Assessment of Climate Events in Changma Season (Korean Monsoon) for Production Trend of Sorghum-Sudangrass Hybrid (*Sorghum bicolor* L.) in the Central Inland Regions of Korea Using Time Series Analysis

M. Kim
Kangwon National University, South Korea

J. Y. Kim
Kangwon National University, South Korea

M. H. Jo
Kangwon National University, South Korea

K. Sung
Kangwon National University, South Korea

H. Jo
Kangwon National University, South Korea

Assessment of climate events in Changma season (Korean monsoon) for production trend of sorghum-sudangrass hybrid (*Sorghum bicolor* L.) in the central inland regions of Korea using time series analysis

Kim, M.*; Kim, J. Y.†; Jo, M. H. †; Sung, K.†; Jo H. †
*Institute of Animal Resources, Kangwon National University, Korea;
† College of Animal Life Sciences, Kangwon National University, Korea;

Key words: sorghum-sudangrass hybrid; heavy rainfall; typhoons; production trend; time series analysis

Abstract
This study aimed to assess the impact of climate events in the Changma (Korean Monsoon) season on the production trend of sorghum-sudangrass hybrid (SSH) in central inland regions using time series analysis. The dataset in Suwon from 1988–2013 (n = 388) was generated by merging SSH data and climate data. The accumulated temperature (SHAT, °C), rainfall amount (SHRA, mm) and sunshine duration (SHSD, hr) from seeding to harvesting were used to assess their impact on the trend of dry matter yield (DMY, kg/ha) for SSH. Furthermore, heavy rainfall (HRF) and typhoons (TPH) were considered as climate events. As a result, the impact of climate events did not affect DMY, even though the frequency and intensity of HRF increased. Conversely, SHAT and SHRA had positive and negative effects on the trend of DMY, respectively. Therefore, the DMY trend of SSH was forecasted to increase until 2045, unlike maize, which has shown a declining trend. The forecasted DMY in 2045 was 14,926 kg/ha. It is likely that the damage by heavy rainfall and typhoons was reduced due to multiple-harvesting and a deeper extension of the root system. Therefore, in an environment that is rapidly changing due to climate change and abnormal weather, such as the Changma season, the cultivation of SSH would be advantageous as it would ensure a stable and robust yield.

Introduction
Climate change has been a major interest to various fields of science over the past two decades, including agriculture (Iglesias et al., 1996; Fischedick et al., 2014). Particular interest needs to be focused on changes in the frequency and intensity of abnormal climate events that can greatly affect crop production. In Korea, increasing winter-spring temperatures and accelerating summer heavy rainfalls (HRF) are considered as being major abnormal climate events caused by climate change (Kang et al., 2011; Kim et al., 2005; Park et al., 2011). The quantity of rainfall in the Changma (Korean monsoon) season accounts for 40–60 % of total average annual rainfall (Lee and Kwon, 2004), with a high likelihood that the prevalence of torrential rainfall increases with increasing occurrence of HRF events. Furthermore, during the Changma season, the arrival of typhoons (TPH) also needs to be looked at because various summer crops are seriously damaged by TPH ahead of harvests (IPCC, 2007).

In general, forage crops that do not rely on facility cultivation are more vulnerable to external environmental shocks. Whole crop maize (Zea mays L.; WCM) and sorghum-sudangrass hybrid (Sorghum bicolor L.; SSH) are typical summer forage crops in the Republic of Korea. According to Kim et al. (2019), WCM has been widely cultivated, however, HRF during the Changma season led to serious yield damage. Furthermore, due to the increasing frequency and intensity of HRF, forecasted WCM yields were predicted to drop to 70% of the previous 30-year average yield by 2045. Conversely, SSH can be harvested multiple times a year, with most of them being non-silking types focused on nutritional growth (Choi et al., 2017; Lee et al., 2000). Therefore, to achieve a stable yield, SSH has been widely cultivated as a forage crop in environments with a high possibility of cultivation failure. To predict SSH yield in the Republic of Korea, climatic, soil and cultivar factors were considered. As a result, the negative impact of summer-concentrated precipitation exceeding the water requirements for growth and development was noticeable (Peng et al., 2020). The variation in yield was estimated to predict optimal seeding and harvesting dates by using the optimum moving response surface methodology (Kim et al., 2020). For long-term SSH yield trends, the impact of accumulated temperature and precipitation was evident (Chemere et al., 2018). These studies focused on the impact of climate change under normal conditions; therefore, their results did not reflect abnormal climatic conditions.

Therefore, this study aims to assess the impact of HRF and TPH events in the Changma season on SSH production trend in central inland regions and aims to forecast DMY using time series analysis.

Methods and Study Site

The raw SSH data (n = 1,076), including the sum of dry matter yields (DMY, kg/ha), number of harvests, year, address, seeding and harvesting dates, etc., were collected from reports on the new variety adaptability experiments by the Rural Development Administration (RDA). Usually, the damage caused by HRF and TPH in the Changma season varies considerably depending on local and topographical conditions; therefore, it was necessary to select a single location for homogeneity of data. Based on the regional classification chart of the Republic of Korea (Ko et al., 2006), SSH is predominantly cultivated in central inland and southern inland regions. Furthermore, it was important to record long-term data to allow for trends to be detected. Considering these two conditions, Suwon (latitude: 37° 15′ N, longitudinal: 127° 04′ E, n = 388) was selected as a representative central inland region of the Republic of Korea during for the period spanning 1988 to 2013 (26 years). Modeling and forecasting were carried out to estimate any missing data (data from some years was missing) using a maximum likelihood algorithm (Jones, 1980).

The climate data from Suwon, including the hourly, daily, and monthly recorded information related to temperature, rainfall and sunshine, was collected from the Korean Meteorological Administration's (KMA) weather information system via open-API (application programming interface). Results for seeding–harvesting accumulated temperature (SHAT, °C), seeding–harvesting rainfall amount (SHRA, mm), seeding–harvesting sunshine duration (SHSD, hr), HRF 1 (frequency of over 7.6 mm/hr rainfall amount), HRF 2 (dummy variable, 1: over 1,000 mm/July, 0: else), and TPH (frequency of a typhoon passing through the Korean Peninsula) were generated.

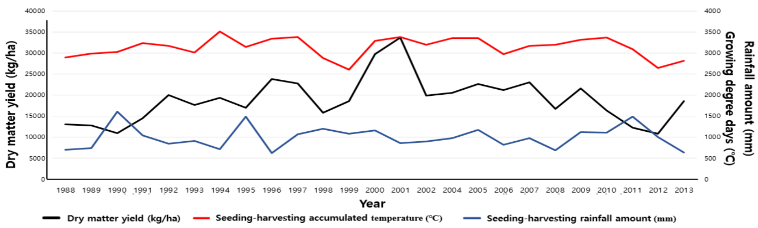
Time series analysis was used to estimate and forecast the trend of SSH production using PROC ARIMA of SAS 9.4 (SAS Institute Inc., Cary, NC)

Results

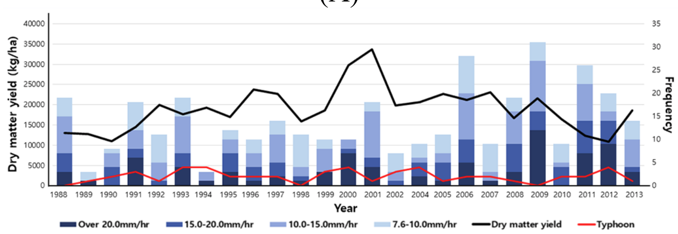
Assessment of the impacts of climate variables on the production of sorghum-sudangrass hybrid

A year by year trend for the effective SHAT and SHRA can be seen in Figure 1A. The trends in DMY and SHAT looked similar over the whole time period (1989–2013), especially between 1992–2007 and 2010–2013. Some trends were noted between DMY and SHRA, however, this was not consistent as some conflicting trends were also detected. For example, the SHRA trend in 2002–2009 showing rainfall of below 1,000 mm was similar to the DMY trend. In contrast, when SHRA was over 1,000 mm, DMY was found to decrease, with the years of 1990, 1995, 1998, 2010, 2011 and 2012 standing out. Therefore, it was hypothesized that the SHAT trend was associated to the overall DMY trend and that the SHRA trend was also correlated to the DMY trend depending on the specific range of rainfall.

To confirm the damage in DMY caused by climate events, DMY each year was compared based on the frequency of HRF and TPH (Table 1). In the case of HRF events, DMY tended to decrease with increasing frequency of HRF 1 and HRF 2, although no statistical significance was noted (P = 0.92 in HRF 1 and P = 0.31 in HRF 2) due to the small sample size. In the case of TPH, there was no significant difference in DMY (P = 0.66) and there was no specific correlation between the two.



(A)



(B)

FIGURE 1. Trend of climate variables by year in the central inland regions of the Republic of Korea (1988–2013): (A) climate variables related to growth and development, (B) climate events in the Changma season.

Yearly trends showing the impact of HRF and TPH, can be seen in Figure 1B. HRF 2 was not considered because of the dummy scale. No real correlation could be found between the trend in DMY with that of HRF 1 and TPH. However, since 2005, the frequency and intensity of HRF 1 have increased. Furthermore, the correlation analysis checking the relationship between HRF 1 and TPH showed a weak, correlation (Spearman's r = 0.41*), which is indicative of some HRF events being associated with TPH events.

TABLE 1. Comparison of the impacts of climate events in the Changma (Korean Monsoon) season on dry matter yield for sorghum-sudangrass hybrid using ANOVA

Events	Frequency	Sum of dry matter yield (kg/ha)	Test
Heavy rainfall 1	Less 10 (n = 10)	19,506.80 ± 1,720.91	F = 0.09 (P = 0.92)
(7.6 mm/hr)	10–20 (n = 12)	18,598.75 ± 1,708.87	
	Over 20 (n = 3)	18,372.33 ± 3,027.91	
Heavy rainfall 2†	0 (n = 13)	20,020.54 ± 1,461.11	F = 1.04 (P = 0.31)
	1 (n = 12)	17,758.58 ± 1,622.83	
Typhoon	0 (n = 2)	17,324.00 ± 4,276.01	F = 0.66 (P = 0.66)
	1 (n = 3)	24,334.00 ± 8,643.23	
	2 (n = 5)	18,194.40 ± 4,174.11	
	3 (n = 5)	17,985.00 ± 4,235.48	
	4 (n = 4)	17,799.25 ± 5,001.15	
	5 (n = 6)	18,937.67 ± 6,404.31	

†Dummy scale (1: over 1,000 mm in Changma season, 0: else)

Estimating and forecasting the production trend of sorghum-sudangrass hybrid

Considering climate variables, the optimal model for showing the trend in DMY of SSH was model 2, as follows:

$$DMY_t = (1 - 0.37)DMY_{t-1} + 0.37DMY_{t-2} + 6.88SHAT_t + 7.32SHAT_{t-1} - 3.55SHPA_t - 3.56SHPA_{t-1},$$

where DMY_{t-i}, $SHAT_{t-i}$ and $SHPA_{t-i}$ are equivalent to DMY, SHAT and SHRA at $t - i$ time, respectively. i is time order; zero means the current point in time. The DMY trend was a first-order in the AR model with one order of non-seasonal differencing. Even though it looked like AR (2) because of the second-order term (DMY_{t-2}). Therefore, SHAT (1) and SHRA (1) had the same order of AR in DMY.

According to Kim et al. (2019), for whole crop maize, HRF in the Changma season occurring concurrently with the plant's pollination stage is likely to cause damage due to lodging and pollination failure. For SSH, the lodging caused by HRF and TPH might be not critical due to their quick regrowth capabilities and short rotations (Armah-Agyeman et al., 2002).

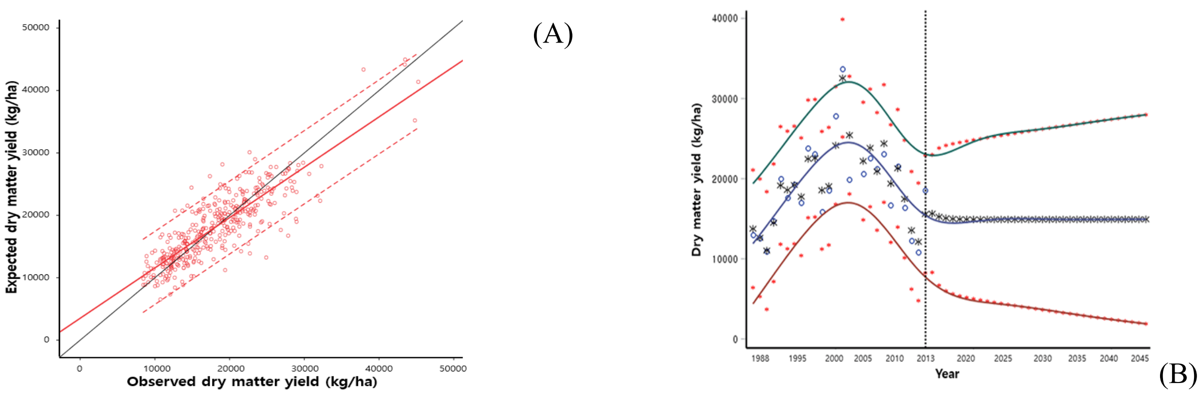


FIGURE 2. Dry matter yield of sorghum-sudangrass hybrid with a 95% confidence interval considering growing degree days and rainfall amount in the central inland regions of Korea (The mean, 95% upper and lower confidence limits are blue, green and red lines, respectively): (A) observed vs. expected dry matter yields, (B) forecasted dry matter yield (1988–2045)

Based on this model, DMY was forecasted from 2014 to 2045 (Figure 2). The forecasted DMY (kg/ha) values were 14,908.06 ± 5,058.72, 14,904.43 ± 5,420.33, 14,909.66 ± 5,754.48, 14,915.13 ± 6,070.15, 14,920.60 ±

6,370.19 and 14,926.09 ± 6,656.72 for the years 2020, 2025, 2030, 2035, 2040 and 2045, respectively. Hence, future trends in DMY show an increase based on the impacts of positive SHAT and negative SHRA.

Discussion [Conclusions/Implications]

In conclusion, no clear damage in the annual total production of sorghum-sudangrass hybrid due to heavy rainfall and typhoons occurrence during the Changma seasons were noted, although excessive rainfall affected the production reduction. It is likely that any short-term damage is not critical due to annual multiple harvests. Therefore, under a rapidly changing environment causing abnormal weather, increasing frequency and intensity of heavy rainfall and typhoons, the cultivation of sorghum-sudangrass hybrid would ensure stable and robust forage production.

Acknowledgements

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Science and ICT (NRF- 2020R1C1C1004618).

References

Fischedick, M., Roy, J., Acquaye, A., Allwood, J., Ceron, J.P. et al., and Tanaka, K., 2014. Industry. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S. et al and Minx, J.C. (eds.)]. Cambridge University Press, Cambridge, England.

Iglesias, A., Erda, L., Rosenzweig, C., 1996. Climate change in Asia: a review of the vulnerability and adaptation of crop production. In Climate Change Vulnerability and Adaptation in Asia and the Pacific (pp. 13–27), Springer, Dordrecht, Netherland.

Intergovernmental Panel on Climate Change [IPCC], 2007. Climate Change 2007: Synthesis Report. Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)] (pp. 104). IPCC, Geneva, Switzerland.

Kang, K., Lee, D., Na, Y., Sim, K., Choi, I., Lee, C., Park, K., Kim, J., 2011. Climate change and Agriculture in Korea, 33rd ed. (pp. 1–25). Rural Development Administration, Seoul, Korea.

Kim, S., Park, C.K., Kim, M.K., 2005. The regime shift of the northern Hemispheric circulation responsible for the spring drought in Korea. J. Kor. Meteorol. Soc. 41(4), 571–585.

Park, T.W., Ho, C.H., Jeong, S.J., Choi, Y.S., Park, S.K., Song, C.K., 2011. Different characteristics of cold day and cold surge frequency over East Asia in a global warming situation. J. Geophys. Res. Atmos. 116(D12).

Lee, S., Kwon, W.T., 2004. A variation of summer rainfall in Korea. J. Kor. Geogr. Soc. 39(6), 819–832.

Choi, G.J., Lee, S.H., Lee, K.W., Ji, H.C., Hwang, T.Y., Kim, K.Y., 2017. Comparison of Growth Characteristics, Productivity and Feed Values between Varieties of Sudangrass and Sorghum-Sudangrass Hybrids. J. Kor. Soc. Grassl. Forage Sci. 37(1), 92–99.

Lee, J.K., Kim, J.G., Shin, D.E., Yoon, S.H., Kim, W.H., Seo, S., Park, G.J., 2000. Effects of cutting frequency on yield and nutritive value between heading and headless varieties of sorghum x sudangrass hybrid. J. Kor. Soc. Grassl. Forage Sci. 20(4): 237–242.

Peng, J., Kim, M., Sung, K., 2020. Yield prediction modeling for sorghum–sudangrass hybrid based on climatic, soil, and cultivar data in the Republic of Korea. Agric. 10(4), 137.

Kim, M., Kim, J.Y., Sung, K., 2020. The optimum seeding and harvesting dates of sorghum–sudangrass hybrid (Sorghum bicolor L.) via optimum moving response surface methodology. Grassl. Sci. (Online published)

Chemere, B., Kim, J., Lee, B., Kim, M., Kim, B., Sung, K., 2018. Detecting long-term dry matter yield trend of sorghum-sudangrass hybrid and climatic factors using time series analysis in the Republic of Korea. Agric. 8(12), 197.

Ko, J.W., Baek, H.J., Kwon, W.T., Park, J.Y., 2006. The characteristics of spatial distribution of temperature and regionalization in Korea. J. Clim. Res. 1(1), 3–14.

Jones, R.H., 1980. Maximum likelihood fitting of ARMA models to time series with missing observations. Technometrics 22(3), 389–395.

Kim, M., Chemere, B., Sung, K., 2019. Effect of Heavy Rainfall Events on the Dry Matter Yield Trend of Whole Crop Maize (Zea mays L.). Agric. 9(4): 75.

Armah-Agyeman, G., Loiland, J., Karow, R., Bean, B., 2002. Sudangrass. OR: Extension & Station Communications, Oregon State University, Corvallis, Oregon.