Figure 3. Seasonal average of tomato production in autumn temperature in °C (1971-2006).

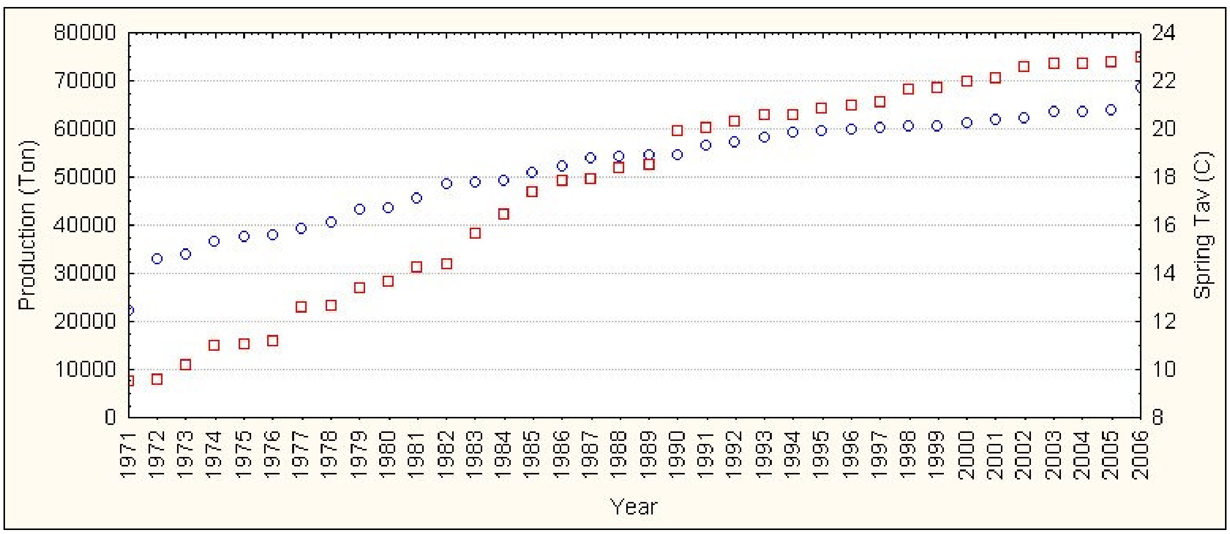

Figure 4. Seasonal average of tomato production in spring temperature in °C (1971-2006)

country. As depicted in Figure 2, minimum temperature was recorded between 1971 and 1990, and for the year 1991 to 2006, a maximum temperature was recorded. This indicates that relationships do appear to change through time.

Seasonal average of tomato production in temperature in °C (1971 - 2006)

Seasonal average of tomato production in autumn temperature in °C (1971-2006)

In autumn, the regression analysis shows that the regional average changes in yields during the past years were less, although the last decades show an increase of production despite the slight increase of the average temperature during the last decades. Figure 3 shows an increase of tomato yield by a factor of two from 1971 to 2006 due to the technology used, because South Africa is a water stressed country.

Seasonal average of tomato production in spring temperature in °C (1971-2006)

In spring, the average temperature increased up to 23°C, which shows a good indication as well for tomato in that particular period of the year. These days, with the advanced technology in the field of farming, the adaptations techniques helped to counterbalance yield losses. Thus tomato yield increased by a factor of three during that

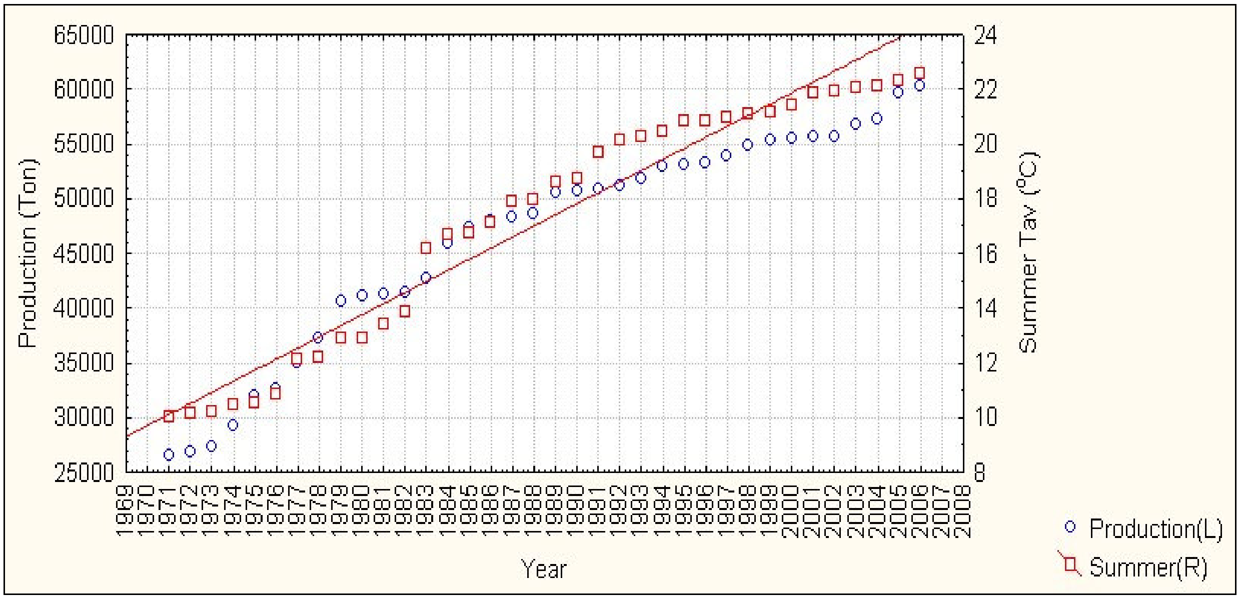

Figure 5. Seasonal average of tomato production in summer temperature in °C (1971-2006).

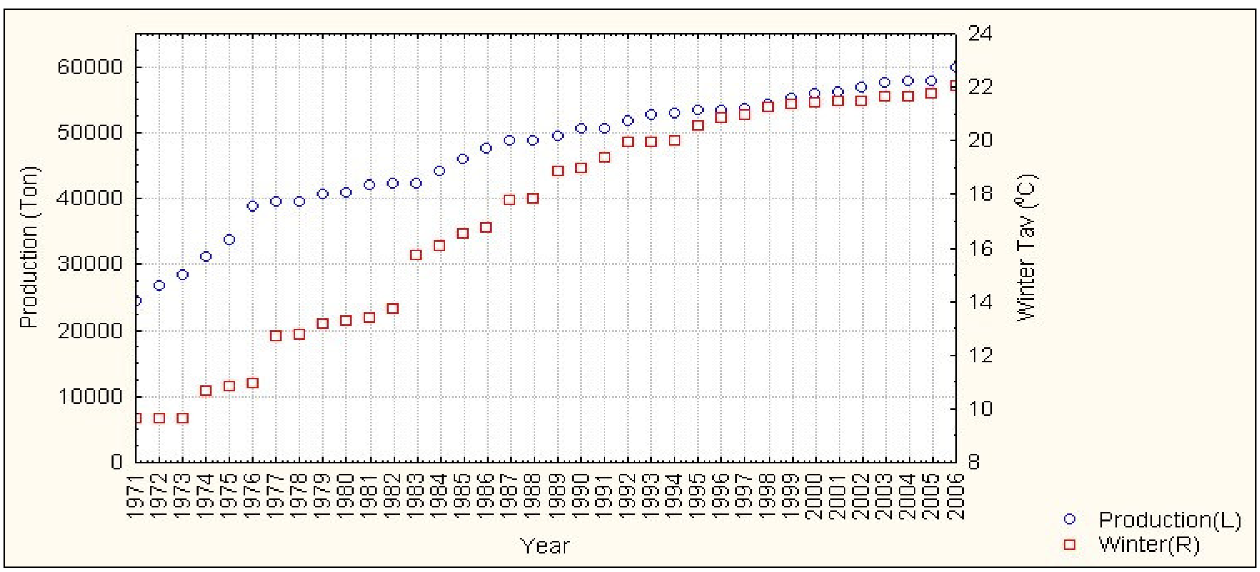

Figure 6. Seasonal average of tomato production in winter temperature in °C (1971-2006).

particular period (1971 to 2006).

Seasonal average of tomato production in summer temperature in ºC (1971-2006)

As depicted in Figure 5, tomato yield during summer season increased by a factor of two from 1971 to 2006. Larger tomato yields were evident in the year 2006 and this yield could be attributed to favorable weather conditions. For example, the higher temperature were also beneficial to production.

Seasonal average of tomato production in winter temperature in ºC (1971-2006)

In winter (Figure 6), there is a slight increase in tomato yield over the years, despite the use of the new agricultural technology in tomato farming. Tomato yield increased by a factor of three during 1971 to 2006. This is probably caused by the irrigation system applied as

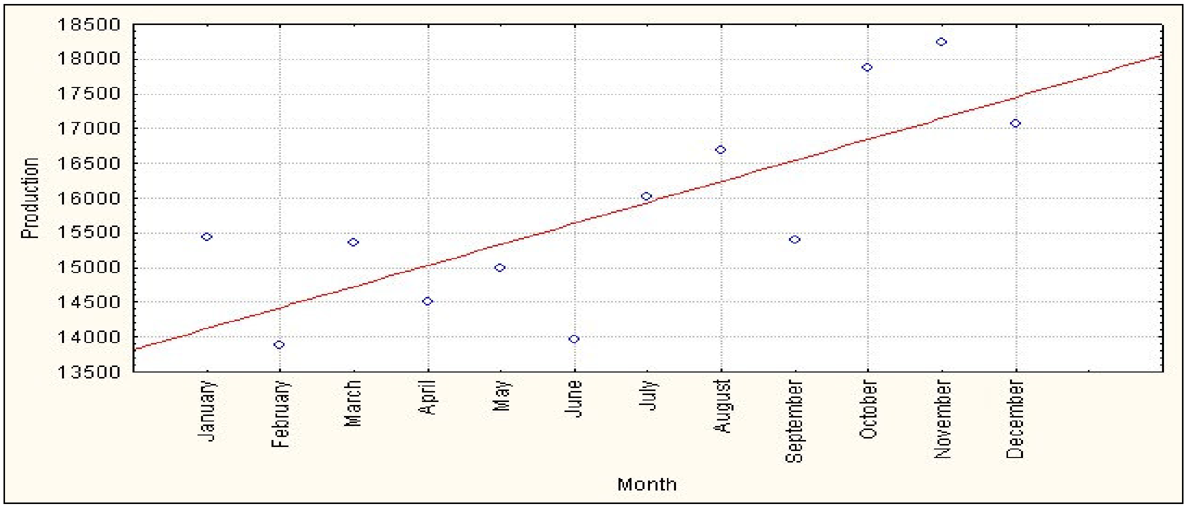

Figure 7. Monthly trend production.

adaptation techniques.

Monthly tomato production

Figure 7 demonstrates that the estimated impacts of climate on tomato yield trends was statistically significant for the tomato yield throughout the months, except for February, April and June, which shows fewer yields.

DISCUSSION

Plant scientists and ecologists currently examine historical records as signs of biological responses to climate change trends. Changes in climatic factors such as temperature, solar radiation and precipitation influenced crop production. For instance, while elevated atmospheric carbon dioxide (CO_2) concentration (above some threshold) has the effect of increasing plant photosynthesis and therefore increase crop yield (for example Kimball, 1993), the changes in temperature and precipitation might (a) hasten plant development and (b) alter water and nutrient budgets thereby causing plant stress. An increase in CO_2 is known to affect the mineral elements such as iron, zinc, manganese and sulphur present in tomatoes. In addition, weeds and other beneficial and harmful insects and microbes present in agro-ecosystems respond to changes in climatic factors. This corroborates with the generally positive response of most invasive and noxious weeds due to the increasing atmospheric CO_2 levels as reported in Ziska (2003).

Tomato is an important vegetable that is prone to heat stress. Optimal temperature values for leaf/stress development, fruit addition and fruit growth, in tomatoes are about 22 - 25°C. The distribution of tomato crop is determined by the climatic resources of a given area. The temperature fields over Limpopo province averaged around these optimal values and therefore could be associated with the high production of tomatoes. Temperatures exceeding 25°C are likely to reduce tomato production. Assuming a non-linear tomato yields response and optimal temperature values, it is expected that there could be about 10% drop in tomato yield for ~1°C rise in temperature above 25°C.

Agriculture in emerging economies such as South Africa has not directly benefited from optimizing the adaptive areas for tomato crops. The variability of tomato production between years as demonstrated in this study could be linked to the seasonal weather effects (and these effects also influence how insects, diseases and weeds affect tomato production). While the effect of temperature on tomato product has spatial and temporal dependence (for example, local and season of sowing), the response of tomato production to future climate change and climate variability will depend on management practices such as the type and levels of water and nutrients present. In order to maintain or increase tomato yields under climate change, an assessment study was done to (a) identify the present yield thresholds and (b) help select appropriate adaptation strategies to support tomato cropping systems in future.

Conclusions

This study examined the correlation of climate change factors such as temperature on tomato production. The results from the present study could be used as a baseline in understanding the consequences of climate change and climate variability on agriculture. As such, the analysis utilized the *Statistica* software to estimate the factor of climate in the current yield trends by applying the regression models to observe trends in climate variables for a period of 36 years from 1971-2006. It was noted that although, there were some relationships between average minimum, maximum and average temperature as well as seasonal temperature and tomato production over Limpopo province, some of the extreme temperature conditions did not affect the tomato production. Our present analysis of the linkage between temperature and tomato production indicate that tomato yield in Limpopo province during 1971-2006 has been increasing, probably by the use of good farming practices, application of fertilizers and the use of irrigation system. However, it is likely that depen-dency observed from our analysis does not account for all other environmental factors and therefore, these results could be too optimistic because they are based on a capital intensive agricultural system with significant adaptative capacity. Regarding the climate variables used in this study, particularly temperature, there is sufficient evidence to conclude that agriculture could be affected by future climate change and climate variability, because the results demonstrate a correlation between temperature and tomato production in Limpopo province.

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