BUKTI KOMUNIKASI DAN SIMILARITY
ARTIKEL JURNAL INTERNASIONAL BEREPUTASI

Water total factor productivity growth of rice and corn crops using data envelopment analysis – malmquist index (West Timor, Indonesia)

Penulis :

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REBUTTAL LETTER

REVIEWER 1

No.	Comments	Responses
1	Please, explain the aim of this study	**Line 93 Page 2 (Rewrite)** This study furthermore aimed to the estimation of paddy and corn water productivity, subsequently to estimating the growth of main crops water total factor productivity growth using non parametric method of DEA-MI.
2	Follow the journal's writing rules	Tim CAPA akan membantu menyelesaikan setelah komentar-komentar dari reviewer selesai.
3	Please, make the first letter capital only in the title and subtitle.	**All part** We have revised this part. **Done**

4	Please highlight the main findings of the study in the abstract and Conclusion	**(a) Line 5-25 Page 1 & (b) Line 420-450 Page 12 (Rewrite)** (a). The results showed that paddy water productivity was in the range of 0.290 kg rice/m^3 to 0.930 kg rice/m^3 and corn water productivity was in the range of 0,553 kg kernel/m^3 to 1.590 kg kernel/m^3. Based on DEA-MI single input-single output analysis, the average index of paddy water total factor productivity (PWTFP) was 1.014 with the average growth of EFC index was 0.992 and TEC index was 1.062. During the period the paddy total water productivity growth was decrease by 37.38% due to the increase of EFC by 0.69% and the decrease of TEC by 37, 81%. Belu district has the highest PWTFP growth. The average growth index of corn water total factor productivity (CWTFP) was 1.008 with the average growth of EFC index was 0.985 and TEC index was 1.023. During the period there was an increase of CWTFP by 5.06% due to the decrease of EFC by 14.85% and the increase of TEC by 23.38%. Belu district has the better CWTFP growth. Based on DEA-MI multi input-multi output analysis, the average main food water total factor productivity (FWTFP) growth index in which the aggregate of paddy and corn water productivity was 1.014 with the average EFC index was 0.994 and TEC index was 1.020. During the period there were a decreasing of FWTFP, EFC dan TEC indices by 19.16%, 8.03% and 12.10% respectively. Kupang municipal as the smallest food producer has the better FWTFP growth index. Worth noting, the average efficiency were considerable high, however with the current practice, in average there were opportunities to increase the production of rice, corn and food by 0.80%, 1.50% and 0.60% respectively without additional input of water. Furthermore the increasing of crop water productivity in the area like The West Timor is strongly advised through the increasing of production technology while maintain the level of water use efficiency.

4.	Please highlight the main findings of the study in the abstract and Conclusion	**(b)** The rice and corn production in semi-arid traditional farming systems fluctuated across years and districts. The productions were using a small proportion of the total rainwater volume in the areas. As a consequence, water productivity of paddy and corn (WP_{Rice} and WP_{Corn}) showed a fluctuating and positive trend. The crop water productivities exceeded Tanzania in Africa; furthermore, those values were in the range but lower than the maximum value of developed countries. This provided ample opportunities to enhance the water productivity of main crops. Based on non parametric DEA-MI in SISO analysis, the growth of Paddy Water Total Factor Productivity (PWTFP) in average was showed an increasing with small change of efficiency (EFC) and an increasing of production technology (TEC). Paddy farmers were efficient in using water for rice production given the current technology level. There was a chance to increase rice production by 0,80% without additional water input. During the period there were a considerable decreasing of PWTFP and TEC compared to the base year of 2000. Paddy farmers in Belu district had the better growth of PWTFP. The average growth of Corn Water Total Factor Productivity (CWTFP) and TEC was increased with the slightly decrease of EFC. Corn farmers were efficient in using water for corn production. There was an opportunity to increase production by 1.50% without additional water input. During the period there was an increasing of CWTFP by 5.06% that influenced by the decreasing of EFC by 14.85% and the increasing of TEC by 23.38%. Corn farmers in Belu district have the better ability to use water for corn production. Based on non parametric DEA-MI in MISO analysis the growth of Food Water Total Factor Productivity (FWTFP) in average was increase due to small decrease of EFC and the increasing of TEC. Main food farmers were efficient in using water for food production and could increase 0.60% of food production without additional water input. During the period, there were a decreasing of FWTFP, EFC and TEC by 19.16%, 8.03% and 12.10% respectively. Kupang municipality has the better FWTFP growth compared to other districts. The production technology changes (TEC) more inflict the growth of crops water TFP growth. The current level of production technology could not fully coupled with the changing of food production environment, therefore to enhance the water productivity growth, it is strongly advised by the improvement of paddy and corn production technology while maintain the level of efficiency.

5	Please, Why are you put this table in the end of the paper? **Tables** **Table 4.** Chain indices of wpfood TFP growth	**Reposition to Line 384 P 11.** **Table 4.** Chain indices of Food Water Total Factor Productivity Growth

REVIEWER 2

No.	Comments	Responses
1	The introduction may be supported with more recent literature than Kijneet al., 2003; Therik, 2000; Piggin, 2003; Molden in 1997; Cai and Rosegrant, 2003; Zwart and Bastiaansen, 2004; Coelli et al., 2005; Jin et al., 2010 and Färe et al., 1994.	**Line 31-95 Page 1-2 (Rewrite)** Be deleted : Kijne et al., 2003; Therik, 2000; Piggin, 2003;; Cai and Rosegrant, 2003; Zwart and Bastiaansen, 2004 Be added : de Fraiture and Wichelns, 2010; Molyneux et al., 2012; Giordano et al., 2017; Blatchford et al., 2018); Edreiraa et al., (2018); Mechri et al., (2017); O'Donnell (2018); Hossain et al., (2012); Tang et al., (2016); Minviel and Latruffe (2016); by Koehuan et al., (2019a); Koehuan et al., (2019b)

<table>
<tr><td>2</td><td>Introduction
As cited at the references list:
a. The literature of Kijneet al., 2003 must be corrected to be Kijne et al., 2003.
b. The literature of Vanuytrechtet al., 2014 must be corrected to be Vanuytrect et al., 2014.
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d. The literature of Jinet al., 2010 must be corrected to be Jin et al., 2010.
e. The literature of Fareet al., 2013 must be corrected to be Färe et al., 2014.</td><td>Line 20-66 Page 1-2
We have revised this part.
Done</td></tr>
<tr><td>3</td><td>Material and Methods
It is essential to indicate the study date.</td><td>Line 98 – 99 Page 2 (Rewrite)
2.1 Research Date and Location
The researched was conducted from February 2017 to August 2018.</td></tr>
<tr><td>4</td><td>Material and Methods
The material and methods may be supported with more recent literature than Piggin, 2003; FAO, 2008; Runtunuwu, 2010; Triatmojo, 2010; Amarasinghe et al., 2007; Coelli et al., 2005; Färeet al., 1994 and Goodridge, 2007.</td><td>Line 97-165 Page 2-4

Be added :
Tang et al., 2016; Toma et al., 2017; Koehuan et al., 2019a; Koehuan et al., 2019b</td></tr>
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5	**Material and Methods** As cited at the references list: a. The literature of Amarasingheet al., 2007 must be corrected to be Amarasinghe et al., 2007. b. The literature of Amarasingheet al., 2014 must be corrected to be Amarasinghe et al., 2014. c. The literature of Coelliet al., 2005 must be corrected to be Coelli et al., 2005. d. The literature of Fär eet al., 1994 must be corrected to be Fär e et al., 1994.	**Line 68-135 Page 2-3** We have revised this part. **Done**
6	**Material and Methods** The following sentence must be completed: Also, a rescaled adjusted partial sums (RAPS) or Buishand test, which is appropriate for developing countries climate stations' consistency tests, was carried out (Santos and Fragoso, 2013; Ahmad and Deni, 2013). There is.	**Line 114-116 Page 3 (Rewrite)** In order to gain the consistency climate data, a rescaled adjusted partial sums (RAPS) or Buishand test, which is appropriate for developing countries climate stations' consistency tests, was carried out (Santos and Fragoso, 2013; Ahmad and Deni, 2013). However, a lack of some climatic data i.e. mean humidity and mean wind speed in districts other than Kupang; therefore, the authors assume both data to be equal to Kupang.
7	**Results and Discussion** The title of Result and Discussion must be corrected to be Results and Discussion.	**Line 137 Page 3** We have revised this part. **Done**

8	**Results and Discussion** The results and discussion may be supported with more recent literature than Coelli and Rao, 2003	**Line 332--338 Page 10** Koehuan et al., (2019a), **Line 368 -371 Page 10-11** Fugile (2010) **Line 400-406 Page 12** Koehuan et al., (2019b)
		Line 226-416 Page 6-12 - Rewrite with additional information
9	**Results and Discussion** As cited at the references list, the literature of Makurira et al., 2003 must be corrected to be Makurira et al., 2011.	**Line 177 Page 5** We have revised this part. **Done**
10	**References** The position of Amarasinghe et al., 2007 must be corrected to be before Amarasinghe et al., 2014.	**Line 389-391 Page 11** We have revised this part. **Done**
11	**References** As CIGR J. author guide, the refernces list must be corrected as follows: Ahmad, N.H. and S.M. Deni (2013). Homogeneity test on daily rainfall series for Malaysia.*Matematika*, 29: 141-150. Alauddin, M. and B.R. Sharma (2013). Inter-district rice water productivity differences in Bangladesh: An empirical exploration and implications.*Ecological Economics*, 93: 210–218. Alauddin, M., U.A. Amarasinghe and B.R. Sharma (2014). Four decades of rice water productivity in Bangladesh: A spatiotemporal analysis of district-level panel data.*Economic Analysis and Policy*, 44 (1):51–64.	**Line 381-453 Page 11-13** We have revised this part. **Done**

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Abstract: This study aims to estimate staple food water productivity based on crop water use and subsequently aimed to analyze the total factor productivity growth using DEA-MI methods. The secondary panel data from 2000-2015 regarding climate data, main food harvested areas and main food production were applied. The results showed that despite higher dependencies on rainwater, staple food production used a small part of the volume. Staple food water productivity showed a fluctuation and positive trends, falling in the range of global estimates but still below the upper value. The single input-single output analysis showed that the mean annual TFP growth of WPPaddy and WPCorn were positive, mainly due to technology change (TEC) rather than the decrease in efficiency change (EFC). However, based on chained indices analysis, WPPaddy had a considerable decrease in TFP growth, while WPCorn had a slight increase. The MIMO analysis indicated that the mean annual food water TFP growth showed a similar pattern, but was in contrast to the chain analysis which showed a decrease in TFP growth and all of the components. Regarding district performance, the Belu districts performed better in the SISO analysis and Kupang municipal, which is even smaller in harvested area and production, performed better in the TFP growth based on MIMO analysis.

Keywords: Crop water, data envelopment analysis, Malmquist index, water productivity.

1 Introduction

Crop water productivity is one of the water demand approaches that is believed to be one of the answers to the question of sustainable agricultural water management, leading to sustainable agricultural development, particularly in developing countries. Sustaining food supply to meet the increasing demand generated by population growth and living standard in the degradation of the environment has posed a threat; therefore, sustaining crop water use efficiency and productivity is an evitable (Kijne et al., 2003; Vanuytrect et al., 2014).

About food production in the semi-arid region of West Timor, the primary food is paddy (*Oryza sativa* L.) and corn (*Zea mays* L.). Agricultural land is the prime source of living for 61% of the population; even though it is believed that the cultivation system is categorized as traditional subsistence farming, the improvements in intensive agriculture are less of a benefit to most farmers. Dryland farming in the form of shifting cultivation dominated food production, with very high dependency on natural resources in which extreme dry seasons and erratic rainfall pose a threat to plant growth that could lead to harvest failure (Therik, 2000; Piggin, 2003).

First introduced by Molden in 1997, generally, in the physical form, crop water productivity (CWP) is defined as crop yield per cubic meter of water consumption. Yield could be in the form of marketable or editable yields. The increase in CWP results not only in the use of less water to produce the same yield, and the same amount of water to produce more food (Cai and Rosegrant, 2003; Zwart and Bastiaansen, 2004).

There has been considerable research regarding crop water productivity; however, little attention has been paid to the study of inter-temporal change or to incorporate a spatial-temporal analysis with time series statistical data (Alauddin and Sharma, 2013). The study by Alauddin et al. (2014) estimated and explored the change in rice WP for 21 Districts in Bangladesh for 37 years; then, factor analysis and the Granger causality test found that technology diffusion is the primary factor affecting rice WP. Subsequently, the research of Alauddin et al. (2014) focused on the evaluation of rice water productivity sustainability, either using irrigated rice (rabi) or rain-fed rice (Kharif), and then proposed policy options to tackle the unsustainable. What is not yet clear is regarding the growth of water productivity and its components of efficiency and technology, i.e., which component and the magnitude in which it affected the total factor productivity growth.

Traditional productivity analysis tends to determine growth, mainly due to technology changes that are valid when production units operate under efficient performance. A more robust method, however, is total factor productivity (TFP) analysis, which is based on the assumption that production units work inefficiently. Therefore, the TFP analysis decomposed growth, either efficiency growth or technology growth (Coelli et al., 2005; Jin et al., 2010). The Malmquist index method based on Fare et al. (1994) is widely used to study TFP growth and its decomposition. The Malmquist index determines the TFP change between two data points by calculating the ratio of the distances of each data point relative to a standard technology. DEA is a linear programming method that is applied to calculate the distance function in the Malmquist index. The increase in TFP, furthermore, could be achieved by a positive shift of production frontier (TEC) or the upward position that matches the production frontier (EFC) (Coelli et al., 2005).

Having understood the importance of sustaining food supplies for the population of West Timor and simultaneously contributing to water productivity studies, no previous study has investigated crop water total factor productivity growth, particularly in the semi-arid region of West Timor. This study furthermore focuses on the estimation of crop water productivity, subsequently in estimating the growth of crop water total factor productivity of rice and corn.

2 Material and Methods

2.1 Research Location

West Timor is part of the East Nusa Tenggara Province (NTT), Indonesia, which consists of four districts (Kupang, South-central Timor or TTS, North-central Timor or TTU and Belu), and a Kupang municipal. Astronomically, West Timor is located at 123°27’40”–125°11’59” East Longitude and 08°56’17”–10°21’56” South Latitude.

West Timor region has a semi-arid climate, with a long dry season from April to November caused by south-east monsoons from Australia that badly affect agricultural production (Piggin, 2003). Worldwide, arid and semi-arid areas consist of 40% land and 37% inhabited by a population. This area has characteristics that include irregular precipitation, long drought periods, evaporation rates exceeding precipitation, and steppe vegetation (FAO, 2008).

2.2 Data Source and Preparation

This study used secondary panel data from 2000 to 2015 provided by the NTT provincial bureau of statistic (BPS NTT), except for the average crop planting time from Runtunuwu et al. (2013), and crop coefficient (Kc), which were based on the Indonesian water resources bureau. In order to fill missing climate data, a typical ratio method was applied (Triatmojo, 2010). Also, a rescaled adjusted partial sums (RAPS) or Buishand test, which is appropriate for developing countries climate stations’ consistency tests, was carried out (Santos and Fragoso, 2013; Ahmad and Deni, 2013). There is. However, a lack of some climatic data i.e. mean humidity and mean wind speed in districts other than Kupang; therefore, the authors assume both data to be equal to Kupang.

2.3 Crop Water Use (CWU) Estimation

CWU is a denominator in water productivity, which determines the volume of water that affects production. CWU describes evapotranspiration from the crop growing area. To date, various studies have been developed and introduced to measure CWU based on statistical time series data, including (Allauddin and Sharma, 2013; Alauddin et al., 2014; Amarasinghe et al., 2007; Amarasinghe et al., 2014; Sharma et al., 2015). In this study, the previous methods were modified not only to meet data availability but also to propose the main crops based on the estimation; therefore, the estimation meets the following equations:

$$\mathrm{CWU_{Paddy}} = \mathrm{HA_{Pd}}\Big[\sum_{j\varepsilon mth}\sum_{i\varepsilon period} \min\left(\mathrm{Kc_{Pd}} \text{ x } \mathrm{ETo_j}, \mathrm{EFFRF_j}\right) \text{x } \frac{\mathrm{d_{ij}}}{\mathrm{n_j}} + \sum_{j\varepsilon mth}\sum_{i\varepsilon period}\left(\mathrm{Kc_{Pd-i}} \text{ x } \mathrm{ETo_j}\right) \text{x } \frac{\mathrm{d_{ij}}}{\mathrm{n_j}}\Big] \quad (1)$$

$$CWU_{Corn} = HA_{corn}[\sum_{j\epsilon mth}\sum_{i\epsilon period}\min\left(Kc_{corni} \times ETo_j, EFFRF_j\right) x\ \frac{d_{ij}}{n_j}$$

$$+\sum_{j\epsilon mth}\sum_{i\epsilon period}\left(Kc_{corn-i} \times ETo_j\right) x\ \frac{d_{ij}}{n_j} \quad (2)$$

Where, HAPd and HACorn are harvested areas of paddy and corn, respectively, Kcpaddy-i and Kccorn-i are crop coefficients of paddy and corn, respectively, and ETоj and EFFRFj are references to evapotranspiration and sufficient rainfall, respectively.

2.4 Crop Water Productivity (CWP) Estimation

$$CWP_{Paddy_{(d,y)}} = {P_{Rice_{(d,y)}}}\Big/{CWU_{Paddy_{(d,y)}}} \quad (3)$$

$$CWP_{Corn_{(d,y)}} = {P_{Kernel_{(d,y)}}}\Big/{CWU_{Corn_{(d,y)}}} \quad (4)$$

Where, CWP is crop water productivity (kg/m3), PRice is rice production (kg), PKernel is corn kernel production (kg), CWUPaddy is paddy water use (m3), CWUCorn is corn water use (m3), d is districts, and y is years.

2.5 Total Factor Productivity (TFP) Growth

Data Envelopment Analysis–Malmquist Index (DEA-MI) was used to gain the total factor productivity change (TFPC) with decomposed efficiency change (EFC) and technology change (TEC). The first step is the analysis of each of the crop separately (single input, single output = SISO). The next step is the analysis of both crops simultaneously (multiple inputs, multiple output = MIMO). The non-parametric linear programming DEA is used to calculate the distance function, furthermore being used by MI to determine the efficiency and technology change that constructed the total factor productivity change. This study furthermore applied an output orientation of the Malmquist index (MI); this orientation intended to reduce the input with the same output or with the same amount of input producing more output. Those conditions are suitable for agricultural conditions in developing countries (Coelli et al., 2005; Xu, 2012) as stated by the following equations based on Färe et al.(1994). Additionally, in this paper, we used the words growth and changed interchangeably.

$$\text{Efficiency change (EFC)} = \frac{d_o^t(q_t, x_t)}{d_o^s(q_s, x_s)} \quad (5)$$

$$\text{Technology change (TEC)} = \left[\frac{d_o^s(q_t, x_t)}{d_o^t(q_t, x_t)} x \frac{d_o^s(q_s, x_s)}{d_o^t(q_s, x_s)}\right]^{1/2} \quad (6)$$

Total factor productivity change (TFPC) = EFC x TEC (7)

Where d_O^s is distance function of current period (s = t), (q_s, x_s) is current period production with input, d_O^t is distance function of t +1 period (t = s + 1), and (q_t ,x_t) is t+1 period production with input.

Total factor productivity change and the component of efficiency change (EFC) and technology change (TEC) were calculated with the help of DEAP Ver.2.1, an open source software, provided by the Centre for Efficiency and Productivity Analysis (CEPA) (Coelli et al., 2005). Cumulative chain indices were applied to determine the growth of total productivity change and its components over time, as stated by the equation below (Goodridge, 2007).

3 Results and Discussion

3.1 Main Food Production and Water

The production of paddy regarding rice and the production of corn regarding corn kernel fluctuate across districts and years. Kupang district was the top rice-producing district while

TTS district was the top for corn kernel production. Kupang municipal showed the lowest production of both rice and corn kernel with the highest fluctuation. About West Timor region, the highest rice production was in 2014, and the lowest was in 2005. The highest corn kernel production was in 2013, and the lowest was in 2011.

The primary food crop production utilized 2.35% of total rainwater volume. Even though paddies used more units of water than corn, because the vast majority of farmers cultivated corn, it used a greater of the volume of water compared to paddies. On average, staple food production used 580,934 mm3 water/year, with the lowest in 2005 and the highest in 2013. In total, both crops used water in a fluctuating and positive trend from 2000-2015.

A non-parametric test indicated that the production and crop water use (CWU) data differed across the districts. The independent sample Kruskal-Wallis tests reported a significant value (p-value < 0.005), highlighting that the distribution of the production and CWU variables differed across the districts. The descriptive statistics and non-parametric test results are presented in Table 1.

Table 1. Descriptive statistics of production and CWU data

Variables	Mean	Std. Deviation	Min	Max	Kruskal-Walis Test (Sig.)
Paddy prod (Kg rice)	13929371.25	12558679.65	90000.00	56869000	0.000
Corn prod (Kg corn kernels)	64312012.50	49580575.67	746000.00	207631000	0.000
CWU_{Paddy} (m3)	31112557.01	25798236.36	209418.17	92297832.51	0.000
CWU_{Corn} (m3)	82281550.76	66013663.09	896406.96	282368043.75	0.000

3.2 Main Food Crop Water Productivity

The average crop water productivity (CWP) of the primary food in West Timor during the last 15 years displayed a fluctuation with positive trends as depicted in Figure 1. WP_{Corn} outnumbers the WP_{Paddy}, with WP_{Paddy}being more diverged than WP_{Corn}. Paddy cultivation is more intensive than corn cultivation; it requires more input factors and technology. Also, paddy cultivation by mostly traditional farmers in semi-arid areas like West Timor shows a production that is capricious. WP_{Paddy} and WP_{Corn} were highest in 2014 and 2009, respectively, and reached the lowest point in 2011. The erratic rainfall and the socio-economic conditions of the farmers were generating uncertainty in the cultivation and production of main foods in semi-arid regions.

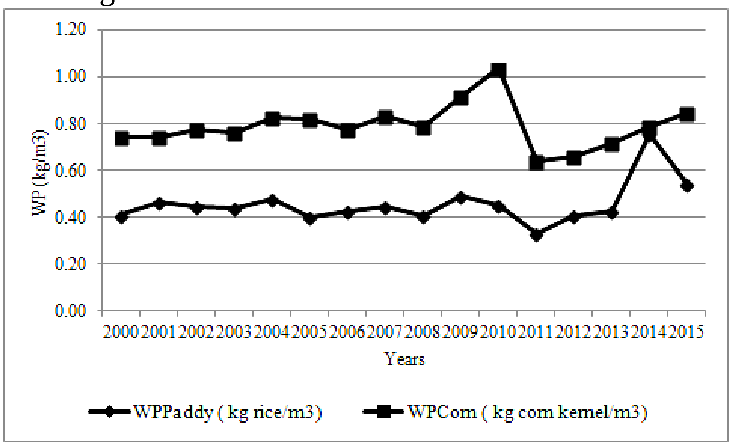
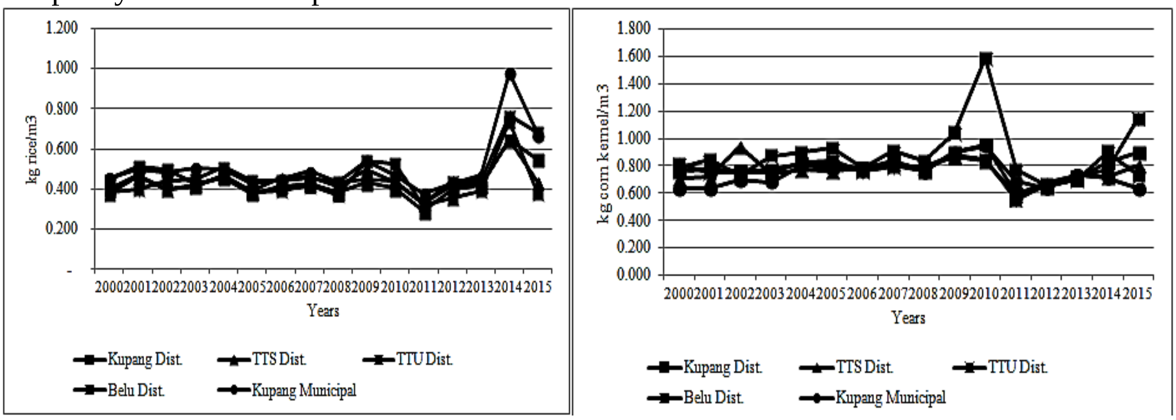


Figure 1. Annually prime food water productivity of West Timor

During 2000 and 2015, crop water productivity of paddy and corn per crop water unit (CWU) in West Timor ranging from 0.290 kg rice/m^3 to 0.930 kg rice/m^3 and from 0.553 kg corn kernel/m^3 to 1.590 kg corn kernel/m^3 respectively. The estimated CWUPaddy was in range with global estimation by Steduto (2007), ranging from 0.150–1.600 kg/m^3; this was relatively higher than that of the Bangladesh population (0.216–0.570 kg/m^3) estimated by Alauddin and Sharma (2013). Likewise, in terms of CWPCorn, the West Timor experience was in range with the results from dry land China and Sub Saharan Africa, which reached 0.100–1.900 kg/m^3, as reported in Sharma et al. (2015) and surpassed the experience of subsistence farmers of Tanzania (0.100–0.600 kg/m^3) (Makurira et al., 2011).

Considering inter-district estimations of WPPaddy, as presented in Figure 2a and 2b, the Kupang municipal had the highest value of WPPaddy, while the TTU district had the lowest. On the other hand, the TTU district had the highest value of WPCorn, in contrast with Belu District, which had the lowest. However, Kupang municipal encountered a stark variation, while the TTS district encountered the lowest variation of CWPPaddy.TTU district experienced a more varied value of CWUCorn compared with TTS district. It is interesting to note that Kupang municipal is a capital city of the NTT Province; even though it possesses the smallest agricultural area, it has better access to agriculture production, factors which enable the capacity of farmers to produce more rice with the available water.



(a) **(b)**

Figure 2. Considering inter-district estimations of (a)WP_{Paddy} (kg rice/ m^3), (b) WPCorn (kg corn kernel/ m3)

3.3 Paddy Water Total Factor Productivity Growth

The data envelopment analysis – Malmquist Index (DEA-MI) approach, aiming to determine total factor productivity (TFP) growth has the ultimate advantage of providing information regarding the influence of efficiency change (EFC) and technology change (TCH). This linear mathematical programming also releases the strict function from which is enable to use non-parametric data (Coelli and Rao, 2003; Goblan, 2016). However, it is important to note that the result was relatively comparative; in this study, the comparison was only with the inter-district of West Timor.

Paddy water total factor productivity (WPPaddy TFP) growth in West Timor during 2000 to 2015, as depicted in Figure 3, showed a fluctuating trend, especially from 2013 to 2015. The mean annual TFP growth of WPPaddy was 1.041, with a mean annual growth of efficiency (EFC) of 0.992 and a mean annual growth of technology (TEC) of 1.062. The highest TFP growth was 1.742 (2013/2014), and the lowest was 0.709 (2014/2015). The highest EFC was 1.082 (2003/2004), and the lowest was 0.830 (2013/2014). The highest TEC was 2.099 (2013/2014), with the lowest being 0.699 (2014/2015). A similar study, estimating the productivity of energy in a paddy cropping system in Nepal using DEA by Pokhrel and Soni (2017), highlighted the efficiency change (EFC) to be within the range of 0.664–0.820, which is considered to show that the use of energy in a paddy production system is proper, but could be more energy efficient. Also, broader production factors include land, labor, seed, fertilizer, and pesticide; the effect on the technical change (EFC) of paddy using DEA in Niger-Africa was investigated by Boubacar et al. (2016). This study found that the average efficiency change is 0.48, with the index range from 0.10 to 1.00. It is important to note that there was an opportunity for farmers in West Timor to save about 1.00% of the precious water to produce rice, about 18% to 34% of energy could be saved by farmers in Nepal to produce rice, and there was a reduction of about 52% of the input productions when growing rice in Niger without jeopardizing the current level of production.

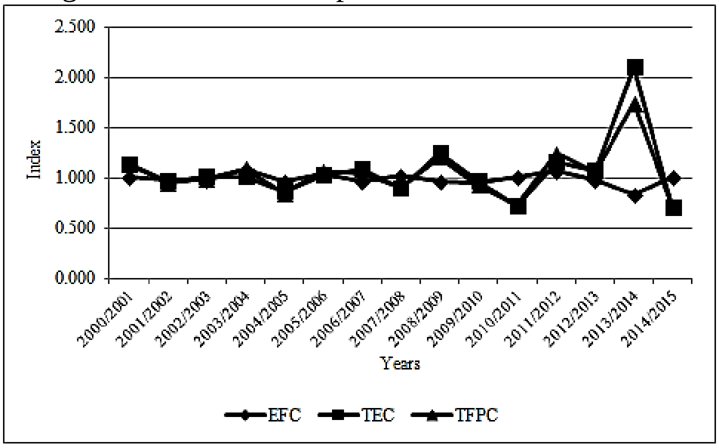


Figure 3. Mean annual WP_{Paddy}TFP growth from 2000-2015

It is worth noting the resemblance in years when TFC and TEC gained high and low indexes, showing that technology changes determine WPPaddy TFP growth rather than efficiency changes. There is, however, a change in technology over the years, which is more due to variety than efficiency. The variety of TEC indicates that the farmers could not cope with the changes in a production environment to some degree.

Surprisingly, despite average technology changes outnumbering efficiency changes and dominating the growth of paddy water TFP growth, based on chain indices, there was an increase in EFC and a decrease in both TEC and TFP. During the same period, the chain indices presented in Table 2 showed that there was a fluctuation in growth, especially in the last period. In the last period, the efficiency index was 1.007, indicating that there was a growth in efficiency of 0.69%. On the other hand, technology and the TFP index were 0.622 and 0.626, respectively, which indicates the downfall of 37.81% of technology growth and 37.38% of TFP growth.

Table 2. Chain indices of wppaddy TFP growth

Year	**EFC**	**TEC**	**TFPC**
2000/2001	1.000	1.000	1.000
2001/2002	0.973	0.863	0.840
2002/2003	0.973	0.899	0.875
2003/2004	1.073	0.895	0.961
2004/2005	0.963	0.771	0.743
2005/2006	1.031	0.913	0.941
2006/2007	0.957	0.961	0.920
2007/2008	1.009	0.792	0.799
2008/2009	0.962	1.107	1.065
2009/2010	0.946	0.864	0.818
2010/2011	0.997	0.641	0.640
2011/2012	1.065	1.028	1.096
2012/2013	0.977	0.948	0.927
2013/2014	0.823	1.867	1.538
2014/2015	1.007	0.622	0.626

The increasing efficiency change indicates that the ability to manage water for paddy fields shows an improvement; however, the negative shift in production function indicates that the use of water tended to exceed this, or that there was a decrease in rice production due to a lack of production innovation. Furthermore, the downfall of TEC results in a reduction of paddy water TFP growth to a considerable level. Furthermore, this result strengthened the need to improve the innovation of paddy production technology in semi-arid regions.

Regarding district performance, Figure 4 shows that there was a variation of TFP growth. Belu district had the highest TFP growth and efficiency change of 1.039 and 1.012, respectively, in contrast with the TTU district, which had the lowest TFP growth and efficiency change of 0.996 and 0.970, respectively. It interesting to note that all of the districts had a similar TEC index of 1.027. This indicates there was an increase in technology, but that the development of production technology is similar across the districts. Also, farmers in all districts of West Timor are highly efficient at using water for rice production in a given technology frontier but have the opportunity to use 1.01% less water to produce the same amount of rice.

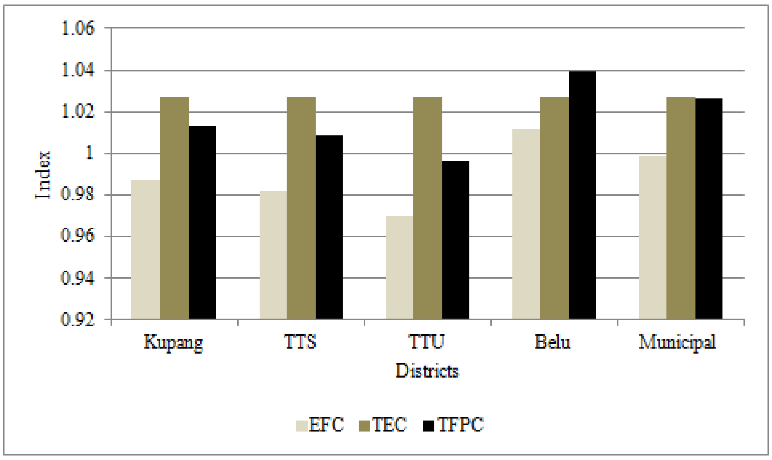


Figure 4. Districts' mean paddy water total factor productivity change

3.4 Corn Water Total Factor Productivity Growth

About the mean corn water TFP growth, Figure 5 shows a fluctuation trend, especially in the last 7 years. TFP growth reached a peak in 2008/2009 and hit the lowest point in 2010/2011. The mean annual WPCorn TFP growth was 1.008, which consisted of an efficiency change of 0.985 and a technology change of 1.023. This result highlights the fact that those farmers in West Timor have a relatively efficient way of using water for corn production. Also, technology changes generated the growth of WPCorn TFP growth rather than efficiency changes. However, the change in technology is more variable than the efficiency change and TFP growth. This highlights the fact that despite corn being a dominant crop in West Timor, the development of cultivation technology does not seem to benefit most of the farmers (Piggin, 2003).

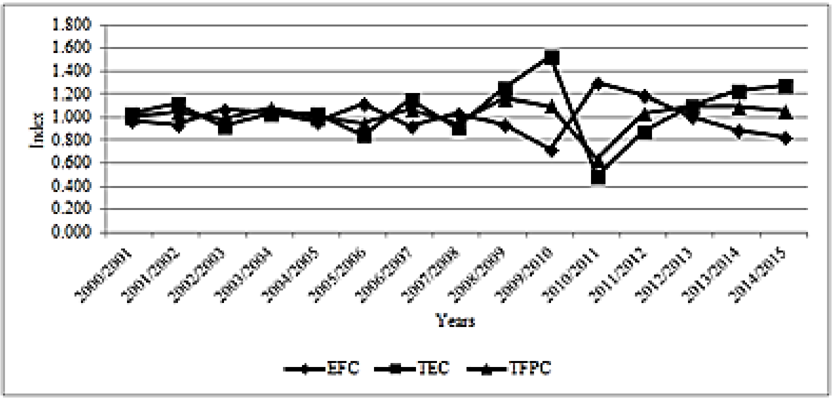


Figure 5. Mean annually WPcorn total factor productivity growth

Concerning chain indices of WPCorn TFP growth during the last 15 years, Table 3 shows a fluctuation with a considerable decrease in efficiency change (-14.85%) in contrast with the considerable increase in technology change (23.38%) that inflicts a 5.06% increase in TFP. Despite corn farmers in West Timor using water to a high level of efficiency, during the same period they experienced a reduction in efficiency change. It was implied that in traditional dry land cultivation in semi-arid regions, the capability of managing water for corn is limited to some degree, leading to the use of water to produce only 85.15% of the potential corn production. However, the improvement in technology change showed a promising sign that could shift the production function upward. The increase in technology was in line with the Provincial Government policy during the last 10 years, to establish corn as a prime commodity.

Table 3. Chain indices of wpcorn TFP growth

Year	EFC	TEC	TFPC
2000/2001	1.000	1.000	1.000
2001/2002	0.959	1.081	1.037
2002/2003	1.094	0.899	0.984
2003/2004	1.077	1.000	1.077
2004/2005	0.988	1.004	0.992
2005/2006	1.150	0.821	0.944
2006/2007	0.952	1.122	1.068
2007/2008	1.057	0.889	0.940
2008/2009	0.958	1.210	1.159
2009/2010	0.738	1.481	1.093
2010/2011	1.334	0.471	0.629
2011/2012	1.219	0.846	1.031
2012/2013	1.031	1.059	1.092
2013/2014	0.909	1.192	1.084
2014/2015	0.852	1.234	1.051

Regarding district performances, Figure 6 shows that the inter-districts WPCorn TFP growth had a slight variation from 0.995 to 1.023. The growth was composed of the variation in efficiency change from 0.973 to 1.000 and an equal technology change of 1.023. Belu district had the highest growth of 2.3%, while TTU district had the lowest growth of -0.46%. The highest improvement of TFP was in Belu district compared to other districts; this was due to farmers in this district being efficient at using water to increase corn production. Despite TTS district having the most significant share of corn production in West Timor, the efficiency improvement is still moderate compared to other districts. On average, corn farmers in all districts showed high efficiency in using water for corn production in a given production frontier, despite farmers potentially reducing the use of water by 1.48% without reducing production.

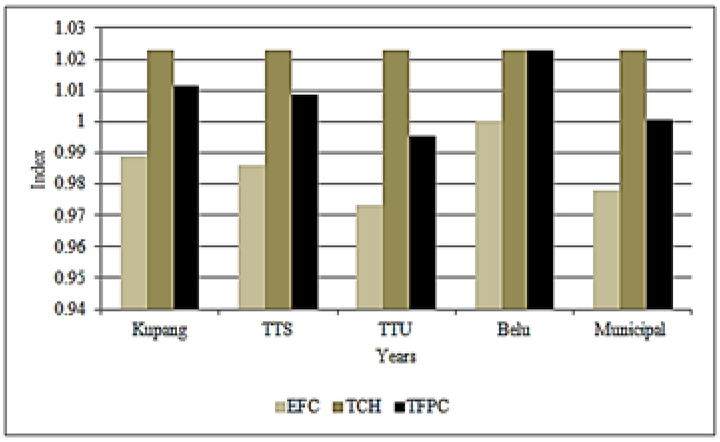


Figure 6. Districts WPCorn TFP growth

3.5 Main Food Water Total Factor Productivity Growth

The primary food crop water productivity was constructed from paddy water productivity (kg rice/m3) and corn water productivity (kg corn kernel/m3). DEA-MI was applied to conduct multi-input multi-output analysis (MIMO); the inputs were paddy water use (CWUPaddy) and corn water use (CWUCorn), while the outputs were paddy production (kg rice) and corn production (kg kernel).

The mean annual food water TFP growth depicted in Figure 7 highlights that there was a fluctuation, particularly in the last 7 years. From 2000-2015, WPFood TFP growth varied between 0.707 and 1.456 which consisted of a variation in efficiency change between 0.916 and 1.016 and the variation in technology change between 0.680 and 1.433. The average WPFood TFP growth was 1.014, with an average EFC of 0.994 and TEC of 1.020. This study supported the study regarding TFP growth in agriculture worldwide from 1980–2000 using DEA-MI by Coelli and Rao (2003), showing that the mean TFP growth of Indonesian agriculture is 0.981, with an efficiency change of 0.978 and technology change of 1.003.

There was a similar result when TEC and TFP reached the highest index in 2010/2011 and the lowest index in 2013/2014. Those results furthermore implied that technology change had a more significant influence on the growth of TFP. It is important to note that WPFood TFP growth and its component of EFC and TEC showed a fluctuated index in which EFC was more stable than TEC and TFP. The fluctuation was either due to unstable food production or variations in water use. Also, it revealed that traditional farmers in semi-arid regions were not adequately coping with the changing environment and production inputs.

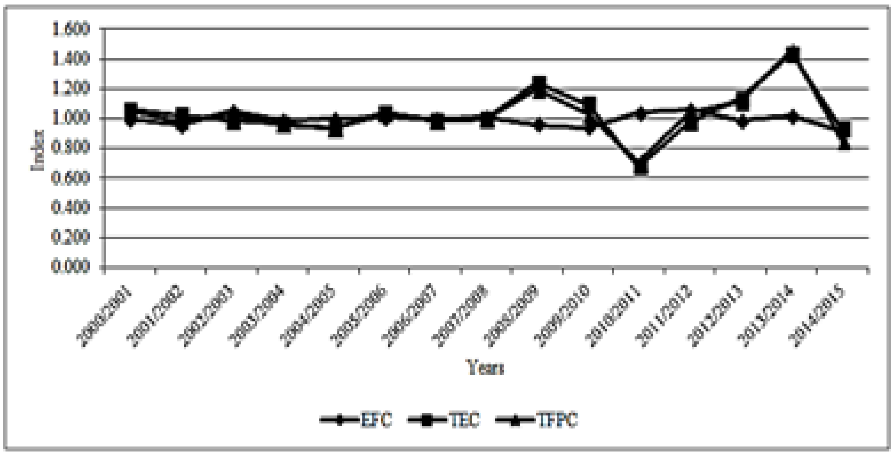


Figure 7. Mean annually WPFood TFP growth

Taking into consideration the chain indices of WPFood TFP growth during the last 16 years, there was an alarming decrease in the annual food and water TFP growth of 19.16%, which was constructed by decreasing the efficiency and technology changes by 8.03% and 12.10%, respectively. The lowest growth of TFPC of -32.95% was in 2010/2011, in which TEC was at the lowest point of -35.73% and EFC of 4.32%. The highest point of TFPC of 38.16% was in 2013/2014, with the highest growth of TEC reaching 35.44% and EFC reaching 2.01%. It is interesting to note that MIMO analysis provided different results compared to per crop analysis (SISO) regarding the magnitude of growth. Additionally, a possible explanation for the decrease in food and water TFP growth and its components was due to the characteristics of traditional farming that hampers innovation in agriculture, causing the production system to fluctuate in the changing environment. It can be said that the farmers' ability to control the change in the environment on a year to year basis seems limited. Regarding district performance, as depicted in Figure 8, WPFood.

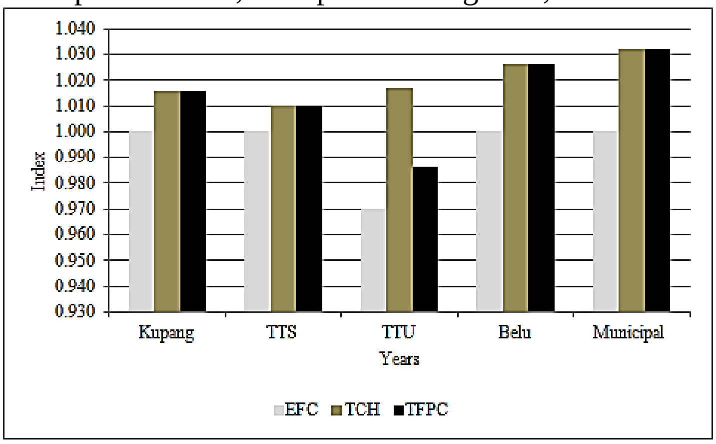


Figure 8. Districts WPFood TFP growth

TFP growth varied from 0.986 to 1.032, with an average of 1.014. Kupang municipal had the highest TFP growth while TTU district had the lowest TFP growth. All districts had an EFC of 1.000, except for TTU district, which was 0.970, and had an average EFC of 0.994. As in SISO analysis, in MIMO analysis there was a variation in TEC from 1.010 (TTS district) to 1.032 (Kupang municipal); the average TEC was 1.020. Remarkably, traditional subsistence farmers of West Timor were relatively efficient in using water for food production under the current level of food production technology.

Also, this result confirmed that in the traditional dryland farming in semi-arid regions, technology changes (TEC) play an essential role in food and water TFP growth. Interestingly, even though Kupang municipal has the smallest food cultivation area and production, it leads in the total food and water productivity growth during the period of analysis. This result might be explained by the fact that water productivity is related to broader factors in the food production system. Kupang municipal, as the capital of the NTT Province, with West Timor being one of the main islands of the province, has better access to and a better quality of food production input factors. This notion is supported by the study in China's agricultural TFP growth for over 30 years by Chen et al. (2008), which points out that agricultural TFP growth from higher income provinces is better than for lower-income provinces. This highlighted the fact that regarding food water productivity growth, intensive farming systems with the smallest areas and better technology would exceed extensive areas with limited technology.

4 Conclusion

The rice and corn production in semi-arid traditional farming systems fluctuated across years and districts. The productions were using a small proportion of the total rainwater volume in the areas. As a consequence, WPRice and WPCorn regarding crop water use showed a fluctuating and positive trend. The crop water productivities exceeded Tanzania in Africa; furthermore, those values were in the range but lower than the maximum value of developed countries. This provided ample opportunities to enhance the water productivity of crops.

Regarding per crops analysis, both WPRice and WPCorn TFP growth showed average fluctuating trends, with technology change dominating the TFP growth. However, in the last period, WPRice TFP growth and technology change experienced a remarkable downfall while WPCorn TFP growth and technology changes increased. Rice farmers were more efficient at water management compared to corn farmers but still had a chance to save water. Regarding district performances, there were variances in both TFP growths due to the efficiency change, where the innovation in production technology was indistinguishable across districts.

In a multi-crops analysis or WPFood TFP growth, the mean annual trend fluctuated with an increase in TFP and both of its components; technology change was a notable component. However, in the last 16 years, all of the growth components had decreased. Interestingly, all districts performed relatively better with small discrepancies in efficiency changes but showed greater variance in technology change and TFP growth. The more intensive farms of the district showed better WPFood TFP growth.

The limitation of this study included the data availability of climate data and the availability of planting data and crop damage data at the district level. The methodology limitation was that the growth comparison was only performed for the districts under study. The authors are encouraged to conduct this kind of study at the national and global level, along with other agricultural commodities.

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Tables

Table 4. Chain indices of wpfood TFP growth

Year	EFC	TEC	TFPC
2000/2001	1.000	1.000	1.000
2001/2002	0.964	0.968	0.933
2002/2003	1.052	0.932	0.981
2003/2004	0.996	0.916	0.912
2004/2005	1.003	0.887	0.889
2005/2006	1.009	0.977	0.986
2006/2007	1.003	0.932	0.935
2007/2008	1.010	0.943	0.953
2008/2009	0.967	1.172	1.133
2009/2010	0.946	1.035	0.979
2010/2011	1.043	0.643	0.670
2011/2012	1.065	0.924	0.985
2012/2013	0.990	1.071	1.060
2013/2014	1.020	1.354	1.382
2014/2015	0.920	0.879	0.808

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Water Total Factor Productivity Growth of Rice and Corn Crops Using Data Envelopment Analysis – Malmquist Index (West Timor, Indonesia)

Abstract

Water is believed to be one of the fundamental inputs for food production; incorporating water productivity analysis in agricultural research has recently increased. So far, however, there has been little discussion about water total factor productivity growth. This study, therefore, focused on the estimation of staple food water productivity based on crop water use and subsequently aimed to analyze the total factor productivity growth using DEA-MI methods. The secondary panel data from 2000-2015 regarding climate data, main food harvested areas and main food production were applied. The results show that despite higher dependencies on rainwater, staple food production used a small part of the volume. Staple food water productivity showed a fluctuation and positive trends, falling in the range of global estimates but still below the upper value. The single input-single output analysis showed that the mean annual TFP growth of WP_{Paddy} and WP_{Corn} was positive, mainly due to technology change (TEC) rather than the decrease in efficiency change (EFC). However, based on chained indices analysis, WP_{Paddy} had a considerable decrease in TFP growth, while WP_{Corn} had a slight increase. The MIMO analysis indicated that the mean annual food water TFP growth showed a similar pattern, but was in contrast to the chain analysis which showed a decrease in TFP growth and all of the components. Regarding district performance, the Belu districts performed better in the SISO analysis and Kupang municipal, which is even smaller in harvested area and production, performed better in the TFP growth based on MIMO analysis.

Keywords: Data envelopment analysis, crop water, Malmquist index, water productivity

I. INTRODUCTION

Crop water productivity is one of the water demand approaches that is believed to be one of the answers to the question of sustainable agricultural water management, leading to sustainable agricultural development, particularly in developing countries. Sustaining food supply to meet the increasing demand generated by population growth and living standard in the degradation of the environment has posed a threat; therefore, sustaining crop water use efficiency and productivity is an evitable [1],[2].

About food production in the semi-arid region of West Timor, the primary food is paddy (*Oryza sativa* L.) and corn (*Zea mays* L.). Agricultural land is the prime source of living for 61% of the population; even though it is believed that the cultivation system is categorized as traditional subsistence farming, the improvements in intensive agriculture are less of a benefit to most farmers. Dryland farming in the form of shifting cultivation dominated food production, with very high dependency on natural resources in which extreme dry seasons and erratic rainfall pose a threat to plant growth that could lead to harvest failure [3],[4].

First introduced by Molden in 1997, generally, in the physical form, crop water productivity (CWP) is defined as crop yield per cubic meter of water consumption. Yield could be in the form of marketable or editable yields. The increase in CWP results not only in the use of less water to produce the same yield, and the same amount of water to produce more food [5],[6].

There has been considerable research regarding crop water productivity; however, little attention has been paid to the study of inter-temporal change or to incorporate a spatial-temporal analysis with time series statistical data [7]. The study by [8] estimated and explored the change in rice WP for 21 Districts in Bangladesh for 37 years; then, factor analysis and the Granger causality test found that technology diffusion is the primary factor affecting rice WP. Subsequently, the research of [8] focused on the evaluation of rice water productivity sustainability, either using irrigated rice (*rabi*) or rain-fed rice (*Kharif*), and then proposed policy options to tackle the unsustainable. What is not yet clear is regarding the growth of water productivity and its components of efficiency and technology, i.e., which component and the magnitude in which it affected the total factor productivity growth.

Traditional productivity analysis tends to determine growth, mainly due to technology changes that are valid when production units operate under efficient performance. A more robust method, however, is total factor productivity (TFP) analysis, which is based on the assumption that production units work inefficiently. Therefore, the TFP analysis decomposed growth, either efficiency growth or technology growth [9],[10]. The Malmquist index method based on [11] is widely used to study TFP growth and its decomposition. The Malmquist index determines the TFP change between two data points by calculating the ratio of the distances of each data point relative to a standard technology. DEA is a linear programming method that is applied to calculate the distance function in the Malmquist index. The increase in TFP, furthermore, could be achieved by a positive shift of production frontier (TEC) or the upward position that matches the production frontier (EFC) [9].

Having understood the importance of sustaining food supplies for the population of West Timor and simultaneously contributing to water productivity studies, no previous study has investigated crop water total factor productivity growth, particularly in the semi-arid region of West Timor. This study furthermore focuses on the estimation of crop water productivity, subsequently in estimating the growth of crop water total factor productivity of rice and corn.

II. MATERIALS AND METHODS

Research Location

West Timor is part of the East Nusa Tenggara Province (NTT), Indonesia, which consists of four districts (Kupang, Southcentral Timor or TTS, Northcentral Timor or TTU and Belu), and a Kupang municipal. Astronomically, West Timor is located at 123°27'40"–125°11'59" East Longitude and 08°56'17"–10°21'56" South Latitude.

West Timor region has a semi-arid climate, with a long dry season from April to November caused by south-east monsoons from Australia that badly affect agricultural production [4]. Worldwide, arid and semi-arid areas consist of 40% land and 37% inhabited by a population. This area has characteristics that include irregular precipitation, long drought periods, evaporation rates exceeding precipitation, and steppe vegetation [12].

Data Sources and Preparations

This study used secondary panel data from 2000 to 2015 provided by the NTT provincial bureau of statistic (BPS NTT), except for the average crop planting time from [13], and crop coefficient (Kc), which were based on the Indonesian water resources bureau. In order to fill missing climate data, a typical ratio method was applied [14]. Also, a rescaled adjusted partial sums (RAPS) or Buishand test, which is appropriate for developing countries climate stations' consistency tests, was carried out [15] [16]. There is. However, a lack of some climatic data i.e. mean humidity and mean wind speed in districts other than Kupang; therefore, the authors assume both data to be equal to Kupang.

Crop Water Use (CWU) Estimation

CWU is a denominator in water productivity, which determines the volume of water that affects production. CWU describes evapotranspiration from the crop growing area. To date, various studies have been developed and introduced to measure CWU based on statistical time series data, including [7],[8],[17],[18],[19]. In this study, the previous methods were modified not only to meet data availability but also to propose the main crops based on the estimation; therefore, the estimation meets the following equations:

$$CWU_{Paddy} = HA_{Pd}\left[\sum_{j \varepsilon mth} \sum_{i \varepsilon period} \min\left(Kc_{Pd} \times ETo_j, EFFRF_j\right) \times \frac{d_{ij}}{n_j} + \sum_{j \varepsilon mth} \sum_{i \varepsilon period} \left(Kc_{Pd\text{-}i} \times ETo_j\right) \times \frac{d_{ij}}{n_j} \right] \quad (1)$$

$$CWU_{Corn} = HA_{corn}\left[\sum_{j \varepsilon mth} \sum_{i \varepsilon period} \min\left(Kc_{corni} \times ETo_j, EFFRF_j\right) \times \frac{d_{ij}}{n_j} + \sum_{j \varepsilon mth} \sum_{i \varepsilon period} \left(Kc_{corn\text{-}i} \times ETo_j\right) \times \frac{d_{ij}}{n_j} \right] \quad (2)$$

Where, HA_{Pd} and HA_{Corn} are harvested areas of paddy and corn, respectively, $Kc_{paddy\text{-}i}$ and $Kc_{corn\text{-}i}$ are crop coefficients of paddy and corn, respectively, and ETo_j and $EFFRF_j$ are references to evapotranspiration and sufficient rainfall, respectively.

The effective rainfall (EFFRF) is estimated based on a 75% excess probability of monthly rainfall [7],[8],[17],[20]. Potential evapotranspiration (ETo) was estimated based on the FAO Penman-Monteith method calculated with the ETo Calculator [21],[22].

Crop Water Productivity (CWP) Estimation

$$CWP_{Paddy_{(d,y)}} = P_{Rice_{(d,y)}} / CWU_{Paddy_{(d,y)}} \quad (3)$$

$$CWP_{Corn_{(d,y)}} = P_{Kernel_{(d,y)}} / CWU_{Corn_{(d,y)}} \quad (4)$$

Where, CWP is crop water productivity (kg/m^3), P_{Rice} is rice production (kg), P_{Kernel} is corn kernel production (kg), CWU_{Paddy} is paddy water use (m^3), CWU_{Corn} is corn water use (m^3), d is districts, and y is years.

Total Factor Productivity (TFP) Growth

Data Envelopment Analysis–Malmquist Index (DEA-MI) was used to gain the total factor productivity change (TFPC) with decomposed efficiency change (EFC) and technology change (TEC). The first step is the analysis of each of the crop separately (single input, single output = SISO). The next step is the analysis of both crops simultaneously (multiple inputs, multiple output = MIMO). The non-parametric linear programming DEA is used to calculate the distance function, furthermore being used by MI to determine the efficiency and technology change that constructed the total factor productivity change. This study furthermore applied an output orientation of the Malmquist index (MI); this orientation intended to reduce the input with the same output or with the same amount of input producing more output. Those conditions are suitable for agricultural conditions in developing countries [9],[23], as stated by the following equations based on [11]. Additionally, in this paper, we used the words growth and changed interchangeably.

$$\text{Efficiency change (EFC)} = \frac{d_o^t(q_t, x_t)}{d_o^s(q_s, x_s)} \qquad (5)$$

$$\text{Technology change (TEC)} = \left[\frac{d_o^s(q_t, x_t)}{d_o^t(q_t, x_t)} \times \frac{d_o^s(q_s, x_s)}{d_o^t(q_s, x_s)}\right]^{1/2} \qquad (6)$$

$$\text{Total factor productivity change (TFPC)} = \text{EFC} \times \text{TEC} \qquad (7)$$

Where d_o^s is distance function of current period (s = t), (q_s, x_s) is current period production with input, d_o^t is distance function of t +1 period (t = s + 1), and (q_t, x_t) is t+1 period production with input.

Total factor productivity change and the component of efficiency change (EFC) and technology change (TEC) were calculated with the help of DEAP Ver.2.1, an open source software, provided by the Centre for Efficiency and Productivity Analysis (CEPA) [9]. Cumulative chain indices were applied to determine the growth of total productivity change and its components over time, as stated by the equation below [24].

$$I_t = \left(X_t / X_{t-1}\right) I_{t-1} \qquad (8)$$

Where I_t = index at the time t, X_t = value at time t, X_{t-1} = value at time t-1, and I_{t-1}= Index at time t-1.

RESULTS AND DISCUSSION

Main Food Production and Water Use

The production of paddy regarding rice and the production of corn regarding corn kernel fluctuate across districts and years. Kupang district was the top rice-producing district while TTS district was the top for corn kernel production. Kupang municipal showed the lowest production of both rice and corn kernel with the highest fluctuation. About West Timor region, the highest rice production was in 2014, and the lowest was in 2005. The highest corn kernel production was in 2013, and the lowest was in 2011.

The primary food crop production utilized 2.35% of total rainwater volume. Even though paddies used more units of water than corn, because the vast majority of farmers cultivated corn, it used a greater of the volume of water compared to paddies. On average, staple food production used 580,934 mm^3 water/year, with the lowest in 2005 and the highest in 2013. In total, both crops used water in a fluctuating and positive trend from 2000-2015.

A non-parametric test indicated that the production and crop water use (CWU) data differed across the districts. The independent sample Kruskal-Wallis tests reported a significant value (p-value < 0.005), highlighting that the distribution of the production and CWU variables differed across the districts. The descriptive statistics and non-parametric test results are presented in Table 1.

TABLE 1
DESCRIPTIVE STATISTICS OF PRODUCTION AND CWU DATA

Variables	Mean	Std. Deviation	Minimum	Maximum	Kruskal-Walis Test (Sig.)
Paddy prod (Kg rice)	13929371.25	12558679.65	90000.00	56869000	0.000
Corn prod (Kg corn kernels)	64312012.50	49580575.67	746000.00	207631000	0.000
CWU_{Paddy} (m3)	31112557.01	25798236.36	209418.17	92297832.51	0.000
CWU_{Corn} (m3)	82281550.76	66013663.09	896406.96	282368043.75	0.000

Main Food Crop Water Productivity

The average crop water productivity (CWP) of the primary food in West Timor during the last 15 years displayed a fluctuation with positive trends as depicted in Figure 1. WP_{Corn} outnumbers the WP_{Paddy}, with WP_{Paddy} being more diverged than WP_{Corn}. Paddy cultivation is more intensive than corn cultivation; it requires more input factors and technology. Also, paddy cultivation by mostly traditional farmers in semi-arid areas like West Timor shows a production that is capricious. WP_{Paddy} and WP_{Corn} were highest in 2014 and 2009, respectively, and reached the lowest point in 2011. The erratic rainfall and the socio-economic conditions of the farmers were generating uncertainty in the cultivation and production of main foods in semi-arid regions.

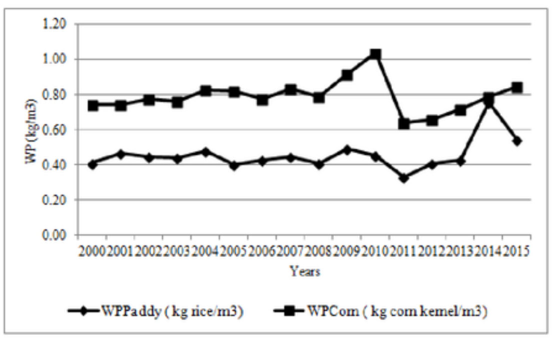

Fig.1 Annually prime food water productivity of West Timor

During 2000 and 2015, crop water productivity of paddy and corn per crop water unit (CWU) in West Timor ranging from 0.290 kg rice/m^3 to 0.930 kg rice/m^3 and from 0.553 kg corn kernel/m^3 to 1.590 kg corn kernel/m^3 respectively. The estimated CWU_{Paddy} was in range with global estimation by [25], ranging from 0.150–1.600 kg/m^3; this was relatively higher than that of the Bangladesh population (0.216–0.570 kg/m^3) estimated by [7]. Likewise, in terms of CWP_{Corn}, the West Timor experience was in range with the results from dry land China and Sub Saharan Africa, which reached 0.100–1.900 kg/m^{3,} as reported in [19] and surpassed the experience of subsistence farmers of Tanzania (0.100–0.600 kg/m^3) [26].

Considering inter-district estimations of WP_{Paddy}, as presented in Figure 2a and 2b, the Kupang municipal had the highest value of WP_{Paddy}, while the TTU district had the lowest. On the other hand, the TTU district had the highest value of WP_{Corn}, in contrast with Belu District, which had the lowest. However, Kupang municipal encountered a stark variation, while the TTS district encountered the lowest variation of CWP_{Paddy}. TTU district experienced a more varied value of CWU_{Corn} compared with TTS district. It is interesting to note that Kupang municipal is a capital city of the NTT Province; even though it possesses the smallest agricultural area, it has better access to agriculture production, factors which enable the capacity of farmers to produce more rice with the available water.

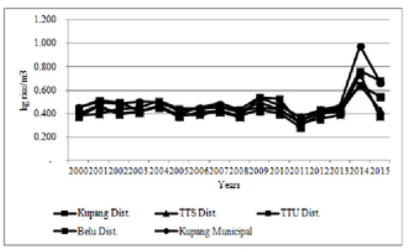

Fig. 2a WP_{Paddy} (kg rice/ m^3)

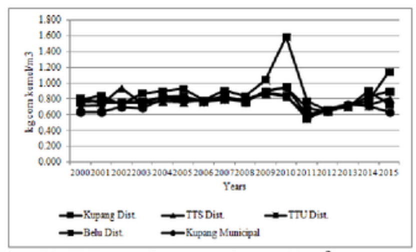

Fig. 2b WP_{Corn} (kg corn kernel/ m^3)

Paddy Water Total Factor Productivity Growth

The data envelopment analysis – Malmquist Index (DEA-MI) approach, aiming to determine total factor productivity (TFP) growth has the ultimate advantage of providing information regarding the influence of efficiency change (EFC) and technology change (TCH). This linear mathematical programming also releases the strict function from which is enable to use non-parametric data [27],[28]. However, it is important to note that the result was relatively comparative; in this study, the comparison was only with the inter-district of West Timor.

Paddy water total factor productivity (WP_{Paddy} TFP) growth in West Timor during 2000 to 2015, as depicted in Figure 3, showed a fluctuating trend, especially from 2013 to 2015. The mean annual TFP growth of WP_{Paddy} was 1.041, with a mean annual growth of efficiency (EFC) of 0.992 and a mean annual growth of technology (TEC) of 1.062. The highest TFP growth was 1.742 (2013/2014), and the lowest was 0.709 (2014/2015).

The highest EFC was 1.082 (2003/2004), and the lowest was 0.830 (2013/2014). The highest TEC was 2.099 (2013/2014), with the lowest being 0.699 (2014/2015).

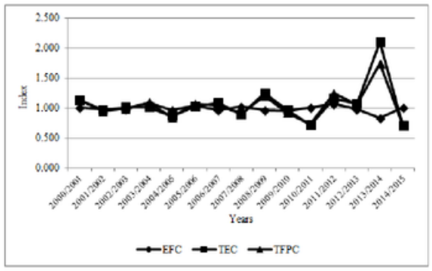

Fig.3. Mean annual WP_{Paddy} TFP growth from 2000-2015

A similar study, estimating the productivity of energy in a paddy cropping system in Nepal using DEA by [29], highlighted the efficiency change (EFC) to be within the range of 0.664–0.820, which is considered to show that the use of energy in a paddy production system is proper, but could be more energy efficient. Also, broader production factors include land, labor, seed, fertilizer, and pesticide; the effect on the technical change (EFC) of paddy using DEA in Niger-Africa was investigated by [30]. This study found that the average efficiency change is 0.48, with the index range from 0.10 to 1.00. It is important to note that there was an opportunity for farmers in West Timor to save about 1.00% of the precious water to produce rice, about 18% to 34% of energy could be saved by farmers in Nepal to produce rice, and there was a reduction of about 52% of the input productions when growing rice in Niger without jeopardizing the current level of production.

It is worth noting the resemblance in years when TFC and TEC gained high and low indexes, showing that technology changes determine WP_{Paddy} TFP growth rather than efficiency changes. There is, however, a change in technology over the years, which is more due to variety than efficiency. The variety of TEC indicates that the farmers could not cope with the changes in a production environment to some degree.

Surprisingly, despite average technology changes outnumbering efficiency changes and dominating the growth of paddy water TFP growth, based on chain indices, there was an increase in EFC and a decrease in both TEC and TFP. During the same period, the chain indices presented in Table 2 showed that there was a fluctuation in growth, especially in the last period. In the last period, the efficiency index was 1.007, indicating that there was a growth in efficiency of 0.69%. On the other hand, technology and the TFP index were 0.622 and 0.626, respectively, which indicates the downfall of 37.81% of technology growth and 37.38% of TFP growth.

TABLE 2.
Chain INDICES of WP_{PADDY} TFP Growth

Year	EFC	TEC	TFPC
2000/2001	1.000	1.000	1.000
2001/2002	0.973	0.863	0.840
2002/2003	0.973	0.899	0.875
2003/2004	1.073	0.895	0.961
2004/2005	0.963	0.771	0.743
2005/2006	1.031	0.913	0.941
2006/2007	0.957	0.961	0.920
2007/2008	1.009	0.792	0.799
2008/2009	0.962	1.107	1.065
2009/2010	0.946	0.864	0.818
2010/2011	0.997	0.641	0.640
2011/2012	1.065	1.028	1.096
2012/2013	0.977	0.948	0.927
2013/2014	0.823	1.867	1.538
2014/2015	1.007	0.622	0.626

The increasing efficiency change indicates that the ability to manage water for paddy fields shows an improvement; however, the negative shift in production function indicates that the use of water tended to exceed this, or that there was a decrease in rice production due to a lack of production innovation. Furthermore, the downfall of TEC results in a reduction of paddy water TFP growth to a considerable level. Furthermore, this result strengthened the need to improve the innovation of paddy production technology in semi-arid regions.

Regarding district performance, Figure 4 shows that there was a variation of TFP growth. Belu district had the highest TFP growth and efficiency change of 1.039 and 1.012, respectively, in contrast with the TTU district, which had the lowest TFP growth and efficiency change of 0.996 and 0.970, respectively. It interesting to note that all of the districts had a similar TEC index of 1.027. This indicates there was an increase in technology, but that the development of production technology is similar across the districts. Also, farmers in all districts of West Timor are highly efficient at using water for rice production in a given technology frontier but have the opportunity to use 1.01% less water to produce the same amount of rice.

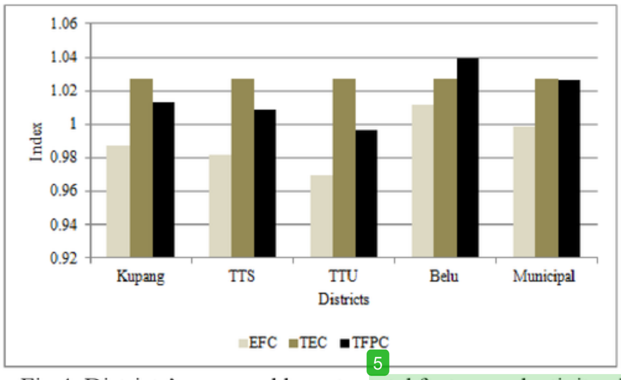

Fig.4 Districts' mean paddy water total factor productivity change

Corn Water Total Factor Productivity Growth

About the mean corn water TFP growth, Figure 5 shows a fluctuation trend, especially in the last 7 years. TFP growth reached a peak in 2008/2009 and hit the lowest point in 2010/2011. The mean annual WP_{Corn} TFP growth was 1.008, which consisted of an efficiency change of 0.985 and a technology change of 1.023. This result highlights the fact that those farmers in West Timor have a relatively efficient way of using water for corn production. Also, technology changes generated the growth of WP_{Corn} TFP growth rather than efficiency changes. However, the change in technology is more variable than the efficiency change and TFP growth. This highlights the fact that despite corn being a dominant crop in West Timor, the development of cultivation technology does not seem to benefit most of the farmers [4].

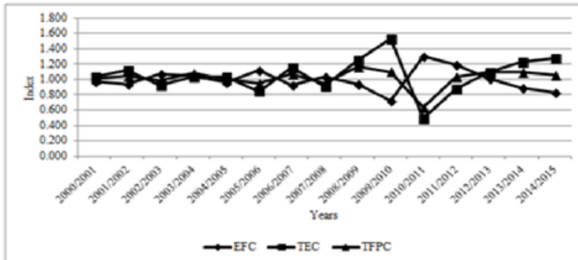

Fig. 5 Mean annually WP_{corn} total factor productivity growth

Concerning chain indices of WP_{Corn} TFP growth during the last 15 years, Table 3 shows a fluctuation with a considerable decrease in efficiency change (-14.85%) in contrast with the considerable increase in technology change (23.38%) that inflicts a 5.06% increase in TFP. Despite corn farmers in West Timor using water to a high level of efficiency, during the same period they experienced a reduction in efficiency change. It was implied that in traditional dry land cultivation in semi-arid regions, the capability of managing water for corn is limited to some degree, leading to the use of water to produce only 85.15% of the potential corn production. However, the improvement in technology change showed a promising sign that could shift the production function upward. The increase in technology was in line with the Provincial Government policy during the last 10 years, to establish corn as a prime commodity.

TABLE 3.
Chain INDICES of WP_{CORN} TFP Growth

Year	EFC	TEC	TFPC
2000/2001	1.000	1.000	1.000
2001/2002	0.959	1.081	1.037
2002/2003	1.094	0.899	0.984
2003/2004	1.077	1.000	1.077
2004/2005	0.988	1.004	0.992
2005/2006	1.150	0.821	0.944
2006/2007	0.952	1.122	1.068
2007/2008	1.057	0.889	0.940
2008/2009	0.958	1.210	1.159
2009/2010	0.738	1.481	1.093
2010/2011	1.334	0.471	0.629
2011/2012	1.219	0.846	1.031
2012/2013	1.031	1.059	1.092
2013/2014	0.909	1.192	1.084

2014/2015	0.852	1.234	1.051

Regarding district performances, Figure 6 shows that the inter-districts WP_{Corn} TFP growth had a slight variation from 0.995 to 1.023. The growth was composed of the variation in efficiency change from 0.973 to 1.000 and an equal technology change of 1.023. Belu district had the highest growth of 2.3%, while TTU district had the lowest growth of -0.46%. The highest improvement of TFP was in Belu district compared to other districts; this was due to farmers in this district being efficient at using water to increase corn production. Despite TTS district having the most significant share of corn production in West Timor, the efficiency improvement is still moderate compared to other districts. On average, corn farmers in all districts showed high efficiency in using water for corn production in a given production frontier, despite farmers potentially reducing the use of water by 1.48% without reducing production.

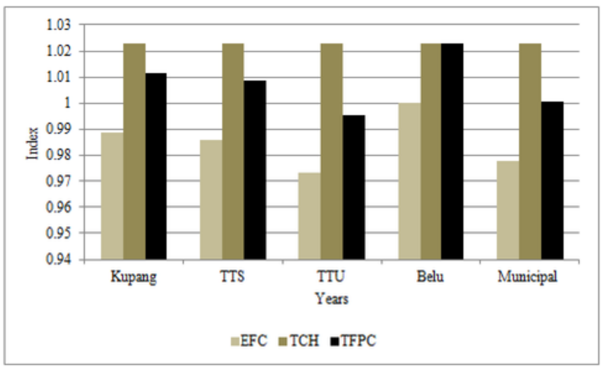

Fig. 6 Districts WP_{Corn} TFP growth

Main Food Water Total Factor Productivity Growth

The primary food crop water productivity was constructed from paddy water productivity (kg rice/m^3) and corn water productivity (kg corn kernel/m^3). DEA-MI was applied to conduct multi-input multi-output analysis (MIMO); the inputs were paddy water use (CWU_{Paddy}) and corn water use (CWU_{Corn}), while the outputs were paddy production (kg rice) and corn production (kg kernel).

The mean annual food water TFP growth depicted in Figure 7 highlights that there was a fluctuation, particularly in the last 7 years. From 2000-2015, WP_{Food} TFP growth varied between 0.707 and 1.456 which consisted of a variation in efficiency change between 0.916 and 1.016 and the variation in technology change between 0.680 and 1.433. The average WP_{Food} TFP growth was 1.014, with an average EFC of 0.994 and TEC of 1.020. This study supported the study regarding TFP growth in agriculture worldwide from 1980–2000 using DEA-MI by [27], showing that the mean TFP growth of Indonesian agriculture is 0.981, with an efficiency change of 0.978 and technology change of 1.003.

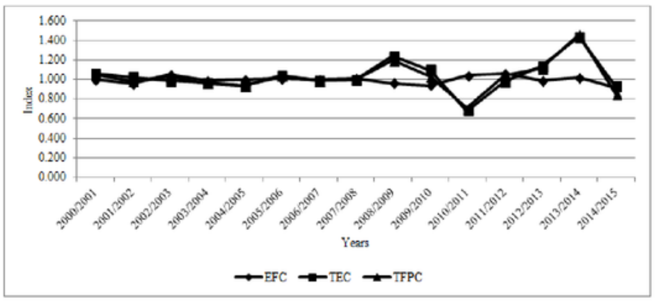

Fig.7 Mean annually WP_{Food} TFP growth

There was a similar result when TEC and TFP reached the highest index in 2010/2011 and the lowest index in 2013/2014. Those results furthermore implied that technology change had a more significant influence on the growth of TFP. It is important to note that WP_{Food} TFP growth and its component of EFC and TEC showed a fluctuated index in which EFC was more stable than TEC and TFP. The fluctuation was either due to unstable food production or variations in water use. Also, it revealed that traditional farmers in semi-arid regions were not adequately coping with the changing environment and production inputs.

TABLE 4.
CHAIN INDICES OF WP_{FOOD} TFP GROWTH

Year	EFC	TEC	TFPC
2000/2001	1.000	1.000	1.000
2001/2002	0.964	0.968	0.933
2002/2003	1.052	0.932	0.981
2003/2004	0.996	0.916	0.912
2004/2005	1.003	0.887	0.889

2005/2006	1.009	0.977	0.986
2006/2007	1.003	0.932	0.935
2007/2008	1.010	0.943	0.953
2008/2009	0.967	1.172	1.133
2009/2010	0.946	1.035	0.979
2010/2011	1.043	0.643	0.670
2011/2012	1.065	0.924	0.985
2012/2013	0.990	1.071	1.060
2013/2014	1.020	1.354	1.382
2014/2015	0.920	0.879	0.808

Taking into consideration the chain indices of WP_{Food} TFP growth during the last 16 years, there was an alarming decrease in the annual food and water TFP growth of 19.16%, which was constructed by decreasing the efficiency and technology changes by 8.03% and 12.10%, respectively. The lowest growth of TFPC of -32.95% was in 2010/2011, in which TEC was at the lowest point of -35.73% and EFC of 4.32%. The highest point of TFPC of 38.16% was in 2013/2014, with the highest growth of TEC reaching 35.44% and EFC reaching 2.01%. It is interesting to note that MIMO analysis provided different results compared to per crop analysis (SISO) regarding the magnitude of growth. Additionally, a possible explanation for the decrease in food and water TFP growth and its components was due to the characteristics of traditional farming that hampers innovation in agriculture, causing the production system to fluctuate in the changing environment. It can be said that the farmers' ability to control the change in the environment on a year to year basis seems limited.

Regarding district performance, as depicted in Figure 8, WP_{Food} TFP growth varied from 0.986 to 1.032, with an average of 1.014. Kupang municipal had the highest TFP growth while TTU district had the lowest TFP growth. All districts had an EFC of 1.000, except for TTU district, which was 0.970, and had an average EFC of 0.994. As in SISO analysis, in MIMO analysis there was a variation in TEC from 1.010 (TTS district) to 1.032 (Kupang municipal); the average TEC was 1.020. Remarkably, traditional subsistence farmers of West Timor were relatively efficient in using water for food production under the current level of food production technology.

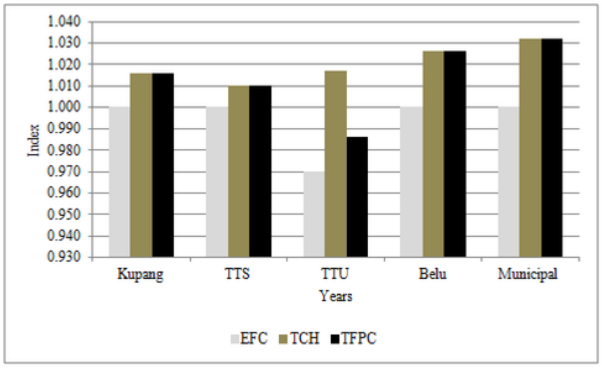

Fig.8 Districts WP_{Food} TFP growth

Also, this result confirmed that in the traditional dryland farming in semi-arid regions, technology changes (TEC) play an essential role in food and water TFP growth. Interestingly, even though Kupang municipal has the smallest food cultivation area and production, it leads in the total food and water productivity growth during the period of analysis. This result might be explained by the fact that water productivity is related to broader factors in the food production system. Kupang municipal, as the capital of the NTT Province, with West Timor being one of the main islands of the province, has better access to and a better quality of food production input factors. This notion is supported by the study in China's agricultural TFP growth for over 30 years by [31], which points out that agricultural TFP growth from higher income provinces is better than for lower-income provinces. This highlighted the fact that regarding food water productivity growth, intensive farming systems with the smallest areas and better technology would exceed extensive areas with limited technology.

CONCLUSIONS

The rice and corn production in semi-arid traditional farming systems fluctuated across years and districts. The productions were using a small proportion of the total rainwater volume in the areas. As a consequence, WP_{Rice} and WP_{Corn} regarding crop water use showed a fluctuating and positive trend. The crop water productivities exceeded

Tanzania in Africa; furthermore, those values were in the range but lower than the maximum value of developed countries. This provided ample opportunities to enhance the water productivity of crops.

Regarding per crops analysis, both WP_{Rice} and WP_{Corn} TFP growth showed average fluctuating trends, with technology change dominating the TFP growth. However, in the last period, WP_{Rice} TFP growth and technology change experienced a remarkable downfall while WP_{Corn} TFP growth and technology changes increased. Rice farmers were more efficient at water management compared to corn farmers but still had a chance to save water. Regarding district performances, there were variances in both TFP growths due to the efficiency change, where the innovation in production technology was indistinguishable across districts.

In a multi-crops analysis or WP_{Food} TFP growth, the mean annual trend fluctuated with an increase in TFP and both of its components; technology change was a notable component. However, in the last 16 years, all of the growth components had decreased. Interestingly, all districts performed relatively better with small discrepancies in efficiency changes but showed greater variance in technology change and TFP growth. The more intensive farms of the district showed better WP_{Food} TFP growth.

The limitation of this study included the data availability of climate data and the availability of planting data and crop damage data at the district level. The methodology limitation was that the growth comparison was only performed for the districts under study. The authors are encouraged to conduct this kind of study at the national and global level, along with other agricultural commodities.

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