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Short Communication

Soybean Production Prediction Based on Its Relationship to Climate Change: A Case Study in Karawang, Indonesia

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Abstract

As a global issue, climate change significantly affects agricultural activities because of extreme weather, shifting rainfall patterns, and increasing temperatures. We evaluated the relationship between climate change and soybean production with the case study in Karawang, Indonesia. Linear regression and Pearson correlation analyses examined climate change trends in six subdistricts of Karawang and their relationship with soybean production factors. The present study evaluated the data from two periods: 1991–2005 and 2006–2020 and found that soybean production could decrease by 6,595.19 tons due to a 60% reduction in harvest area, totaling 1,139.41 ha, despite a productivity increase of 5.91 in the latter period. Pearson correlation analysis indicated a significant positive relationship between air temperature and soybean productivity, while rainfall showed no significant correlation. However, projections reveal a decline in soybean production due to declining soybean harvest area by 2030. The study focused on soybeans in Karawang, but the method can be applied to other regions and crops for broader climate change mitigation research.

Keywords: Harvest area; Increasing temperatures; Linear regression; Pearson correlation; Soybean

Introduction

Climate change is a global issue that has profound impacts on life, such as extreme weather events, changes in rainfall patterns, rising temperatures (IPCC 2022; Pope *et al.* 2022), and eventually damaging agricultural sector (Malhi *et al.* 2021). Some of the impacts of climate change on agriculture include reduced productivity and production, leading to crop failures, damage to agricultural land resources, increased intensity of floods and droughts, and heightened intensity of plant pests. Developing nations, particularly those in Sub-Saharan Africa and Asia are the most susceptible to adverse impacts (IPCC 2014). Recent observations indicate a rise in global temperatures by 0.9°C since the nineteenth century (Eftekhari 2022).

Temperature is a critical factor to consider due to its impact on various plants, including tropical fruit plants (Efendi and Budiarto 2022), kaffir lime (Budiarto and Sholikin 2022; Budiarto *et al.* 2024), vegetable (Bisbis *et al.* 2018), tomato (Suminar *et al.* 2022; Rahmat *et al.* 2023), corn (Mubarok *et al.* 2022), sugarcane, rice, cotton (Hussain *et al.* 2022) and soybeans (Ramteke *et al.* 2015; Feng *et al.* 2021). Soybean (*Glycine max* L.) is an important food crop for maintaining global food security (Dilawari *et al.* 2022), including Indonesia (Harsono *et al.* 2022). This crop is highly influenced by climate, including temperature and rainfall. Increased temperatures in tropical regions can affect soybean productivity, causing the plants to flower quickly and resulting in lower yields. Moreover, high temperatures can lead to increased transpiration and plant stress, such as an increase in reactive oxygen species (Mubarok *et al.* 2024). Therefore, efforts are made to continually increase soybean production during global warming, especially in production center areas.

Karawang Regency is one of the soybean-producing centers in Indonesia (Ministry of Agriculture 2023). It is necessary to further investigate the soybean production status and its relation to climate change in Karawang Regency. Therefore, the present study aimed to evaluate the relationship between climate change and soybean production with the case study in Karawang, Indonesia. The implication of this study is the provision of future projection of soybean development in Karawang Regency.

Materials and Methods

This research was conducted in Karawang Regency (107°02'40" E – 5°56'34" S), West Java Province, Indonesia

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in 2022. The study used descriptive and verificative methods to collect primary and secondary data. Primary data consisted of in-depth interviews with soybean farmers, the leaders of farmer groups, and agricultural extension officers. Secondary data, encompassing climate information (*i.e*., air temperature and rainfall) and soybean cultivation data (production, productivity, and harvested area) from 1991 to 2020, were collected from various sources including Meteorological, Climatological and Geophysical Agency (BMKG), Statistics Indonesia (BPS), the Ministry of Agriculture (MoA) and the Agricultural Office of Karawang Regency.

Sampling was done in six sub-districts continuously producing soybeans: Lemahabang, Tirtamulya, Jatisari, Pangkalan, Tegalwaru, and Ciampel. The 20-year data on climate and production were divided into two 15-year periods, namely 1991–2005 and 2006–2020. This division aimed to examine the differences in climate and production between the first 15 years and the subsequent period. Analysis was carried out to investigate whether there were climate change phenomena in Karawang Regency by identifying temperature and rainfall change trends over the 15-year periods. These trends were sought using the linear regression equation ($Y = b0 + b1X$) applied to annual data to identify differences in climate change between the two 15-year periods. The correlation between climate elements and soybean production, productivity, and harvested area was also analyzed. The correlation analysis aimed to determine the strength of the relationship between climate elements and soybean production factors. Pearson correlation analysis was employed for this purpose.

Results

Changes in soybean production, productivity, and harvest area

Based on production data, harvest area, and productivity of soybeans obtained from the Agricultural Office of Karawang Regency, the analysis of changes in soybean production, harvest area, and productivity in Karawang Regency was clustered into two periods, namely Period I (1991 to 2005) and Period II (2006 to 2020), as shown in Table 1. Soybean production in Karawang Regency experienced a decrease of -6,595.19 tons, attributed to the reduction in soybean harvest area during these two periods, amounting to -1,139.41 ha (Table 1). There was an increase in soybean productivity by 5.91 in the period 2006–2020 compared to the previous period of 1991–2005. Unfortunately, the soybean harvest area decreased by 60%, or approximately 1,139.41 ha.

Analysis of soybean production trend

Fig. 1 showed the trend of soybean production in Karawang Regency from 1991 to 2020. It tended to decrease by -391.07 tons per year, expressed by the linear regression equation $Yt = -391.07*t + 800601$ with an R^2 of 0.0472. The fluctuating development of soybeans in Karawang Regency had occurred over the last 30 years (1991–2020). Meanwhile, soybean production in Karawang Regency had been continuously decreasing from 1994 to 2012, experiencing a brief increase in 2015, followed by a decline in 2016.

Analysis of soybean harvest area trend

Based on Fig. 2 and 3, it was evident that the soybean harvest area trend in Karawang Regency from 1991 to 2020 tended to decrease by -77.14 ha per year. This trend could be expressed by the linear regression equation $Yt = -77.14*t + 2508.8$, with an R^2 of 0.1977. The fluctuating development of soybean harvest area in Karawang Regency had occurred over the last 30 years (1991–2020). The highest soybean harvest area in Karawang Regency was recorded in 1993 at 6,592 ha, with the highest soybean yield in Pangkalan Subdistrict reaching 1,569 tons. Meanwhile, the soybean harvest area in Karawang Regency had been continuously decreasing from 1994 to 1996, experiencing a brief increase in 1996, followed by a decline in 2000.

Analysis of soybean productivity trends

Present work found an increasing trend of soybean productivity in Karawang Regency from 1991 to 2020, by 0.3345 ha per year. This trend could be expressed by the linear regression equation $Yt = 0.3345*t + 8.602$, with an R^2 of 0.587. The fluctuating development of soybean productivity in Karawang Regency had occurred over the last 30 years (1991–2020). Meanwhile, soybean productivity in Karawang Regency had continued to increase from 2003 to 2011, experienced a decline in 2012, but saw an increase again from 2013 to 2014.

Correlation analysis of climate change and soybean production

Correlation analysis was one of the statistical methods used to determine the magnitude indicating the strength or weakness of the relationship between one variable and another, regardless of whether one variable depends on another or not. The relationship between variables could be interpreted based on its correlation coefficient, which was classified as depicted in Table 2. The results of the correlation analysis of air temperature with soybean harvest area, productivity, and production from 1991 to 2005 could be seen in Table 3. It was shown that air temperature, both in the periods from 1991 to 2005 and from 2006 to 2020, positively and significantly correlated to soybean productivity in Karawang Regency. It was implied that the higher the air temperature, the higher the soybean productivity.

Table 1: Changes in production, harvest area, and productivity of soybeans in Karawang Regency in the period 1991-2005 and 2006-2020

Variable	Period 1 (1991-2005)	Period 2 (2006-2020)	Alteration
Production (tons)	19,602.66	13,007.47	-6,595.19
Productivity (ton/ha)	1.083	1.674	0.591
Harvested area (ha)	1,882.80	743.39	-1,139.41

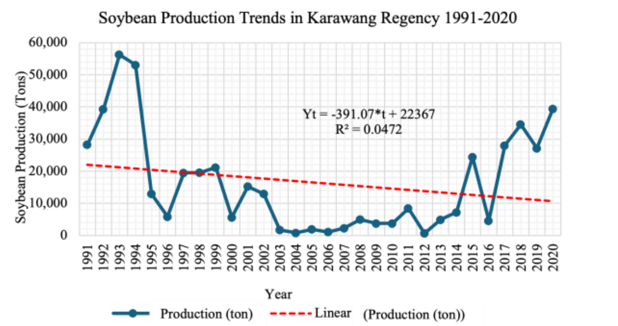

Fig. 1: Trends Analysis of Soybean Production Change in Karawang Regency during 1991-2020

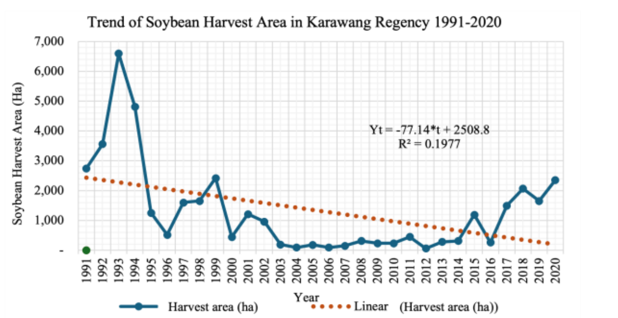

Fig. 2: Trends Analysis of Soybean Harvest Area Change in Karawang Regency during 1991-2020

On the other hand, a non-significant correlation between rainfall during the periods of 1991–2005 and 2006–2020 and soybean harvest area, productivity, and production in Karawang Regency were also noticed (Table 3).

Discussion

In Karawang regency within two periods, soybean production decreased by 6,595.19 tons due to a 60% reduction in harvest area, totaling 1,139.41 ha, despite a productivity increase of 5.91 in the later period. Land conversion significantly reduced soybean production, especially in Karawang Regency, which recorded in 2012 for only 64 ha (Statistics Indonesia 2012). Aside land conversion, the farmer's perception of soybean farming is also less profitable than other crops, due to low soybean prices (Harsono 2008). Despite this, soybean productivity slightly increased as the higher temperature in Period II compared to Period 1. It was also caused by adopting Integrated Crop Management (ICM) and using superior

Table 2: Interpretation of Coefficient Correlation

Coefficient Interval	Relationship Level
0	No correlation
0.01 – 0.25	Weak
0.26 – 0.50	Enough
0.51 – 0.75	Strong
0.76 – 0.99	Very strong
1	Perfect

Source: Sarwono 2006

Table 3: Correlation analysis of air temperature, rainfall intensity and soybean productivity, production and harvest area in both periods of 1991-2005 and 2006-2020

Variable climate	Correlation value		
	Harvest area	Productivity	Production
Air Temperature (1991-2005)	-0.1124	0.6375*	-0.0329
Air Temperature (2006-2020)	0.4365	0.5736*	0.4811
Rainfall (1991-2005)	-0.0685	-0.2934	0.0962
Rainfall (2006-2020)	-0.4299	-0.1112	-0.4182

Information: *) is correlation significant level _ real 5%

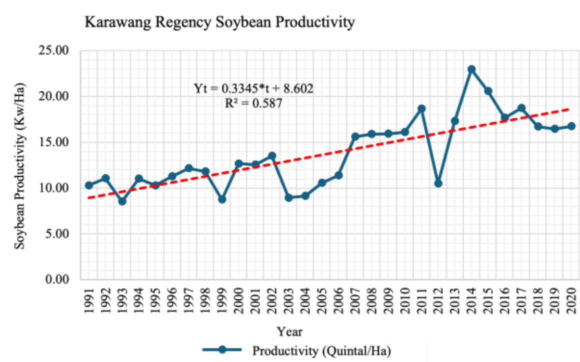

Fig. 3: Trends Analysis of Soybean Productivity Change in Karawang Regency during 1991-2020

varieties like Anjasmoro, Grobogan and Nuansa Sanggabuana. Farmers also applied recommended NPK fertilization and optimal weed control. Soybean planting in Karawang is typically done in the second season after rice, around April-July, in irrigated paddy fields, with adjustments in rainfed and upland fields based on water availability. Karawang Regency benefits from robust irrigation infrastructure. This ensures a stable water supply for soybean cultivation during El Niño, maintaining plant growth and productivity. Moreover, the infrastructure helps prevent floods during heavy rainfall or La Niña events, thanks to well-designed irrigation channels and reservoirs. The impact of climate change on soybean production can be overcome by implementing strategic adaptation options, as reported by Ruminta *et al.* (2020) in Garut Regency.

Present work also provided a soybean production projection in Karawang Regency up to 2030. The projection in Fig. 4 indicates a significant decline in soybean cultivation area in Karawang Regency from 2021 to 2030, with a trend of -69.381, as also indicated by the Ministry of Agriculture (2023). By 2030, there might be minimal

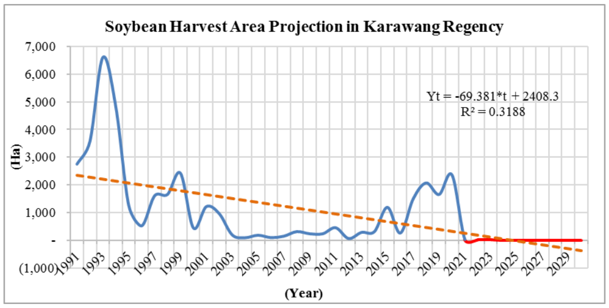

Fig. 4: Projection of soybean harvest area in Karawang Regency

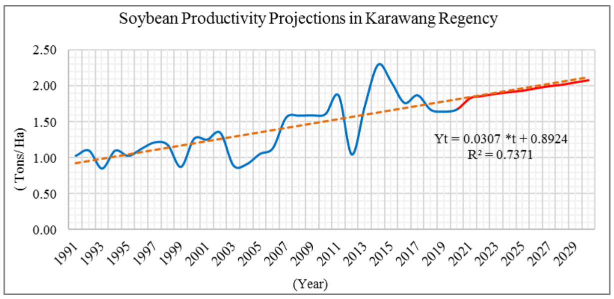

Fig. 5: Projection of soybean productivity in Karawang Regency

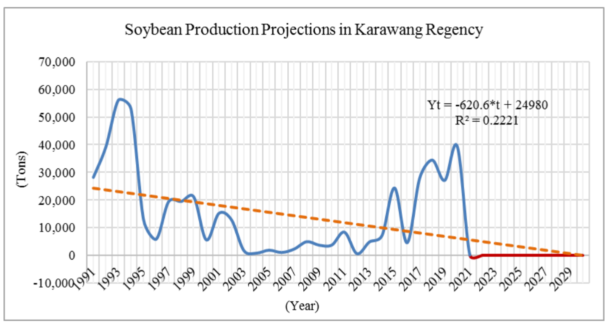

Fig. 6: Projection of soybean production in Karawang Regency

soybean cultivation due to the agricultural focus on rice crops supported by grants and insurance guarantees for rice farmers. Additionally, soybean harvest area projections in Indonesia continue to decrease due to competition for land and the conversion of soybean fields to non-agricultural uses driven by economic factors and population growth.

Fig. 5 indicates a rising trend in soybean productivity in Karawang Regency, with an increase of 0.0307 tons/ha. Various factors influence this rise, including agroecological suitability and technological advancements. Government initiatives, such as integrated crop management and superior seed development programs, contribute to this improvement. These efforts aim to enhance self-sufficiency and national productivity in soybeans (Setyawan and Huda 2022).

Fig. 6 indicates a declining trend in soybean production in Karawang Regency from 2021 to 2030, with an annual decrease of -620.6 tons. This decline is attributed to land competition with other commodities like corn and chili. The reduction in harvest area directly impacts soybean production in the region. This instability underscores the importance of addressing both harvest area and productivity to sustain soybean production (Aldillah 2023).

The projection made by present work was enriched the state of art of climate-based projection. Based on previous climate assessments conducted in Pakistan (Ali *et al.* 2019; Amin *et al.* 2018), particularly concerning cotton production (Rahman *et al.* 2018), a similar methodology can be employed to predict soybean yields by leveraging machine learning techniques (Torsoni *et al.* 2023). This would facilitate an understanding of the future dynamics of global soybean cultivation under various climate change scenarios (Feng *et al.* 2021). Additionally, Europe has utilized data-driven projections to enhance its soybean self-sufficiency in the face of climate change (Guilpar *et al.* 2022). The projection in this study was limited to soybeans in Karawang Regency. However, the method can be applied to other regions and crops based on climate data, enabling future research in larger areas and plant species for strategic climate change mitigation.

Conclusion

Soybean production in Karawang Regency, divided into two periods (1991–2005 and 2006–2020), experienced a decrease of -6,595.19 tons, attributed to the reduction in soybean harvest area during these two periods, amounting to -1,139.41 ha. It is shown that air temperature, both in the periods from 1991 to 2005 and from 2006 to 2020, correlates positively and significantly with soybean productivity in Karawang Regency. There is an opportunity to increase soybean productivity with an increase in temperature, however, our projections suggest a decline in soybean cultivation area by 2030, largely due to competition with other crops and land conversion.

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Author Contributions

R, TN, MAS and RM planned the experiments, R conducted the experiment, RM supervised the experiment, R, TN, MAS and RM interpreted the results, and RM received research funding. All authors wrote and revised the manuscript.

Conflicts of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study are available in Meteorological, Climatological and Geophysical Agency (BMKG), Statistics Indonesia (BPS), the Ministry of Agriculture (MoA), and the Agricultural Office of Karawang Regency.

Ethics Approval

Not applicable to this paper

Funding Source

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