academicJournals

Vol. 10(4), pp. 58-66, April 2018
DOI: 10.5897/JABSD2017.0303
Article Number: 9520E0556308
ISSN 2141-2340

http://www.academicjournals.org/JABSD

Journal of Agricultural Biotechnology and Sustainable Development

Full length Research Paper

Do fertilizers and cropland influence the agricultural production value in the same way? Evidence using the autoregressive distributed lags approach of cointegration

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Received 26 November, 2017; Accepted 16 February, 2018

Cropland and fertilizers are two prominent and non-spared factors of agricultural sustainable production. This study mainly aimed to examine the response of crop production value to cropland used and chemical fertilizers supplied by using the Autoregressive Distributed Lags approach of cointegration over the period 1980 to 2016. The bound test and the error correction term showed that the amount of nitrogen (*N*), phosphorus (*P*) and potassium (*K*) consumed, the optimal ratio *N-P-K* applied, the amount of hectares cultivated for temporary and permanent crops are strongly linked to the growth of crop production value. The results may be analyzed following three ways: in the long-term, both cropland used and fertilizers ratio supplied appear greatly to induce a positive impact; in the short-term, the previous farming activity on a cropland might provide a positive influence; even though fertilizers' *ratio* supplied may not induce a substantial effect in the short-term, however, fertilizers nutrient supplied solely may impact the production value. In addition, the number of machines and the labor force are shown to foster the growth of crop production value in the long-term and short-term respectively. For the sake of agricultural sustainability, the findings support a farming system including a complementarity between multi-planting with high nitrogen nutrient requirements, trees plantation (agroforestry) and mechanization.

Key words: Fertilizer, cropland, crop production, sustainable agriculture, auto regressive distributed lags model.

INTRODUCTION

Nutrients management and land management are two key challenges to deal with for global food production and agricultural sustainability. The latter consists of environment friendly practices of farming (crop rotation,

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JEL classification: C22, Q01, Q15.

multi-cropping, agroforestry, land management, etc.) and technologies use (Nutrients and pests management, etc.) that allow the production of crops without damages to human or natural systems.

In recent years, crop production per hectare increasingly depends on agricultural science and technology advances, farm infrastructures, fertilizers use, pesticides use, planting structures for crops, water management and policy for agriculture production. Different input factors have different influences on agricultural production. For instance, while the Integrated Pest Management (IPM) seeks to use pesticides when other options are ineffective (Hassanali et al., 2008; Bale et al., 2008), the Integrated Nutrients Management (INM) seeks to balance both organic and inorganic fertilizers (Goulding et al., 2008; Ahmad et al., 2011). Indeed, the ideal should be the development of organic farming. (Anup et al., 2017; Verena et al., 2017; Zeynab et al., 2017). However, it must mainly benefit from the system of financial supporting order to encourage certain farmers to change a manner of production to a more environmentally friendly one, or to avoid the decision of others to resign from production using ecological methods (Iwona and Marta, 2017).

Inorganic fertilizers are chemical compounds applied either through the soil or through plants leaves to promote the growth. Fertilizer plays a vital role in achieving high level of production by providing essential plant nutrients (Olowoake and Ojo, 2014; Ramasamy et al., 2013). Nitrogen nutrient is recognized to offer the green impact and foster the photosynthesis, phosphorus is destined to play a major role in root growth and energy transfer activities within the plant, whereas potassium is supposed to help plants in flowering and fructification. Balanced fertilization is one of the most important farming tools, given that it enables a rational use of fertilizers with other inputs for a best possible supply of all essential nutrients.

Actually, famers used to resort to more chemical fertilizers for the purpose of increasing crops production in response to diverse constraints they face while bringing more area under cultivation and while restoring deficiency of nutrients in soil (Planning Commission of India, 2011). Owing to these serious concerns, sustaining agricultural production growth and yield requires nowadays the application of fertilizer best management practice (Roberts, 2007) which is summed up under the term “4Rs” namely: right product, right rate, right time and right place. Otherwise, the consequence of excessive use of chemicals beyond the limit of absorption of the plants might cause secondary effects to the soil and the plants (Doll and Baranski, 2011). Many other factors should be considered in the expectation of drawing a great impact from fertilizers use.

Lonester et al. (2017) found that when they are subsidized, fertilizers may not only increase farmers’ market participation as sellers, but also raise the total quantity of crop sold, and favor crop commercialization. Lenis et al. (2017) suggest that except dropping transportation costs, other constraints such as soil quality, timely access, availability of complementary inputs (for example, improved seeds, irrigation and credit), as well as good management practices on farmland are also necessary for improving the profitability of fertilizers use. For concerns regarding farmland or even ecosystem services, Powlson et al. (2011) advocate the management of deforested land, conversed grasslands to arable cropping and drainage of wetlands in relation to sustainable agriculture practices.

In this context, Jill Caviglia-Harris (2003) found the slash-and-burn practice to be inconsistent with sustainable agriculture compared to those such as agroforestry, apiculture and aquaculture, rather it may cause deforestation with all its consequences. In other words, the conversion of forests to cropland would entail major environmental costs (Jordan et al., 2014).

Accordingly, Jayne et al. (2014) propose that agricultural and rural development strategies need to more anticipate the implications of rapidly changing land. Furthermore, a number of researches are conducted in investigating on the long-term effects of single fertilizers upon the soil fertility and productivity (Bi et al., 2014; Suman et al., 2016; Venkatesan et al., 2004). Following Kumar and Yaday (2008), the yield response of grains further to a direct nitrogen fertilizer supply would decline over the long period. In contrast, the application of phosphorous and potassium over time would allow the grains yield to increase. Their findings also revealed that balanced doses of nitrogen, phosphorous, and potassium are required to maintain durably soil fertility and boost the grains yield.

The present research does raise the main question that how are chemical technologies use and cropland management linked to the agricultural production value? And, are the influence of fertilizers supplied and the influence of cropland cultivated complementary over the years? The main objective of this study is to analyze the evolution of the relationship between chemicals, cropland and crop production value over the years. The methodological approach is based on time series data over the period 1980 to 2016 pertaining to the country of Benin[1], and then, using the Autoregressive Distributed Lags (ARDL) model of cointegration (Pesaran and Shin, 1999; Pesaran et al., 2001). The attention is mostly directed on the influence of single fertilizer use, combined fertilizers supply as well as cultivated cropland in the short and long terms, and then, the corresponding suggestions are put forward.

[1]A country located in the Western Africa,Benin is a tropical nation, highly dependent on agriculture, with substantial employment and income arising from subsistence farming. Its climate is hot and humid. It has two rainy and two dry seasons per year.

Modeling and data description

Theoretical modeling

The mathematical equation estimated in this study is based on Cobb-Douglas (C-D) production function. It may be written as:

$$Y = A_0 \exp(\delta t) \prod_{i=1}^{p} X^{\alpha_i} \quad (1)$$

where Y isthe output or income value, A_0 is the level of the output or income at the base period, exp represents the exponential function, δ is the parameter of technological progress, t indicates the time variable expressing the influence of technological progress, p is the number of factors of production, X is a matrix of factors of production and α_i is the parameter of ith factor of production. It may be demonstrated that the α_i are the output or income elasticity coefficients. Thus, seeking the partial derivative on *X* in Equation (1), we can get:

$$\alpha_i = \frac{\partial Y}{\partial X_i} \times \frac{X_i}{Y} \quad (2)$$

X_i is the ith factor of production. The values of α_i are obtained by applying the logarithm on both sides of equation (1). Thus, the basic specification is given as follows:

$$ln(Y) = ln(A_0) + \delta t + \sum_{i=1}^{p} \alpha_i \, ln(X_i) \quad (3)$$

where ln represents the logarithm function.

Availability of data and materials

The dataset supporting the conclusions of this article are included within the article its additional files. The study is based on annual time series data of 37 observations (1980 to 2016) obtained from different sources, including the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Conference on Trade and Development (UNCTAD). Table 1 provides variable definitions and data sources. Figure 1 provides information that a linear equation model may describe correctly the relationship between the variables of interest. It shows that the number of machines used, the labor force, and the number of hectares cultivated for temporary and permanent crops are positively related to the growth of crop production value. Meanwhile, the impact of chemicals would be positive over time when they are supplied as direct fertilizers, but the obviousness of their linear relationship with the growth of crop production value does not appear so strong.

RESULTS AND DISCUSSION

This section is devoted to unit-root test, appropriate ARDL model selection, bound test, long-run equation estimation, and short-run equation estimation. Following the study of Odhiambo (2009) and Narayan and Smyth (2006), the long-run relationship between variables indicates that there is Granger-causality in at least one direction which is determined by the F-statistic and the coefficient of the lagged error correction term.

Unit-root test on variables

The application of the ARDL approach requires that no variable is integrated of an order more than one. Table 2 shows that this requirement is met given that therein, no variable is found to be I (2).

Selection of appropriate ARDL model

The optimum lag order (*k*) is selected by referring to Akaike Information Criterion (AIC). The ARDL model of equation (4) with lag 4 (AIC=-8.579143) is found to perform relatively better.

$$Dy_t = a_0 + \alpha y_{t-1} + \sum_{n=1}^{T} \beta_n X_{n,t-1} + \sum_{i=1}^{k} \gamma_i Dy_{t-i} + \sum_{n=1}^{T} \sum_{i=1}^{k} \delta_{ni} DX_{n,t-i} + \varepsilon_t \quad (4)$$

where, D symbolizes the first difference operator, y is the dependent variable, X_n is a matrix of explanatory variables, a_0, α, β_n, $\gamma_i \delta_{ni}$ are coefficients (*i* expressing the number of lag). The tests of suitability showed that the specified ARDL model is free from serial correlation and heteroskedasticity. On the other hand, the model appears to be stable in the sense of recursive residual test for structural stability. Moreover, the null hypothesis that the residuals are normally distributed cannot be rejected (Figure 2).

Bound test of cointegration

The bound test (Wald test) is given in Table 3. It is run through the Prob.Chi-square. Since this probability is less than 5%, the null hypothesis that all long-run coefficients are jointly equal to zero cannot be accepted. In addition, t-statistic tests are run on both the dependent and independent variables in order to avoid degenerate cases**.** Therefore, we do conclude that the variables of interest are bound together, in other words, they are cointegrated.

Estimation of long-run coefficients

Based on equation (3), the growth of crop production value is estimated by a long-run model (Table 4). The regression model performs well, predicting 99% of the specified equation correctly. The causality between the value of crop production and its determinant factors is established through the F-statistic. The residuals coming from the estimation are normally distributed and the diagnostic does not reveal any problem of serial correlation and heteroscedasticity.

In addition, the null hypothesis that the coefficients of dummies are equal to zero cannot be accepted, meaning that the other factors above-mentioned have influenced significantly the growth of crop production value over the

Table 1. Variable definitions and data sources

Variable	Definition	Sources
VCROP	Value of agricultural crop production (constant 2004-2006, 1000 International US dollars)	FAO, 2017
N	Number of tons consumed as nitrogen fertilizer	FAO, 2017
P	Number of tons consumed as phosphorus fertilizer	FAO, 2017
K	Number of tons consumed as potassium fertilizer	FAO, 2017
*RATIO**[1]	Ratio between nitrogen, phosphorus and potassium	Determined by the author
ALAND[2]	Number of hectares cultivated for arable land & permanent crops	FAO, 2017
MACHIN	The number of machines (tractors, harvesters, threshers) used	FAO, 2017
LABOR	Number of persons having participated in the agricultural crop production	UNCTAD, 2017
*Dum**[2]	Dummy variable for other potential determinant factor; 1, 0	Determined by the author

[1]Note: Ratio*, denotes the combination *N-P-K*. It is expressed like a dummy variable that takes the value "1" except for the years 2007, 2008, 2010 and "0" otherwise. It is obtained through the following two steps: (1) dividing each annual amount of fertilizer by its corresponding annual amount of *K* and getting two groups of combinations, the first group being recognized as optimal ratios (Srivastava and Ethel, 2009), and the second,as non-optimal ratios (refer to year 2007, 2008 and 2010); (2) affecting the value "1" when the ratio is supposed to be optimal and the value "0" otherwise. Thus, the variable *Ratio* measures the optimum requirement of inorganic fertilizers recommended for sustaining agricultural crop production.
*[2] Note : *Dum*, is a dummy variable introduced in order to capture the impact of other factor such as water management, new varieties of seed adoption, pesticides management,public technical and financial assistance, and natural phenomena (for example, flooding, precipitations).

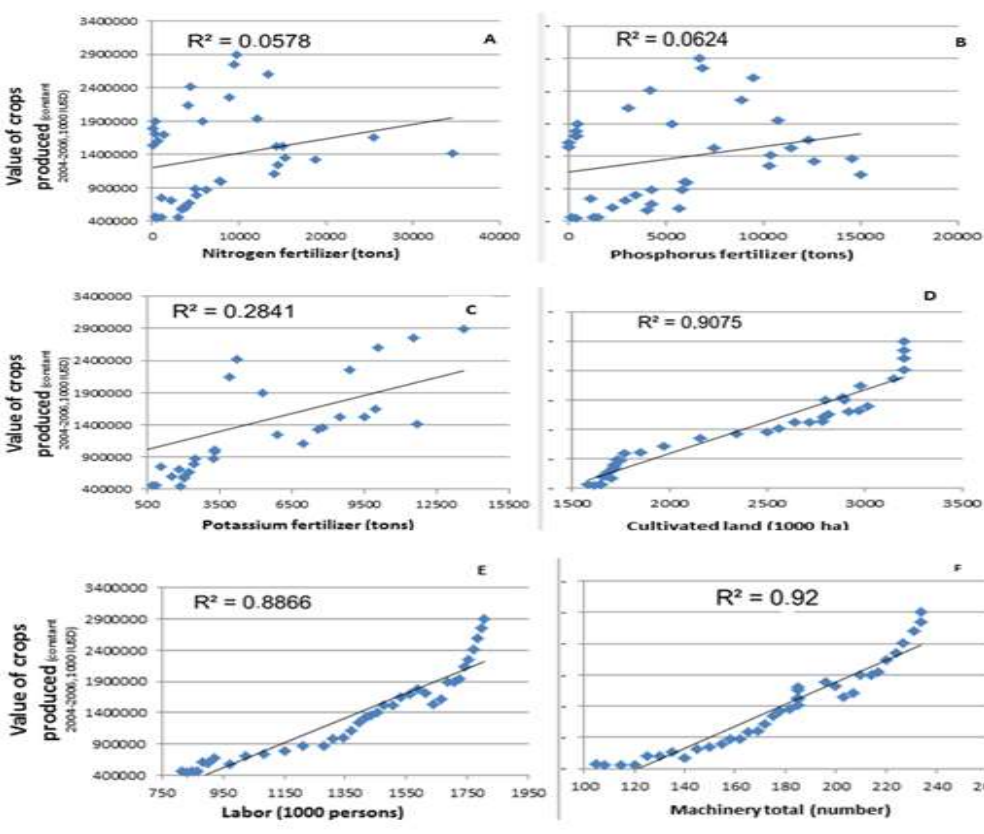

Figure 1. (a) Relationship between nitrogen fertilizer used and value of crops produced (1980-2016). (b) Relationship between phosphorous fertilizer used and value of crops produced (1980-2016); (c) Relationship between potassium fertilizer used and value of crops produced (1980-2016); (d) Relationship between cultivated land area and value of crops produced (1980-2016); (e) Relationship between labor force used and value of crops produced (1980-2016); (f) Relationship between number of machines used and value of crops produced (1980-2016).

[2] According to the FAO, "Arable land" refers to land producing crops requiring annual replanting or fallow land or pasture used for such crops within any five-year period" (multiple-cropped areas are counted only once).A briefer definition appearing in the Eurostat glossary similarly refers to actual, rather than potential use: land worked (ploughed or tilled) regularly, generally under a system of crop rotation.
"Permanent cropland", meanwhile, refers to land producing crops which do not require annual replanting. It includes forested plantations used to harvest coffee, rubber, or fruitbut not tree farms or proper forests used for wood or timber.

Table 2. ADF unit-root test[3] on variables.

Variable	Unit-root test in[4]	ADF test statistic	Test critical values	Integration order
LVCROP	First difference, including intercept	-8.303335	-3.632900***	I (1)
LN	First difference, including intercept	-3.266967	-2.954021**	I (0)
LP	First difference, without intercept nor trend	-5.432033	-2.632688***	I (1)
LK	First difference, including intercept	-3.797912	-3.661661***	I (0)
LALAND	First difference, without intercept nor trend	-2.488680	-1.950687**	I (1)
LMACHIN	First difference, including intercept	-5.590737	-3.626784***	I (0)
LLABOR	First difference, including intercept	-13.69832	-3.670170***	I (0)

***Indicates significance at the 1% level; ** Indicates significance at the 5% level.

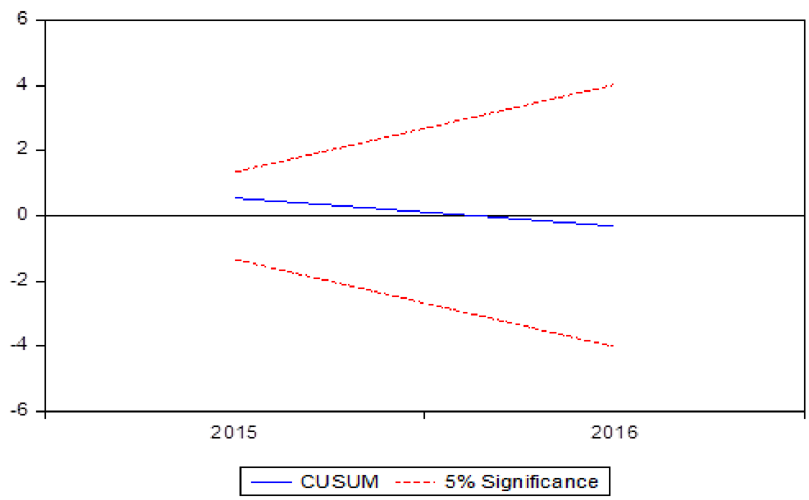

Figure 2. Stability diagnostic test on the ARDL model.

Table 3. Bound test for cointegration.

Wald test for joint significance:			
Null hypothesis: The coefficients of all lagged variables below are jointly equal to zero			
Test statistic	Value	df	Probability
F-statistic	160.0389	(7.2)	0.0062
Chi-square	1120.272	7	0.0000
T-statistic tests on lagged variable			
variable		**Value**	**Std. Err.**
LVCROP(-1)		-2.523529***	0.256349
LN(-1)		-0.259071***	0.024411
LP(-1)		0.230906***	0.019822
LK(-1)		0.103154**	0.018871
LALAND(-1)		1.594530**	0.234670
LMACHIN(-1)		1.336539*	0.353814
LLABOR(-1)		2.384072***	0.148744

***Indicates significance at the 1% level; ** Indicates significance at the 5% level; * Indicates significance at the 10% level.

[3] From Eviews software
[4] Maxlag = 9

Table 4. Estimated long-run coefficients.

Sample : 1980-2016 (*N = 37*)		
Variable	**Coefficient**	**S.E.**
Constant	-44.61761***	8.803430
YEAR	0.025609***	0.005060
LN	0.082994***	0.025639
LP	-0.035049**	0.016360
LK	-0.025460*	0.015035
RATIO	0.292208***	0.096638
LALAND	0.378562***	0.0111098
LMACHIN	0.554333*	0.288178
LLABOR	0.163634	0.199811
Dum87	-0.171571***	0.043469
Dum83	-0.214864***	0.046609
Dum08	0.261608***	0.078125
Dum04	0.186459***	0.059152
Adjusted R^2	0.994	-
F-statistic	592.177***	-
Durbin-Watson stat (DW)	2.014	-

***Indicates significance at the 1% level; **Indicates significance at the 5% level; *Indicates significance at the 10% level.

period of study. The results indicated that the growth of crop production value (*VCROP*) was influenced by all the explanatory variables except *LABOR*. The technological progress appears greatly to be a major determinant of boosting the productivity of limited input factors, notably land factor (Fan, 1991).

When nitrogen is supplied as a direct fertilizer, its impact on the growth of crop production would be significantly positive in a relatively long period. This outcome seems to be quite substantial in the sense of evergreen production according to the role played by the said factor (Tables 3 and 4). Unlike nitrogen, the impact of phosphorus and potassium nutrients appears unobvious. Even though previous research (Kumar and Yaday, 2008) contradicts this result, it nevertheless, proposes the experimentation of balanced doses of N-P-K for maintaining durably soil fertility and boosting the grains yield. Indeed, the variable *Ratio* in this study appears greatly to be positively related to the growth of crops production. Thus, once plants fertilization is performed at 100% in an optimal way, ceteris paribus, it would foster an increase in the value of crop production by approximately 29%. However, with regard to food security goal, policies and actions are needed to make the chemical technologies available and affordable to small farmers (Pedro et al., 2016; Powlson et al., 2011).

In the other hand, policies and strategies seeking to manage more efficiently the flows of nutrients in ways that minimize environmental damage should be taken in both developed and developing rapidly areas. Beyond all the aforementioned concerns, nutrients should be applied in accordance with soil characteristics that differ from a country to another. For instance, Niu and Hao (2017) found the treatment with 270 kg N/ha/year and 59 kg P/ha**/**year to represent the most economical fertilizer rates for salt-affected soils on the North China plains.

The number of hectares cultivated (*ALAND*) would influence positively the growth of crop production value. This result is similar to that obtained by Luo and Huang (2013). Since the variable includes agricultural sustainable practices, the outcome may be viewed as highlighting the fact that associating permanent crops cultivation with temporary crops on a same farm land might greatly impact the growth of crop production and its sustainability. In other words, such a farming system may appear effective to slow down deforestation or extension of arable land (Caviglia-Harris, 2003; Derek et al., 2014). In the country of Benin, a number of small farmers do draw a significant benefit from permanent cropping (for example, coconut, palm, cashew, mango) and the concerned staple crops are included in the basket of main commodities for export.

The number of machines is destined to capture the importance of agricultural mechanization (labor-saving technology). It's found that as the number of machines (*MACHIN*) increases so does the value of crop production. This outcome, not only appears consistent with Futoshi (2016) by emphasizing that machines and land must be complementary, but it also highlights that optimal fertilization ratios and land management should move together for the sake of food security and agricultural sustainability (United Nations, Sustainable Development Goal 2)[5]. Furthermore, the residuals coming from the long-run estimation are found to have no unit-root at level.

[5] Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Table 5. Estimated short-run coefficients by ARDL approach.

Sample : 1980-2016 (*N = 37*)		
Variable	**Coefficient**	**S.E.**
Constant	0.549283	2.162844
YEAR	-0.000244	0.001072
DLVCROP(-1)	-0.129895	0.112322
DLN(-1)	-0.004808	0.012730
DLN(-2)	0.004805	0.014712
DLN(-3)	0.022353*	0.011130
DLP(-1)	-0.007066	0.010792
DLP(-2)	-0.017329	0.011796
DLP(-3)	-0.021823**	0.008621
DLK(-1)	0.006503	0.006488
DLK(-2)	0.019952***	0.006048
DLK(-3)	0.019459***	0.004613
RATIO	0.019314	0.030211
DLALAND(-1)	0.752711*	0.367390
DLALAND(-2)	-2.220779***	0.524459
DLMACHIN(-1)	-0.469284	0.718629
DLLABOR(-1)	4.482919***	1.309953
DLLABOR(-2)	-4.342043***	1.228740
ECT(-1)	-0.683089**	0.270060
Dum87	-0.165441***	0.033625
Dum84	0.266409***	0.043888
Dum96-00	0.109121***	0.033782
Dum94	0.115597**	0.046167
Adjusted R^2	0.886	-
F-statistic	12.3116**	-
Durbin-Watson stat (DW)	1.75	-

***Indicates significance at the 1% level; ** Indicates significance at the 5% level; *Indicates significance at the 10% level.

Estimation of short-run coefficients

The short-run model (Table 5) performs well, predicting 89% of the specified equation correctly. The model passed through all the econometric diagnostic tests, and the null hypothesis that the coefficients of dummies are equal to zero cannot be accepted. The parameter of the lagged Error Correction Term is significantly negative, confirming the existence of a long-run convergence of the underlying variables. This implies that any disequilibrium in the previous period is adjusted at a speed of 68% to the current period.

Empirically, the response of crop production growth to variables lagged by one-period relating to fertilizers is found unobvious. Meanwhile, the results show that fertilizers applied solely since three years or two years (case of potassium) might impact significantly the growth of crop production value for the current period. This seems to highlight the importance of laying fallow a cropland for at least two years. In other words, the effect produced by *N*, *P or K* nutrients applied today would be more effective in a medium-long term.

Moreover, the two-period lags and one-period lag of the variable *Aland* displayed a solid relationship with the growth of crop production value. In other words, current period's land management (farming practice, fertilizers, water, weed, and pest management, etc.) may foster crops grown in the next period. Therefore, postharvest state of cropland should be well handled in order to draw profit from postharvest positive externalities generated by, among others, crop residues, manures applied, synthetic fertilizers, energy used.

The short-run estimation showed that the variable *labor* does follow the same trend with that designating farming system (*ALAND)* in terms of the generated effect. The findings indicated that the quality and quantity of labor force engaged today appear greatly to be related to the production value expected in the following period. However, apart from Derek and Jayne (2014), Jayne et al. (2014) state that the enormous challenges that mounting land pressure do take source from a rapidly rising labor force associated with demographic conditions, and limited nonfarm job creation.

The result does not reveal an obvious influence of one-period lag of the variable *MACHIN*. However, as discussed earlier, machines should be used in complementarity with land management in pursuance of food security and sustainable agriculture goal.

After all, the findings coming from the short-run and long-run estimations may be summed up as follows (Table 6) with assumption that agricultural sustainable practices (namely multi-cropping and agroforestry) are

Table 6. Summary of potential effect of chemical fertilizers and cropland.

Period	**Long-run**					**Short-run**				
Variable	*N*	*P*	*K*	*Ratio*	*ALAND*	*N*	*P*	*K*	*Ratio*	*ALAND*
Number of lag (Maxlag=3)				-		1, 2, (resp. (3))	1, 2, (resp. (3))	1, (resp. (2, 3))	-	1, (resp. (2))
Influence on crop production growth	+	-	-	+	+	Unclear, (resp.(+))	Unclear, (resp.(-))	unclear, (resp. (+))	Unclear	+, (resp. (-))

conducted on the cropland. The ultimate objective here is to direct attention on the matter to take into account during the ex-ante and the postharvest management of cropland.

Conclusion

This research examined the dynamic response of crop production value to cropland use and chemical fertilizers supply by using the Autoregressive Distributed Lags approach of cointegration over the period 1980-2016. The bound test and the Error Correction term determined that the amount of nitrogen (*N*), phosphorus (*P*) and potassium (*K*) consumed, the optimal ratio *N-P-K* applied, the amount of hectares cultivated for temporary and permanent cropsare strongly linked to the growth of crop production value. In compliance with the main objective, the findings may be summarized in three ways:

(a) In the long-term, both *cropland* used and fertilizers *ratio* supplied appear greatly to induce a positive impact.
(b) In the short-term, previous farming activity on a c*ropland* might induce a positive influence in the current period.
(c) Even though fertilizers' *ratio* supplied may not induce a substantial effect in the short-term, however, fertilizers nutrient supplied solely may impact the production value.

In addition, the number of machines used and the labor force appear to be significant in the long-term and the short-run respectively (Table 6). For the sake of food security and agricultural sustainability, the findings support a farming system that completes multi-planting with high nitrogen nutrient requirements, trees plantation (agroforestry) and mechanization. This suggestion appears attractive following Berihun et al. (2014), George (2014) and Megan and Christopher (2017) for the fact that the agricultural technology adopted is likely to be linked with farm income.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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