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Prediction of Nitrous Oxide (N_2O) Emission Based on Paddy Harvest Area in Lampung Province Indonesia using ARIMA on IPCC Model

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ABSTRACT

Agricultural are significant sources of N_2O emission. Lampung, Indonesia is an area dominated by agriculture including crops that emit N_2O on their cultivation practices especially the fertilizers: paddy and vegetables. Last census in 2015 recorded that paddy fields were 1.321.120 ha and vegetables 99,284 ha with fertilizers recommendations were 200 kg/ha urea (without organic materials) and 150 kg/ha urea (if added with 2 tons/ha manure). This study aimed to estimate and predict N_2O emissions based on the paddy field area using IPCC 2006 model. The IPCC model was applied to the paddy field data 1993 to 2012 from the Indonesian Ministry of Agriculture to estimate the N_2O emission and then using Box Jenkins model to predict the emission for following years. The results showed that the prediction of N_2O emission on the following years would be in the range of 0.282- 0.451Gg/year using only synthetic fertilizer and if added with organic fertilizers would be 5,846-9,359 Gg/year. These results were lower compared to some countries; however, this result was not implied that fertilizer recommendations in Lampung were safe since the results came from default numbers of the model. More researches should be conducted that local emission factors would be available that fertilizer recommendation could be evaluated.

Keywords: ARIMA, Box Jenkin, IPCC model, N_2O emission.

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I. Introduction

Both nitrous oxide (N_2O) and nitric oxide (NO) are important components of the global biogeochemical nitrogen (N) cycle that contribute to global warming and the deterioration of the atmospheric environment. N_2O concentration in the atmospheric is currently increasing at a rate of 0.2–0.3 percent yr^{-1}, which was mainly attributed to the expansion and intensification of agriculture production [1]. Moreover, Nitrous oxide (N_2O) has a global warming potential (GWP) 298 times greater than that of carbon dioxide (CO2) on a 100-year horizon [2].

Agricultural production is a significant source of atmospheric N_2O, which contributes approximately 60 and 10 percent of global anthropogenic from N_2O and NO sources, respectively, largely due to increased fertilizer application in croplands. Specifically, agricultural soils are considered as an important source of N_2O and NO emission entering the atmosphere; globally releasing approximately 2.8 Tg N yr^{-1} and 1.6 Tg N yr^{-1}. To feed the world's increasing population, considerable amounts of synthetic fertilizer will keep being applied to the soils to improve crop yield [1], [3], [4]. Although it resulted in increased N_2O emissions, additional N is often applied either in the form of inorganic N fertilizers or organic amendments (e.g., crop residues, manure, compost, etc.) to prevent N limitations to crop growth [5].

Synthetic fertilizer is a major nitrogen supply for the agroecosystems in China. To produce enough food to feed its large population, with the intensively managed cropland area that only occupying 7 percent of the global total, the annual consumption of synthetic N fertilizer in China accounted for 30% of the total global consumption in 2004 and consumed 32.4 million tons of synthetic N fertilizer in 2007, constituting about one-third of the global total [3], [6], [7]. Compared to non-vegetable cropping systems such as rice-wheat rotations, much more nitrogen fertilizer is applied per unit area of vegetable fields. For instance, vegetable fields receive synthetic nitrogen fertilizers at a rate of approximately 1,000 kg N ha^{-1} yr^{-1} in the Tai-Lake region China, whereas the amount applied to rice-wheat or rice-oilseed rape rotations is only around 500 kg N ha^{-1} yr^{-1}. Besides, vegetable fields are usually treated with organic manure at the same time with a quantity equivalent to at least half of the amount of synthetic nitrogen applied [1]. However, estimation of N_2O and NO emissions from croplands have large uncertainties since the sources and sinks of N_2O and NO are not well characterized in different agroecosystems (rice paddies, grain upland croplands, vegetable cropping systems).

Rice is the staple food of the 95% of total Indonesia populations and ninety-five percent of rice is produced from paddy rice cultivation, mostly involves full wetting period. Technically irrigated paddy rice areas were 4.4 million ha throughout Indonesia, and 60.8% were located on Java island in 2013 [8] Lampung, one province in Indonesia outside Java Island is an area dominated by the agriculture sector including crops that produce N_2O emission: paddy and vegetables. The government has subsidized 266.782,8 tons of fertilizers, while fertilizer production was 246.957 tons (BPS [9]. Nitrogen fertilizer (chemical and organic) for paddy in Lampung that recommended by the Government Agricultural Agency was 200 kg/ha N (without organic materials) and 150 kg/ha N with an additional 2 ton/ha organic fertilizers. All countries that produce rice realized that paddy field has a potential to emit greenhouse gas especially methane and nitrogen and tried to quantify them; in The Philippines [10], India [11], [12], Thailand [13], Japan [14], Ghana [15] and Latin America and Caribbean [16].

IPCC developed a mathematical model to estimate N_2O emission from atmospheric deposition of N volatilized from managed soils based on fertilizer N applied to soils [17]. The model typically assumed that there is a linear relationship between N_2O emission and nitrogen (N) input from fertilizer, and therefore using emission factors (EF). These IPCC national GHG inventory guidelines played an important role in fostering the incorporation of scientific evidence into national climate policy mechanisms [18]. In the current IPCC methodology, the total amount of N applied is considered as the major factor controlling N_2O emission from agricultural soils. One single N_2O emission factor of 1.25% of total N applied is used for all types of fertilizers and manures and application techniques. This suggests a linear relationship between the amount of N applied and the N_2O emission [19]. However, a growing body of studies showed a non-linear, exponential relationship between N_2O emission and N input [20]. Another research in Iowa, USA showed that the IPCC methodology may underestimate N_2O emission in the regions where soil rewetting and thawing are common and that conditions predicted by future climate-change scenarios may increase N_2O emissions [21]. Similar to that the average overall emission factor for Mediterranean agriculture was 0.5%, which is substantially lower than the IPCC default value of 1% [22].

Increasing nutrient use efficiency and reducing nutrient loss in agricultural systems while simultaneously improving crop yields is a critical sustainability challenge facing food sustainability. Therefore, this study was aimed to estimate N_2O emissions based on paddy and horticulture field area and the recommended fertilizers for Lampung Province Indonesia.

II. Methods and Data

A. Methods

1) Estimation of annual N_2O emission

N_2O emission from the paddy field was calculated based on the mathematical model released by IPCC [17] Tier 1 for indirect N_2O emission.

$$N_2O\ (ATD)\text{–}N = [(FSN \cdot FracGASF) + ((FON + FPRP) \cdot FracGASM)] \cdot EF4 \quad (1)$$

where

N_2O (ATD)–N = annual amount of N_2O–N produced from atmospheric deposition of N volatilized from managed soils, kg N_2O–N yr^{-1};

FSN = annual amount of synthetic fertilizer N applied to soils, kg N yr^{-1};

FracGASF = volatilisation from synthetic fertiliser], (kg NH3–N + NOx–N) (kg N applied) –1;

FON = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N yr^{-1};

FPRP = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1};

FracGASM = volatilization from all organic N fertilizers applied, and dung and urine deposited by grazing animals], (kg NH3–N + NOx–N) (kg N applied or deposited)

EF4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH3–N + NOx–N volatilized)-1].

Conversion from N_2O (ATD)-N emission to N_2O emission was done using the below equation:

$$N_2O\ (ATD) = N_2O(ATD)\ \text{–}N \cdot 44/28 \quad (2)$$

2) Forecasting annual emission

Paddy field area in Lampung was applied to IPCC mathematical model to get annual N_2O emission in Lampung Province. Data from the estimation would be used as the database to forecast the N_2O emission range for the near future using the Box-Jenkins method (ARIMA model). The Box-Jenkins method (ARIMA model) was developed through identification and estimation steps. This model was introduced by Box and Jenkins in 1960 which is used to forecast a single variable [23]. In identification, the model was tentatively categorized whether it was random, stationer, or seasonal and whether there was AR (autoregressive), MA (moving average), or both ARMA (autoregressive moving average) processes. The next step was estimating parameters of the tentative model, this step included nonlinear estimation, parameter test, and model fitness, and finally, with those approaches, the best ARIMA model for the forecasting would be achieved. Details were presented along with the results.

B. Data

This research used existing data which were: (1) data of paddy field and horticulture harvest in Lampung from 1993-2012, attained from the Lampung Statistical Bureau. Nitrogen fertilizer recommendation (synthetic, organic) for paddy field in Lampung Province by Dinas Pertanian (government agriculture office) based on which was 200 kg/ha urea (without organic materials) and 150 kg/ha urea (added with 2 tons/ha manure).

III. Results and Discussions

The area of paddy field and emission of N_2O was presented in Table I.

TABLE I: PADDY HARVEST AREA IN LAMPUNG PROVINCE AND EMISSION OF NITROUS OXIDE

Year	Area (ha)	N_2O Emission (Gg/year)	Year	Area (ha)	N_2O Emission (Gg/year)
1993	433.1	0.272	2003	472.6	0.297
1994	425.9	0.268	2004	495.5	0.311
1995	514.4	0.323	2005	496.5	0.312
1996	515.2	0.324	2006	494.1	0.311
1997	454.1	0.285	2007	524.9	0.330
1998	521.6	0.328	2008	506.5	0.318
1999	476.9	0.300	2009	570.4	0.359
2000	496.9	0.312	2010	590.6	0.371
2001	501.2	0.315	2011	606.9	0.382
2002	475.5	0.299	2012	626.2	0.394

The next step was determining the functions and the plots of autocorrelation and partial autocorrelation of the emission. The results were presented in Fig. 1 and 2. From the graphs, it should be continued with determining whether the data showed the pattern of random, stationer, cyclic, AR (autoregressive) and MA (moving average) processes.

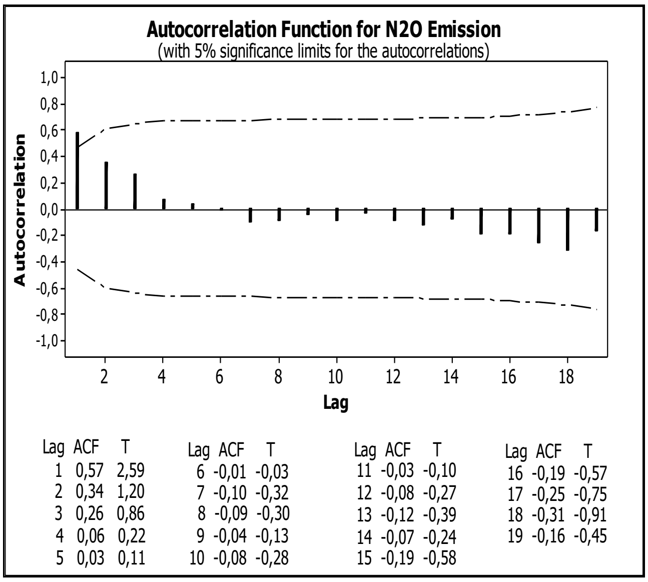

Fig. 1. ACF of the N_2O emission in Lampung Province (1993-2012).

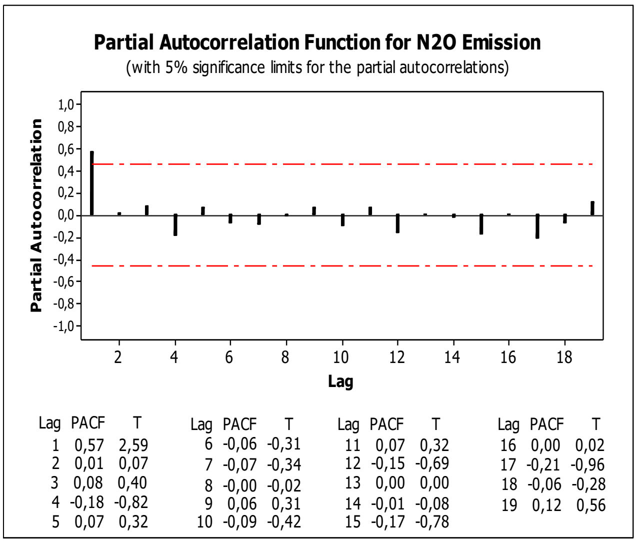

Fig. 2. PACF of the N_2O emission in Lampung Province (1993-2012).

A. Random Pattern Test

ACF could be used to determine whether some data collection was random or not. Data collection could be categorized as random when coefficients rk lied on the border:

$$rk + Z\alpha/2\ (1/\sqrt{n}) \qquad (3)$$

where Zα/2 was values obtained from Table Z of the normal curve with α = 0.05 (95% level of confidence), and n was the number of observations.

Using (3) with n = 20 and 0,025=1.96 then the upper and lower border could be determined, and the value was + 0,438 (see the strike dotted line on Fig. 1 and 2). Data could be considered random if the coefficient rk was inside the borders. The ACF showed that r1=0,579 higher than 0,438 meant that autocorrelation coefficients when k = 1 were significantly different from 0. When k > 1 all autocorrelations were not significantly different from 0. The same results were shown from PACF, for k = 1 and r = 0,579; higher than 0,438. With these results, it could be concluded that the data series was random

B. Stationary Test

Autocorrelation coefficient (ACF) after second time lag (k = 2) and the third (k = 3), which was r4 (k = 4) = 0,069, approached to zero. This meant ACF did not show a tendency to skew diagonally from left to right with the increasing time lags, indicated that the data was stationer, no differentiated data was needed. Therefore, in this research, the prediction of nitrous oxide emission would determine by order d = 0.

C. Circular Test

The autocorrelation in the ACF did not show any repetition; there was no indication in the ACF that the autocorrelation on both the second- or third-time lags was significantly different from zero. Therefore, it could be concluded no seasonal effect on the data. Then, it can be determined that a model would be used was ARIMA without seasonal effects.

D. The Autoregressive (AR) Test

The ACF also showed that the autocorrelation decreased exponentially (r1=0,579 > r2=0,346 > r3=0,266 > r4=0,069 > r5=0,036), approached zero on second and third time lags; a sign of autoregressive (AR) process. The order was determined by indicating number of partial autocorrelations which were significantly different from zero and since that was only one r1 (0,579 > + 0,438) than the prediction of the emission would be on order p = 1.

E. MA (Moving Average)

The moving average could be indicated by the values of partial autocorrelation that decreased exponentially. No such indicator happened in the data; therefore, the emission prediction, the MA order would be q = 0. From all identification steps above, it could be concluded that the ARIMA model which suitable to predict the nitrous oxide emission from the paddy field in Lampung was ARIMA (1,0,0). However, model order should also be compared by the trial and error process, so that the best model could be found. Therefore, other ARIMA models such as ARIMA

(0,0,1) and ARIMA (1,0,1) would also be fitted as comparisons. The results were presented in Table II. The ARIMA (0,0,1). For α=0,05; | t | for MA (1) parameter was higher than t 0,025(24) = 2,064. This meant the estimating value of the model parameter was significantly different from zero (reject H0). The p parameter on MA (1) was 0,001; lower than α =0,05 (reject H0). In conclusion the model could be accepted.

TABLE II: MODEL ANALYSIS: ARIMA (0,0,1) ARIMA (1,0,0) AND ARIMA (1,0,1)

Type	Coef	SE Coef	T	p	MSE
MA 1	-0,6986	0,1670	-4,18	0,001	0,0007402
AR 1	0,9005	0,1773	5,08	0,000	0,00054147
AR 1	1,0274	0,1654	6,21	0,000	0,00052230
MA 1	0,3493	0,3266	1,07	0,300	

The ARIMA (1,0,1) model. For α=0,05; | t | for AR (1) parameter was higher than t 0,025(23) = 2,069. This meant the estimating value of the model parameter was significantly different from zero (reject H0). The p parameter AR (1) was 0,00; lower than α =0,05 (reject H0). However, for MA (1) parameter, | t | was lower than t 0,025(23) = 2,069 with α=0,05. This meant the estimating value of the model parameter was not significantly different from zero (accept H0). Similarly, p parameter of MA (1) was 0,300; higher than α = 0,05 (accept H_0). In conclusion, this model was rejected. Based on those two steps there were two model candidates for predicting nitrous oxide emission which was ARIMA (0,0,1) and ARIMA (1,0,0); the results from these models were presented in Table III; while from ARIMA (1,0,0) model was presented on Table IV and both in Fig. 3.

TABLE III: EMISSION PREDICTION FROM ARIMA (0,0,1) MODEL.

Period of	Prediction	Lower limit	Higher limit
21	0,349	0,295	0,402
22	0,321	0,256	0,386
23	0,321	0,256	0,386
24	0,321	0,256	0,386
25	0,321	0,256	0,386

TABLE IV: EMISSION PREDICTION FROM ARIMA (1,0,0) MODEL.

Period of	Prediction	Lower limit	Higher limit
21	0,387	0,341	0,433
22	0,381	0,320	0,442
23	0,376	0,304	0,447
24	0,371	0,292	0,450
25	0,366	0,282	0,451

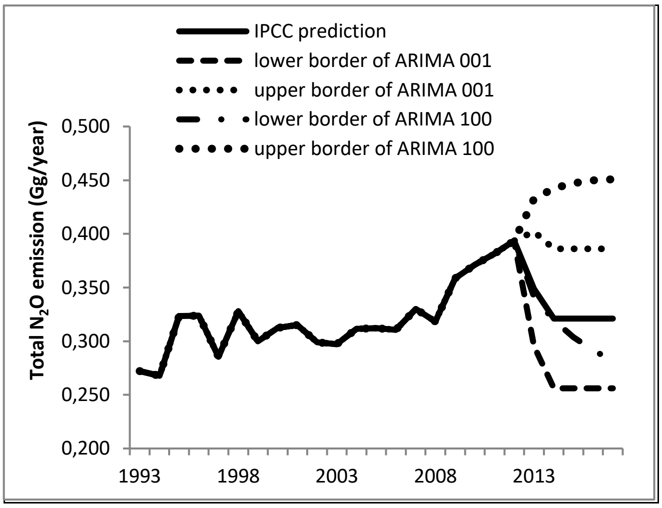

Fig. 3. The plot of N_2O emission prediction from both ARIMA (0,0,1) and ARIMA (1,0,0).

One model should be chosen to get the best prediction results; A comparison between these models was presented in Table V. Based on the criteria then the ARIMA (1,0,0) model was chosen since it had a smaller mean square, even though both models had simple model equations. From the IPCC model based on data of paddy field area in Lampung Province from 1993 to 2012 using only synthetic fertilizers, the emission would be 0.272-0.394 Gg/year. Using the chosen model, the prediction shortly would be in the range of 0.282-0.451Gg/year.

TABLE V: COMPOSITE MEAN SQUARE AND EQUATIONS OF THE MODELS

Model	Composite Mean square	Equation
ARIMA (0,0,1)	0,00074020	Xt = μ + et – θ1et-1
ARIMA (1,0,0)	0,00054147	Xt = μ + Φ1Xt-1 + et

F. N_2O Emission from Synthetic Fertilizers Combined with Organic Fertilizers

This study also attempted to estimate and predict N_2O emission from synthetic fertilizers (150 kg/ha) combined with organic fertilizers (manure 2 tons/ha). Calculated from the same equations; the result was presented in Table VI.

TABLE VI: ESTIMATION OF N_2O EMISSION FROM SYNTHETIC FERTILIZERS COMBINED WITH ORGANIC FERTILIZERS FROM PADDY FIELD AREA IN LAMPUNG PROVINCE

Year	Area (ha)	N_2O Emission (Gg/year)	Year	Area (ha)	N_2O Emission (Gg/year)
1993	433.1	5.649	2003	472.6	6.165
1994	425.9	5.555	2004	495.5	6.463
1995	514.4	6.709	2005	496.5	6.476
1996	515.2	6.720	2006	494.1	6.445
1997	454.1	5.923	2007	524.9	6.847
1998	521.6	6.803	2008	506.5	6.607
1999	476.9	6.220	2009	570.4	7.440
2000	496.9	6.481	2010	590.6	7.703
2001	501.1	6.536	2011	606.9	7.917
2002	475.5	6.201	2012	626.2	8.167

Following all ACF, PAF procedures as above, the results were presented as in Fig. 6 and 7. Strike lines on Fig. 4 and 5 were upper and lower borders for random series with a 95% level of confidence. Using (3) with n=20 and 0,025 = 1,96, upper and lower borders were + 0,438. On the ACF, r1 = 0,579 higher than 0,438 which meant autocorrelation coefficient when k = 1 significantly different from zero, while when k > 1, all coefficients not significantly different from zero. The same results were obtained on PACF, when k = 1, r = 0,579 higher than 0,438, meant it was significantly different from zero. When k>1, all partial coefficients were not significantly different from zero. it can be concluded that the data series was random.

G. Stationary Test

Autocorrelation coefficient (ACF) after second time lag (k = 2) and the third (k = 3), which was r4 (k=4) = 0,069, approached to zero. This meant ACF did not show a tendency to skew diagonally from left to right with the increasing time lags, indicated that the data was stationer, no differentiated data was needed. Therefore, in this research, the prediction of nitrous oxide emission would determine by order d=0.

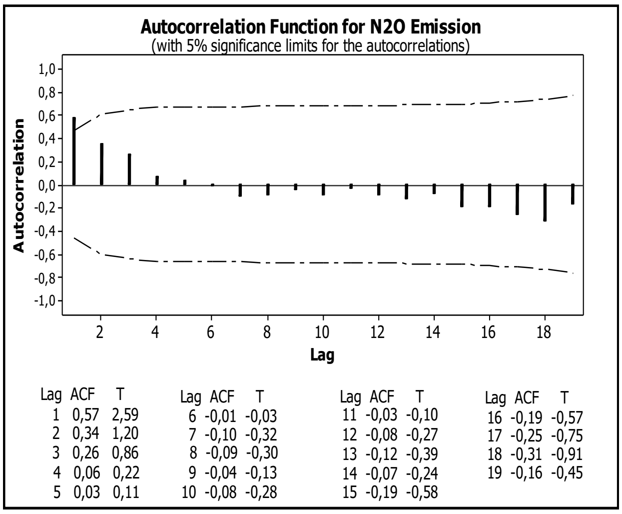

Fig. 4. ACF of N_2O emission data from paddy field area in Lampung Province 1993-2012.

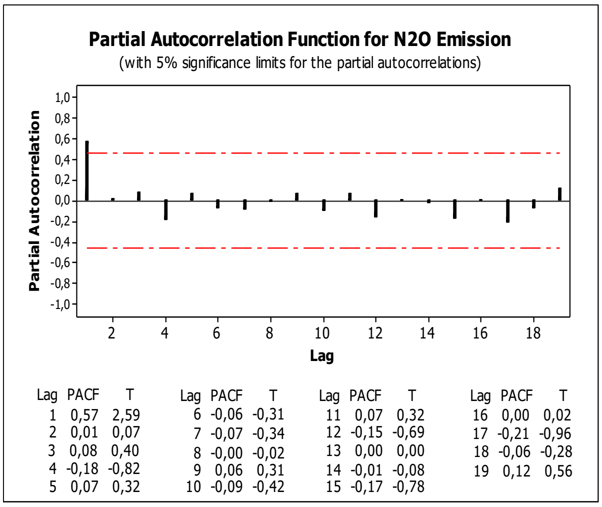

Fig. 5. PACF of N_2O emission data from paddy field area in Lampung Province 1993-2012.

H. Circular Test

The autocorrelation in the ACF did not show any repetition; there was no indication in the ACF that the autocorrelation on the second or third time lags was significantly different from zero. Therefore, it could be concluded no seasonal effect on the data. Then, it can be determined that a model would be used was ARIMA without seasonal effects.

I. The Autoregressive (AR) Test

The ACF also showed that the autocorrelation decreased exponentially (r1 = 0,579 > r2 = 0,346 > r3 = 0,266 > r4 = 0,069 > r5 = 0,036), approached zero on second and third time lags; a sign of autoregressive (AR) process. The order was determined by indicating number of partial autocorrelations which were significantly different from zero and since that was only one r1 (0,579 > + 0,438) than the prediction of the emission would be on order p = 1.

J. MA (Moving Average)

The moving average could be indicated by the values of partial autocorrelation that decreased exponentially. No such indicator happened in the data; therefore, the emission prediction, the MA order would be q = 0. From all identification steps above, ARIMA (1,0,0) model was determined as the tentative model suitable to predict nitrous oxide emission from the paddy field in Lampung. However, model order should also be compared by the trial and error process, so that the best model could be found. Therefore, other ARIMA models which were ARIMA (0,0,1) would be fitted as an alternative. The next step would be to estimate the model parameters and the results were presented in Table VII.

TABLE VII: MODEL ANALYSIS: ARIMA (0,0,1) AND ARIMA (1,0,0)

Type	Coef	SE Coef	T	p	MSE
MA 1	-0,6985	0,1671	4,18	0,001	0,31870
AR 1	0,9011	0,1773	5,08	0,000	0,23324

For α = 0,05; | t | for MA (1) parameter was higher than t 0,025(24) = 2,064. This meant the estimating value of the model parameter was significantly different from zero (reject H0). The p parameter on MA (1) was 0,001; lower than α =0,05 (reject H0). In conclusion, the model could be accepted. For α = 0,05; | t | for AR (1) parameter was higher than t 0,025(23) = 2,064. This meant the estimating value of the model parameter was significantly different from zero (reject H0). The p parameter AR (1) was 0,00; lower than α =0,05 (reject H0); the model could also be accepted. The results of N_2O emission estimation from model ARIMA (0,0,1) were presented in Table VIII while from model ARIMA (1,0,0) was presented in Table IX. One model should be chosen to get the best prediction results; the next criteria would be the composite mean square value and simplicity of the model. A comparison between these models was presented in Table X.

TABLE VIII: N_2O EMISSION ESTIMATION FROM ARIMA (0,0,1) MODEL

Period of	Prediction	Lower limit	Higher limit
21	7,236	6,129	8,343
22	6,663	5,313	8,013
23	6,663	5,313	8,013
24	6,663	5,313	8,013
25	6,663	5,313	8,013

TABLE IX: N_2O EMISSION ESTIMATION FROM ARIMA (1,0,0) MODEL

Period of	Prediction	lower limit	higher limit
21	8,029	7,083	8,976
22	7,905	6,631	9,180
23	7,794	6,305	9,282
24	7,693	6,051	9,335
25	7,602	5,846	9,359

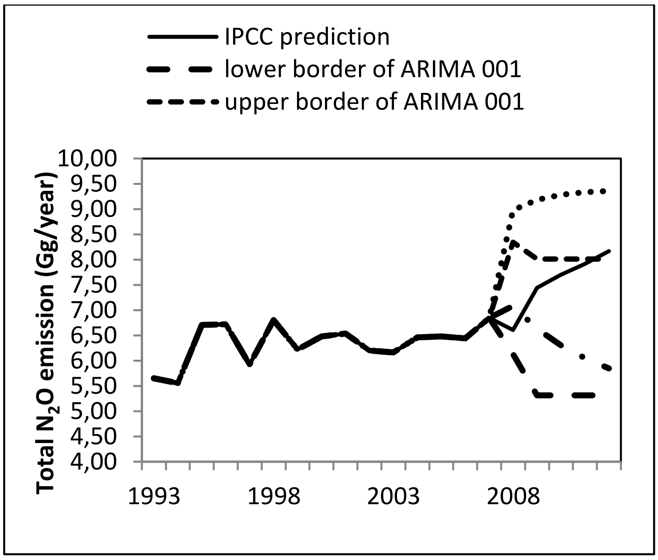

Fig. 6. The plot of N_2O emission prediction from both ARIMA (0,0,1) and ARIMA (1,0,0) model.

TABLE X: COMPOSITE MEAN SQUARE AND EQUATIONS OF THE MODELS

Model	Composite Mean square	Equation
ARIMA (0,0,1)	0,31870	Xt = μ + et – θ1et-1
ARIMA (1,0,0)	0,23324	Xt = μ + Φ1Xt-1 + et

Based on the criteria then the ARIMA (1,0,0) model was chosen, and it can be concluded that using the IPCC model based on paddy field area in Lampung Province from 1993 to 2012 using both synthetic and organic fertilizers, the emission would be 5.649-8,167 Gg/year. Then, using the chosen ARIMA (1,0,0) model the prediction shortly would be in the range of 5,846-9,359 Gg/year. There was no time-series data for horticulture commodities area, only the last data showed that Lampung had an area of 99,248 ha in total for horticulture. Following the IPCC model (2006) those horticulture areas would emit 0.062 Gg/year using only synthetic fertilizer and 1.294 Gg/year using both synthetic and organic fertilizer.

Since rice is the most important staple food in Indonesia, the government of Indonesia implemented a policy called Sustainable Land for Food Agriculture Protection. The land was protected and developed for producing stable food to maintain food independence, security, and self-supplied [24]. The concern related to N_2O emission would be the intensive fertilizer applications to reach the production targets for the growing populations. In general, adjusting the fertilizer N rate to a suitable level is crucial for reducing both N_2O and NO emissions. On the other hand, we should keep in mind the importance of improving N use efficiency by crops by changing fertilizer application methods, placement, and timing, such as deep placement of urea fertilizer [25], [26]. As de-nitrification and nitrification depend on a source of labile soil N, the higher emissions of NO and N_2O will occur at higher concentrations of N in the soil.

IV. CONCLUSIONS

The N_2O emission in Lampung Province using IPCC 2006 model was lower compared to some other countries. However, this result was not implied that fertilizer recommendations in Lampung were safe since the results came from the default number of the model. More researches should be conducted that local emission factors would be available that fertilizer recommendation could be evaluated.

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