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Analysis of trends and driving factors for plantation crop production

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Abstract

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In this paper, we present a comparison of linear, quadratic, and exponential trend model to forecasting agricultural production 15 years later. In addition, this paper also analyses whether the land area factor or land productivity factor affects changes in the amount of agricultural production. The analysis shows that the quadratic model is more applicable to predict production trends than the linear and exponential trend models. The increase in yield per unit area as the dominant factor driving the production of several crops indicates the intensification program is running well in the research area. The increase in land area as the dominant factor affecting the production of several crops indicates that the extensification program is easy to implement due to the availability of agricultural land in agricultural locations.

Keywords: trend analysis; production driving factors; exponential trend model; linear trend model; quadratic trend model

Introduction

The increase in agricultural products is increasing along with the increase in the world population and the rapid growth of industry (Feenstra, 2002). Increasing global yields will enable farmers to meet global feed, fuel and food needs (Edgerton, 2009). As strategic step, future food security can focus on sustainable intensification or extensification of production (Grinsven et al., 2015; Garnet & Godfray, 2012; Tilman, 2011). Intensification and extensification can be used to increase agricultural production. The difference is that intensification is an increase in production through increased yields per unit area while extensification is an increase in production through the expansion of agricultural areas. In developing countries with low population densities, it is still possible to carry out extensification and intensification programs. Both intensification and extensification have their respective weaknesses. Henderson et al. (1993); Costa & Foley (2000) stated that new land cultivation is a high-cost option with the risk of losing invaluable tropical forest resources, as well as the potential for negative feedback on the global climate system. According to Alkemade et al. (2009) and Vuuren (2012) land intensification can be a direct threat to biodiversity. Meanwhile, according to Grinsven et al. (2015), farmers carry out intensification practices by adding many external input factors such as fertilizers that cause environmental pollution.

In terms of policy making, it would be more useful if the information obtained can be used as a reference to consider whether development programs should be focused. Statistical data show that agricultural production fluctuates yearly. Meanwhile, several problems related to agricultural production include small land ownership and control, limited superior seeds and capital, weak institutional capacity, as well as the absence of harmony between agricultural extension workers and other sectors. Therefore, good production planning is needed to maintain and develop the strategic role of crops by determining the right program direction. Planning is related to estimates from past conditions and the future therefore, changes in production need to be analyzed using time series/trend analysis to determine the pattern of data and predict the next trend (Wu & Song, 2007; Graham & Allan, 2008). In terms of increasing production, it would be more useful if the information obtained can be used as a reference to consider whether development programs should be focused on extensification or intensification. The dominant factors driving production growth, whether a rise in yield per unit area or an increase in land area, can be discovered by analyzing trends. Theoretically, the most decisive aspect is the accuracy of the model used and the data/information obtained, as well as the time of the data collection. In this study, 3 trend models were used to obtain the best accuracy.

Material and Methods

Time series data on production of *Coffea* (coffee), *Theobroma cacao* L. (cocoa), *Syzygium aromaticum* (clove), *Piper ningrum* (pepper), and *Alleurites moluccana* L. (candlenut) and land area of these plantation crops from 2010 to 2020 can be seen in Figure 1. Data obtained from the statistical agency of the Department of Agriculture and Plantation in the Enrekang district, Indonesia. The research location can be seen in the Figure 2.

Trend analysis on plantation commodity production

Annual data on crop production were analysed using linear, quadratic, and exponential trend models. Production data tend to change every year. The trend graph formed uses the

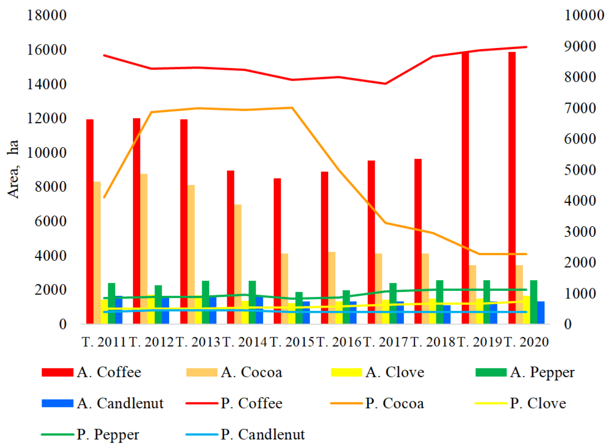

Fig. 1. Production data and plantation area for 2011 to 2020

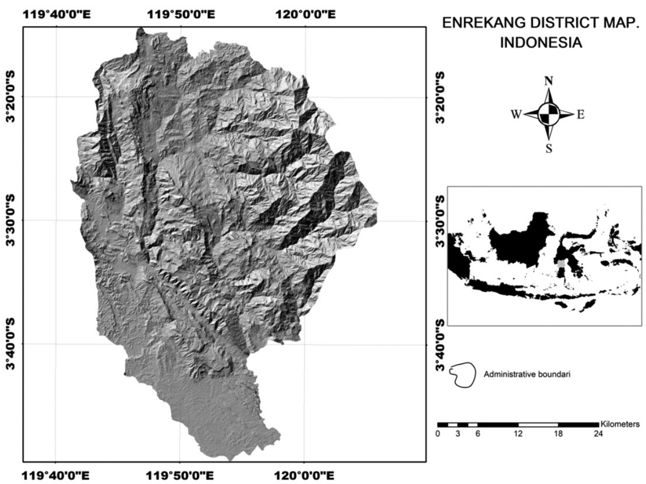

Fig. 2. Research location map

time variable (t) as the horizontal axis and the production quantity also an area as the vertical axis (P_{it}). Furthermore, the trend analysis of production data aims to show the patterns during the analysis period, hence, the best method is determined to estimate data with the minimum possible error rate.

The linear trend model was used to identify the possibility of production changes. It is defined in Equation 1 and has been implemented in various studies including Calderini & Slafer (1999) and Hafner (2003).

$$y_{it} = \beta_0 + \beta_1 t_i, \quad (1)$$

where: t_i – time index (1 for 2010, 2 for 2011, etc.) ; β_0 – constant ; β_1 – annual change in production or trend direction.

The quadratic trend method is used to determine the incidence, acceleration, deceleration, or stagnation in production (Sawant, 1983; Oyenweanku and Okeye, 2005). The determination of the quadratic trend defined in equation 2 is almost the same as the linear model (Dajan, 1988).

$$y_{it} = \beta_0 + \beta_1 t_i + t_i^2, \quad (2)$$

where: t_i^2 – time index squares.

In the quadratic model, the main factor to determine the development of crop production is the value of β_2. Negative β_2 coefficient indicates downward production growth while a positive value indicates an upward trend (Oyenweanku, 2004; Maikasuwa & Ala, 2013).

Furthermore, exponential trends were also applied in this study. In this trend, the independent variable increases multiple times and is not linear, hence, it is suitable for scatter diagrams with increasing data spread. This trend has been widely used by researchers to predict population, production, income, and other conditions (Udom, 2006; Diebold, 2007; Ojiako et al., 2008). The quadratic trend is defined in the following equation 3.

$$y_{it} = \beta_0 e^{\beta_1 t_i} \quad (3)$$

Selection of the fit trend models

The best estimation method was selected by comparing the coefficient of determination (R^2), the percentage of error, and also based on the location of the data points on the trend line used (Makridakis et al., 1998).

R^2 measures the accuracy or suitability of a regression line applied to the data (equation 4). It is defined as:

$$R^2 = \frac{REGSS}{TSS} = \frac{\sum_{it=1}^{n}(\widehat{y_{it}} - \bar{y})^2}{\sum_{it=1}^{n}(y_t - \bar{y})^2}, \quad (4)$$

where: *TSS* – Total sum square; *REGSS* – The sum square of the regression; y_t – time series value in period t; $\widehat{y_{it}}$ – The estimated production value in the period t; $\bar{y}$ – Average time series value.

Almost all prediction methods have prediction errors (Ismail & Sabri, 2014; McKenzie, 2011). The error rate in the trend model was tested using the Mean Absolute Percent Error (MAPE). It is a measure of relative accuracy used to determine the percentage deviation of the estimation results. In addition, it is used to calculate the margin of error for the method used (Moon & Tao, 2011). Khair et al. (2017); Myttenaere et al. (2016) used the MAPE method to determine the level of error from the trend model made. It is defined in equation 5.

$$\left[\frac{1}{n}\sum_{it=1}^{n}\frac{|y_t - \widehat{y_{it}}|}{y_t}\right] x\ 100\% \quad (5)$$

The trend model accuracy plays an important role in decision-making, meanwhile, the estimated value of the regression trend equation is used to predict production in the next few years. Furthermore, the best model is characterized by the highest coefficient of determination (R2) and the lowest MAPE value.

Dominant factors driving production

To increase production, useful information is needed as a reference to obtain the most appropriate program. Previous studies stated that farmers' poverty is reduced by increasing agricultural productivity (Thirtle et al., 2003; Prabha &Chatterjee, 2009; Prabha & Chatterjee, 2010).

The dominant factor driving production namely an increase in harvested area or yield per unit area is defined in the equation 6:

$$q_{it} = a_{it} y_{it}, \quad (6)$$

where: q_{it} – total production of commodity i in year t; a_{it} – total area harvested for commodity i in year t; y_{it} – result of unit area of commodity i in year t.

The logarithmic transformation of both sides in equation (7) and the differentiation to the period of study produced the equation:

$$\begin{aligned} &\log q_{it} = \log a_{it} + \log y_{it} \\ &\textit{differentiation}\ \log q_{it} = \textit{differentiation}\ \log a_{it} + \\ &+ \textit{differentiation}\ \log y_{it} \\ &I_q = I_a + I_y \end{aligned} \quad (7)$$

Equation 7 shows that the production growth rate (I_q) is equal to the land growth rate (I_a) plus the unit area yield growth (I_y). It is derived from equation 9 which states the total production of commodity i in year t is equal to the total production of resistant area multiplied by the total yield of the unit land area. Furthermore, the growth rate of the three components was estimated from the logarithmic differentiation of total production, land area, as well as the result of unit area for year t, and year t initial analysis. Based on the contribution of (I_q), (I_a), and (I_y) in equation 10, the information regarding the dominant factors driving production growth during the study period was determined. When production growth is dominated by an increase in harvested area, then the extensification program is the main driver of production. This implies that strategies related to agricultural innovation and technology, are not suitable for increasing production growth. Furthermore, extension programs have not been optimal, especially technology transfer at the farmer level.

Results and Discussion

Production growth trend

Plantation production data were analyzed using linear, quadratic, and exponential trend methods to compare and select the best method based on the production pattern at the study location. The best trend model is characterized by the highest coefficient of determination (R^2) and the lowest MAPE value. The higher the R^2 value, the more appropriate the regression model is applied to the data. Meanwhile, the lower the MAPE value, the smaller the difference between the actual and estimated data. The comparison of the equations, coefficient of determination, and the average percentage error of the three models are described in Table 1 and the best trend models are marked in red.

The accuracy of the trend model plays an important role in decision-making, meanwhile, the estimated value is used to predict future conditions (Atsalakis & Valavanis. 2009; Kitani et al., 2012). In this study, the estimated value of the trend regression equation was used to predict production in the next few years. From the comparison of trend models carried out on the production data of 5 plantation crops, it was concluded that the quadratic trend model is the best because it has the highest R^2 value and the lowest MAPE.

Table 1. Comparison of regression models, coefficient of determination, average percentage error of linear, quadratic, and exponential trends on plantation crop production data

Commodity		Linear	Quadratic	Exponential
Coffee	Model	43.927x + 8130,4	$44.129x^2 – 441.5x + 9101,2$	$8134.7e^{0.005x}$
	R^2	0.1037	0.7733	0.0953
	MAPE	3.8	0.8	3.8
Cocoa	Model	-494.72x + 7493	$-121.79x^2 + 844.95x + 4813.6$	$8438.6e^{-0.121x}$
	R^2	0.5387	0.7477	0.6094
	MAPE	23.6	10.5	23.3
Clove	Model	25.569x + 446.73	$2.3326x^2 – 0.0897x + 498.04$	$460.18e^{0.0429x}$
	R^2	0.92	0.9704	0.9349
	MAPE	2.8	2.0	2.7
Pepper	Model	34.441x + 780.38	$3.8832x^2 – 8.274x + 865.81$	$795.05e^{0.0348x}$
	R^2	0.7033	0.7605	0.6886
	MAPE	5.4	4.8	5.3
Candlenut	Model	-4.8262x + 443.92	$-0.3397x^2 – 1.0896x + 436.44$	$443.44e^{-0.011x}$
	R^2	0.3336	0.6442	0.3343
	MAPE	3.8	4.1	3.8

Source: Own calculation

Table 1 shows that 5 quadratic trend equations met the selection criteria. This indicates that the quadratic trend method is most suitable for predicting production patterns at the study location. Quadratic equation model $y = 2.3326x^2 – 0.0897x + 498.04$ is the best choice for clove plants. In this equation, the determination coefficient of clove production is 0.97, indicating that the square of time specified affects the estimated value of clove production by 97%. Meanwhile, the MAPE value of 2.0 on the quadratic trend of clove plants indicates that the average percentage error between the actual and estimated value is 2% as shown in Table 3. The quadratic equation model $y= 3.8832x^2 – 8.274x + 865.81$ for pepper plants is the best compared to linear and exponential equations. Based on the quadratic model, the pepper plant determination coefficient of 0.76 with a MAPE value of 4.6 implies that the time and estimation results have a relationship of 76% where the average percentage of error is 4%. Furthermore, the quadratic regression equation for coffee plants was $y = 44.129x^2 – 441.5x + 9101.2$ with a coefficient of determination 0.7 and a MAPE value of 0.8. The independent variable of time and the estimation results on coffee production has a relationship of 70% and error of 0.8%, an error rate of <1%, indicates that it is well applied. Moreover, the average value of the percentage error between the estimated and the actual value of cocoa production based on the quadratic model was 10%. Based on this result, the growth of cocoa production in the study area is assumed to be non-linear and non-geometric (not growing very fast).

Table 2 shows that the coefficient of β_1 in the linear, quadratic, and exponential methods is positive for coffee, clove, and pepper plants. This indicates that for over 10 years, the trend direction of these plants is positive. Furthermore, the quadratic trend shows a positive direction and coefficient of β_2. This indicates that between 2010 and 2020 there was an accelerated increase in production output leading to nonlinear production patterns. This is also in line with Cornish et al. (2007) which stated that analysis of long-term trends (periods of 10 years or more) often cover the potential for small changes. Furthermore, Table 2 shows that the coefficients of β_1 (in linear and exponential trends) and β_2 (quadratic trend) were < 0. This indicates that for 10 years, cocoa and candlenut experienced a negative growth trend. In general, the decline in production between 2010 to 2020 for cocoa and candlenut was caused by a decrease in land area. Variations in growth reflect responses to the factors that influence a commodity, the graphs are shown in Figures 2, 3 and 4. Meanwhile, the accuracy of a trend model plays an important role in decision-making. It is used to predict production for the next few years.

Table 2. The coefficients of linear, quadratic, and exponential trend regression equations

Commodity	β_1			B_2
	Linear	quadratic	Exponential	
Coffee	43.9	-441.0	0.005	44.1
Cocoa	-494.72	844.95	-0.121	-0.121
Clove	25.57	-0.0089	0.00429	2.33
Pepper	34.4	-8.3	0.0	3.9
Candlenut	-4.82	-1.08	-0.001	-0.033

Source: Own calculation

Table 3. Comparison of factual value, quadratic estimates, linear, and exponential trend models

Commodity	Trend model	Year….										MAPE
		1	2	3	4	5	6	7	8	9	10	
Coffee	Factual value	8701	8267	8312	8230	7904	7998	7793	8672	8871	8972	-
	Quadratic	8704	8395	8174	8041	7997	8041	8173	8393	8702	9099	0.8
	Linear	8174	8218	8262	8306	8350	8394	8438	8482	8526	8570	3.8
	Exponential	8175	8216	8258	8299	8341	8382	8424	8467	8509	8552	3.8
Cocoa	Factual value	4100	6866	6987	6945	7018	4999	3288	2960	2278	2279	
	Quadratic	5537	6016	6252	6245	5994	5499	4761	3779	2553	1084	10.5
	Linear	8174	8218	8262	8306	8350	8394	8438	8482	8526	8570	23.6
	Exponential	7477	6625	5870	5201	4608	4083	3618	3205	2840	2516	23.3
Clove	Factual value	509	501	509	547	539.4	577.72	631	661.32	664	734.1	
	Quadratic	500	507	519	535	556	581	612	647	686	730	2.0
	Linear	472	498	523	549	575	600	626	651	677	702	2.8
	Exponential	480	501	523	546	570	595	621	649	677	707	2.7
Pepper	Factual value	850	883	883	961	825	869	1056	1124	1124	1124	
	Quadratic	861	865	876	895	922	956	998	1048	1106	1171	4.8
	Linear	815	849	884	918	953	987	1021	1056	1090	1125	5.4
	Exponential	823	852	883	914	946	980	1014	1050	1087	1126	5.3
Candlenut	Factual value	403	454	453	455	402	401	399	402	402	402	
	Quadratic	435	433	430	427	422	418	412	406	399	392	4.1
	Linear	439	434	429	425	420	415	410	405	400	396	3.8
	Exponential	439	434	429	424	420	415	411	406	402	397	3.8

Source: Own calculation

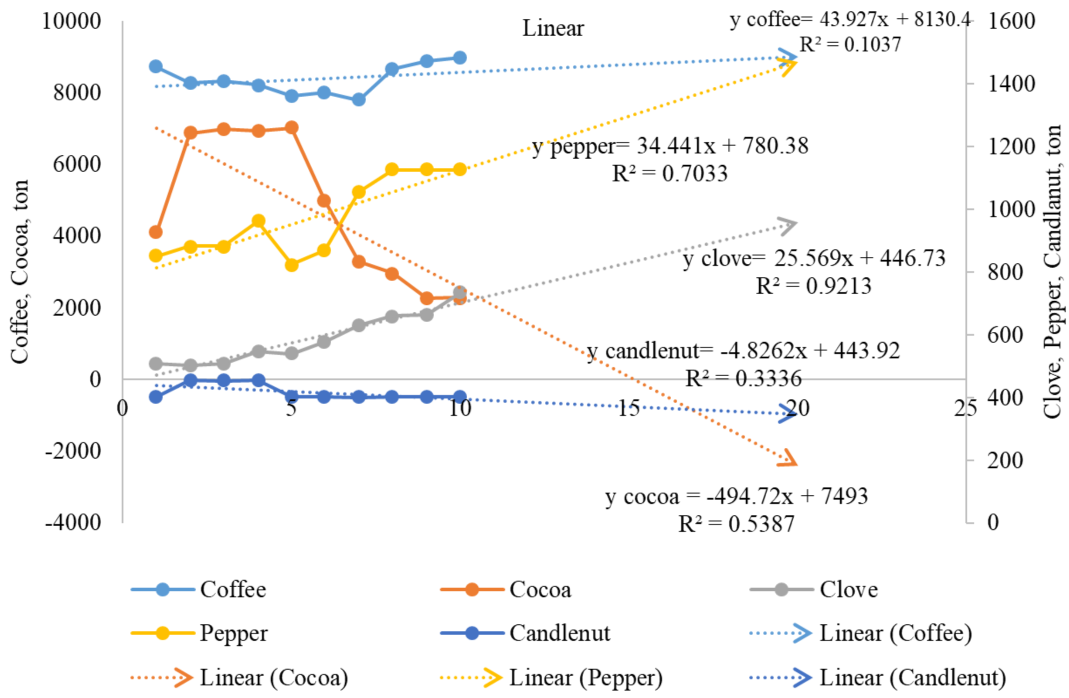

Fig. 3. Linear trend of plantation crop production at the study location

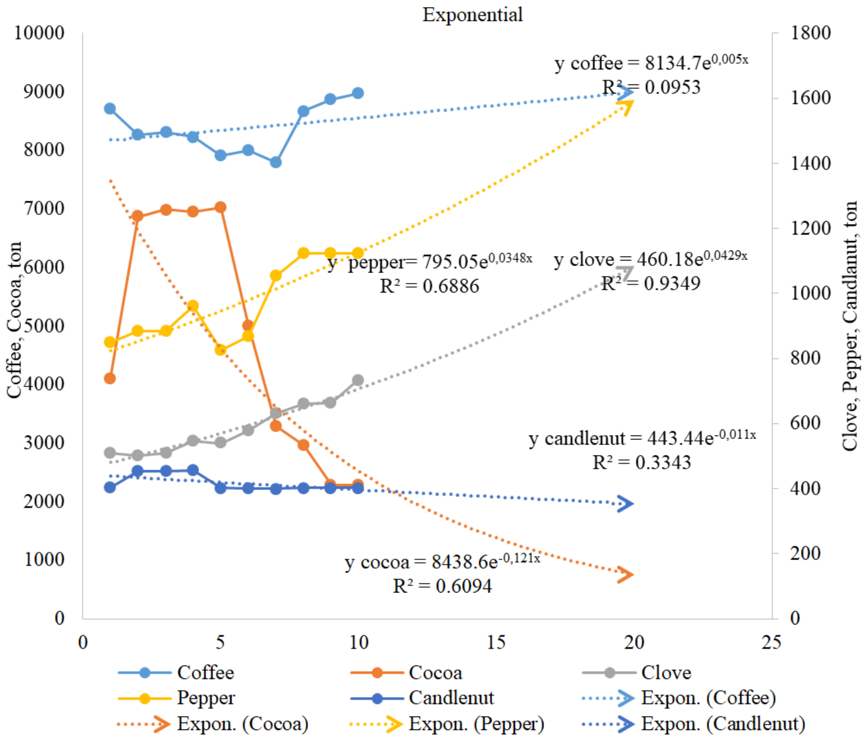

Fig. 4. Exponential trend of plantation crop production at the study location

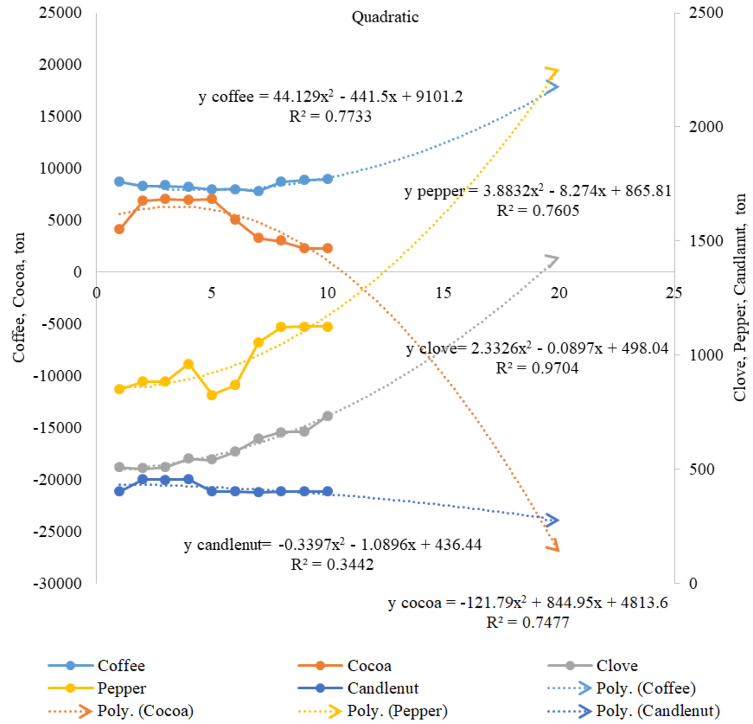

Fig. 5. Quadratic trend of plantation crop production at the study location

Factors driving production growth

Agricultural products form the basis of rural development and are utilized as the main source of income for rural communities (Bettencourt et al., 2015). Agricultural production is increased when useful information is available to direct possible programs for development either by increasing yields per unit or harvested area. In this study, the production growth rate was defined as the land growth rate plus the yield growth per unit area which was differentiated from the equation which states that total production is equal to harvested area multiplied by yield per unit. The three growth components were estimated by regressing the logarithm of production, land area, and yield per unit area to time. Based on the contribution of these parameters, the dominant factor driving production was identified and described in Table 4.

Table 4. Production growth, land area unit, and the harvested area of plantation crops in the study area

Commodity	Production	an area	Land area unit result
	%		
Coffee	1.3	12.4	-11.0
Cocoa	-25.5	-26.2	0.7
Clove	15.9	6.7	9.2
Pepper	12.1	3.0	9.1
Candlenut	-0.1	-10.2	10.1

Source: Own calculation

The growth rate of plantation crop production is caused by both increase in harvested area and yield per unit. Table 4 shows the growth, harvested area, and yield per unit area of coffee, cocoa, clove, black pepper, and pepper crops in 2010 to 2020. It also provides an overview of the harvested area and yields per unit contribution, as well as information on the dominant factors driving production growth in the study area. In 2010 to 2020, the growth rate of crop production varied, the highest average was found in clove, pepper, coffee, candlenut, and cocoa respectively. Based on results, coffee plants production increased by 1.3%, land by 12.4%, and yield per unit area of -11%. An increase in the land by 12% raised production by 1.3% despite the decrease in yield of the unit area by -11%. This decline indicates that the coffee plant development program needs serious attention. Based on the analysis conducted, this decline was caused by climate change. The harvest season, which is followed by rainfall, caused the coffee flowers (prospective coffee cherries) to fall to the ground. Moreover, the decrease in yield per unit area of land indicates that activities related to technological innovation, research, and extension programs are not optimally carried out at the farmer level. Although, there was a decline in yields per unit area of land, the increase in the harvested area between 2010 and 2020 improved production. This indicates that the extensification program of the coffee land area is the main factor driving production growth. An increase in production by enlarging harvested area is possible through government policies in the form of input and output price subsidies as well as the provision of marketing infrastructure to keep operations effective. Furthermore, cocoa production declined by -25.5% due to a decrease in land by -26.2%. Farmers tends to maximize efforts to achieve satisfaction even with limited resources by rationally maintaining the farming business which has a positive impact on incentives both economic and non-economic (Ehrenberg & Smith, 2021). This implies that the decrease in cocoa plantations was due to the negative response of cocoa farmers to the incentives received, hence, the farming business was not maintained. Clove and pepper plants production improved by 16% and 12%, respectively due to an increase in the yield of land area by 9% and harvested area by 7% for clove and 3% for pepper. This is because the farming community maintained clove and pepper plants due to the positive incentives received by farmers. Moreover, the extensification and intensification program increased production in 2010 to 2020.

Conclusion

Planning is related to current and past situations to create better future conditions. In the agricultural sector, production planning plays a strategic role to preserve and even develop drops. Therefore, analysis of trends to reveal the dominant factors driving and inhibiting production growth is needed to produce appropriate and efficient policies. Changes in crop production data were analyzed using linear, quadratic, and exponential trend methods. The best trend is characterized by the highest coefficient of determination and the smallest average error percentage. From the 15 regression equations estimated from the 5 plantation crops, 5 quadratic regression equations met the criteria. This indicates that the quadratic model is more applicable for predicting the production trend compared to the linear and the exponential model. Trend analysis shows that the two factors, both yield per unit area of land and agricultural area have an effect on production. The dominant factor in increasing coffee production and decreasing cocoa production in 2010 to 2020 is the harvested area. This indicates that the extensification of coffee farming land is the main factor driving production growth. In addition, this indicates the existence of government policy in the form of input price subsidies as well as the provision of infrastructure to support plant operations of coffee plants. The increase in the harvested areas indicates that the extensification program is easy to implement due to the availability of agricultural land. Meanwhile, the increase in yields per unit of the land area is the dominant factor driving the production of clove and pepper plants. This indicates that the role of agricultural intensification programs in the form of technology, research, and extension applications has been optimal at the farmer level. In addition, the increase in yields per unit both plants indicates non-vulnerability to the impacts of climate change.

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