RELATIONSHIP OF THE SUNSPOT NUMBER WITH CROP YIELD FOR SELECTED CROPS IN DIFFERENT COUNTRIES: A MATHEMATICAL APPROACH

V.A.C. Hansani*, A.P.H. Somarathna[1*], D.A.P.D.P. Ranasinghe[1], A.T. Bulathsinghala[1], K.A.C. Nilmini[1], J.V. Wijesekera[2], R.K.C.S. Rajakulathunga[1], H.R.S. Udani[1], B.K.S. Perera[1], W.C.S. Senarath[1]

[1]Institute of Astronomy, Colombo, Sri Lanka
[2]University of Padova, Italy.

INTRODUCTION

Agricultural crop production is considered one of the most focused areas since malnutrition has become a major crisis in the world (Sellam & Poovammal, 2016). Due to this high demand for food, there is much concern about the factors that could affect yield, and the effect of the weather has been identified as a key factor (Crop, Cyclical, Liu, Agricultural & Society, 1978). Most of the climatic parameters on which agriculture partially or entirely depends seem to arise from the output of the sun in the forms of electromagnetic radiation, energetic particles (Champaneri & Technology, 2020) and changes that occur in the magnetic field (Wijesekera, Jayaratne, & Adassuriya, 2018). Sunspot behaviour follows a predictable pattern and the Sunspot Number (SSN) is the key indicator of solar activity (Hathaway, 2015). Predicting crop yield responses to climate changes and other variabilities are usually done by using process-based modelling or statistical modelling (Michel & Makowski, 2013). In the preliminary study, parametric analysis of data on SSN and crop yield was carried out, and the coefficients obtained from the analysis were used in a modelled equation to predict the yield of selected crops (rice, tea and sugarcane) in Sri Lanka (Wijesekera, 2021). It is important to validate the model when implementing the model for predicting yield as it is intended for use in decision-making for the coming years. Therefore, the validation of this model will offer the ubiquitous opportunity to evaluate the effects of SSN on crop yields all over the world. The main objective of this study is to investigate the validity of the proposed crop yield model against SSN in latitudinally different countries and thereby, stress the importance of accounting SSN in the conventional weather parameter when predicting crop yields across the globe.

METHODOLOGY

Data on the total cultivated area (ha) with yields (hg ha^{-1}) of rice, tea and sugarcane from 1961 to 2019 was obtained from the Food and Agricultural Organization, Statistics Division (FAOSTAT), while online data on the yearly mean total SSN was retrieved from the World Data Center - Sunspots Index and Long-term Solar Observations (WDC - SILSO) from 1961 to 2019. The crop yield model over SSN has used the study to investigate the relationship between crop yields against SSN for tea, rice and sugarcane in Sri Lanka. The observed yield with SSN, time and cultivated area as input variables were studied and Minitab Software was used for polynomial regression analysis to obtain coefficients for the parameters in Nigeria (Champaneri & Technology, 2020). Multiple linear regression was used in this study, which best represented the relationship between solar activity and crop yield variables to predict the yield of crops in Sri Lanka. The analysis yielded parametric coefficients and those were inputted into the modeled equation for each study of the crop as expressed in equations [1], [2] and [3]. The equations were used to generate predicted outputs for rice, tea and sugarcane, respectively. The model was used in this work to predict the yield mentioned above (Champaneri & Technology, 2020).

[1] $\text{Yield (tea)} = -181437.5670 - 2.8200(\text{SSN}) + 103.7268(\text{T}) - 0.0596(\text{A})$

[2] $\text{Yield (rice)} = -845920.0180 + 5.5404(\text{SSN}) + 441.1705(\text{T}) - 0.0037(\text{A})$

[3] $\text{Yield (sugarcane)} = -14378029.9100 - 72.4455(\text{SSN}) + 7507.3474(\text{T}) - 7.4666(\text{A})$

The *SSN*, *T* and *A* represent the sunspot number, time and cultivated area, respectively. The validity of this crop yield model against the sunspot number created for Sri Lanka was applied for different countries throughout the world. Climate effects were ignored in the selection of countries that are on the equator (Sri Lanka, Indonesia, Kenya and Brazil) and near the equator (India), and in high latitudes (Madagascar, South Africa, Argentina, USA and China). Crops (banana, soybean and tea) that grow in the selected countries were analysed to investigate the predicted yield of different countries that are on the equator, near the equator and in high latitudes using the same model. The coefficient of determination was used to evaluate the efficiency of the model.

RESULTS AND DISCUSSION

The preliminary study showed that a significant decrease in the yield of the crops during and around periods of solar maximum (1968, 1989 and 2000) and increase in the yield of the crops during the periods of solar minimum (1976, 1996 and 2008). Nonetheless, the influence of solar activity is evident, as seen in the model results, and this could be attributed to the amplified effects of the sun, which is owing to direct thermal circulation at the study location. The heterogeneity of the coefficient of variation in the yield of the crops throughout the study period can be credited to various factors in addition to solar variability. The magnification of the effects of solar activity through solar radiation is most noticeable in regions of direct thermal circulation (Pustil'nik & Yom Din, 2013). Countries located near the equator receive direct solar radiation compared to the countries in the Polar regions. Sunshine received, directly through radiation and indirectly through its effect upon air temperatures influences the distribution of crops. Studies have found that the yield increases when SSN is increased in countries in the north and south poles (Pustil'nik & Yom Din, 2013).

In contrast, some countries like Nigeria show records of low yields for some crops during the periods of maximum solar activity while there is a significant increase in yields of crops during periods of minimum solar activity (Commission, Adagba, & Ikyo, 2021). In addition, the quality and quantity of the sunlight transmitted to growing crops are both dependent upon atmospheric conditions and upon the season of the year. They vary from place to place and from month to month around the globe (Champaneri & Technology, 2020). The cultivated area can be considered in the study to be a better input variable in crop yield prediction. The use of SSN to the conventional weather or climate parameters has shown that the activity level of the sun can also be employed as a forecaster in predicting the yield of crops in retrospect and the future on a short-term basis. The results given below show the calculated R^2 values for the crops grown in countries on the equator and near the equator and in high latitudes. The model is estimated at the country scale.

Table 1: The calculated R^2 values for the crops grown in countries on the equator and near the equator and in high latitudes.

Countries	**Tea (R^2)**	**Banana (R^2)**	**Soybean (R^2)**
India	0.93	0.88	0.68
Kenya	0.92	0.68	-
Sri Lanka	0.82	-	-
Indonesia	-	0.88	0.96
Brazil	-	-	0.92
Madagascar	0.92	0.74	-
China	0.94	0.92	0.89
Argentina	0.91	-	0.79
South Africa	-	0.94	0.67
USA	-	-	0.90

According to these results, R^2 values were greater than 0.82 for tea, 0.88 for banana and 0.67 for soybean. The coefficient of determination is the square of the Pearson's product-moment correlation coefficient ($R^2 = r^2$) and describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 to 1.0, with higher values indicating better agreement (David R Legates, 1AD). The model performed considerably well for all the countries worldwide.

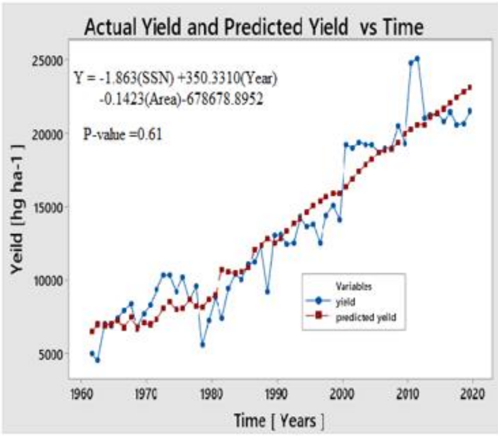


Figure 1: Actual and predicted yield for tea in Argentina

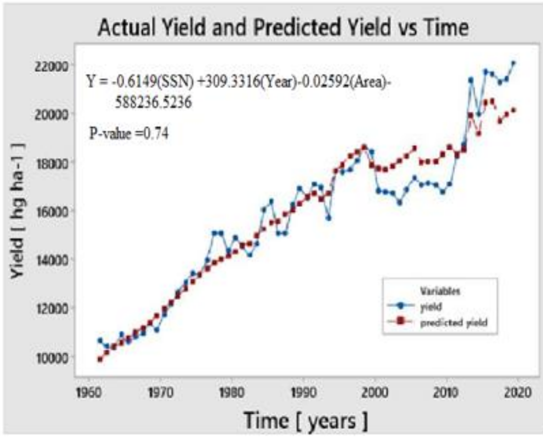
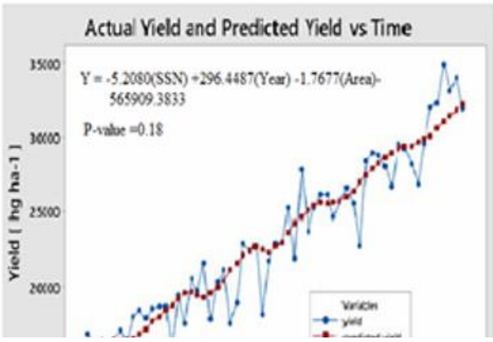
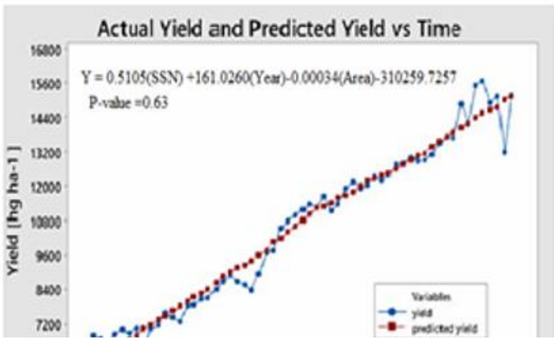
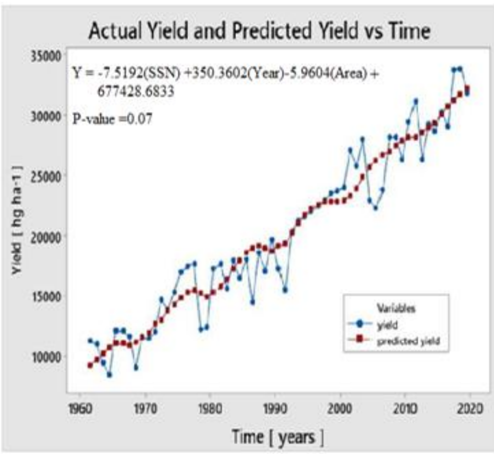


Figure 2: Actual and predicted yield for tea in India.







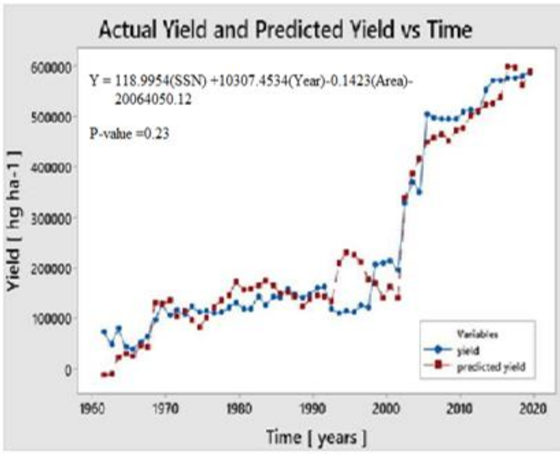


Figure 5: Actual and predicted yield for banana in China

Figure 6: Actual and predicted yield for banana in South Africa

Figures 1 and 2 show the actual and predicted yields of tea for Argentina and India, Figures 3 and 4 show the actual and predicted yields of soybean for the USA and Indonesia, and Figures 5 and 6 show the actual and predicted yields of banana for China and South Africa, respectively. For the selected food crops and regions throughout the world, the validation results are within this range and hence, the model can be seen to be robust against the SSN on latitudinally different countries. Further, the model could be satisfactorily employed in the assessment of impacts of and adaptations to climate variability due to solar activity and sunspots. Furthermore, these results revealed the validity of this model.

CONCLUSION

The R^2 values obtained from multiple linear regression fluctuates between 0.67 – 0.96. The p-values obtained for Sri Lanka and other countries under study were greater than the 0.05 level of significance for every crop considered in this study. It concludes that the model performed considerably well for the countries under study for the selected crops. Further, it is obvious that there is an effect of SSN on crop yield similarly to other parameters that affect crops. Comparably, a model using a polynomial regression analysis can be a better representation for different crops in other countries and further studies on this are currently underway.

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ACKNOWLEDGMENTS

The authors would like to extend their gratitude toward the Institute of Astronomy for providing the facilities to conduct this research.