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

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Abstract: This study aims to estimate main food water productivity based on crop water use and subsequently aimed to analyze the total factor productivity growth using non-parametric Data envelopment analysis-Malmqist index (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 paddy water productivity was in the range of 0.290 to 0.930 kg rice m^{-3} and corn water productivity was in the range of 0. 553 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 efficiency change (EFC) index was 0.992, and technological change (TEC) index was 1.062. 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. 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 was a decrease of FWTFP, EFC dan TEC indices by 19.16%, 8.03%, and 12.10% respectively. Kupang municipal as the smallest food producer has a better FWTFP growth index. Furthermore, the increase of crop water productivity in the area like The West Timor is strongly advised through the increasing of production techniques.

Keywords: crop water use, data envelopment analysis, malmquist index, water productivity

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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

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an evitable (De Fraiture and Wichelns, 2010; Vanuytrecht et al., 2014).

Regarding 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 a 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 (Piggin, 2003; Molyneux et al., 2012).

Crop water productivity (CWP) was first promoted by Seckler (1996) and strengthen by Molden (1997), that concept that evolved from the irrigation efficiency concept marked the beginning of a new era of water management and become the center of the International Water Management Institute (IWMI) and related institutions research agenda. In the physical term, crop water productivity (CWP) is defined as a crop yield per cubic meter of water consumption. Yields 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 but with the same amount of water to produce more food. Considering future development, crop water productivity should be supported the broader sustainable development for people, the planet, and prosperity (Giordano et al., 2017; Blatchford et al., 2018). Besides, Edreira et al. (2018) insist that beside global analysis there is important to consider a local-level analysis of CWP to improve management practices.

Concerning productivity analysis, Mechri et al. (2017) defined that productivity is the description of the relationship between outputs that produce by the set of inputs. The productivity measure is the description of the transformation process of input into products that effected by efficiency and technology change. Therefore, O'Donnell (2018) explain that productivity analysis including estimating and explaining changes in productivity. It requires an appropriate estimation method and appropriate decomposition into efficiency and technological change. Hossain et al. (2012) stated that total factor productivity (TFP) is considerably used to determine productivity change. There are two main methods in TFP calculation that are stochastic frontier analysis (SFA) that is parametric and data envelopment analysis (DEA) that is non-parametric.

Tang et al. (2016) stated that Data envelopment analysis- Malmquist Index (DEA-MI) is employed to decomposed total factor productivity (TFP) to the component of efficiency change (EFC) and technological change (TEC). Minviel and Latruffe (2016) explain that the DEA method is powerful in the evaluation of relative efficiency and productivity of the production unit. The advantages of this method including it does not need any functional forms of input and output, it just requires quantity data of input and output, it may be used at any stage of aggregation: from the farm-degree to sector, country, or maybe international levels, it enables multi input-multi output (MIMO) analysis.

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.

The researches 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 was first time reported by Koehuan et al. (2019a, 2019b). Koehuan et al. (2019a) reported the growth of corn water total factor productivity (CWTFP) and it's a component of efficiency (EFC) and technology process (TEC). Meanwhile, Koehuan et al. (2019b) reported the growth of food water total factor productivity (FWTFP) and its component of EFC and TEC, however, both studies using parametric approaches of stochastic frontier analysis - Malmquist index (SFA-MI). What is not yet clear is regarding the growth of main food water total factor productivity and its components of efficiency and technology, i.e., which component and the magnitude in which it affected the total factor productivity growth in non-parametric approached.

This study furthermore aimed to the estimation of paddy and corn water productivity, subsequently to estimate the growth of main crops water total factor productivity growth using a non-parametric method of DEA-MI.

2 Material and methods

2.1 Research date and location

The researched was conducted from February 2017 to August 2018. The research location was West Timor. The 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 (Food and Agriculture Organization, 2008).

2.2 Data source and preparation

This study used secondary panel data from 2000 to 2015 provided by the NTT provincial bureau of statistics, 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. To fill missing climate data, a typical ratio method was applied (Triatmojo, 2010). 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.

2.3 Crop water use estimation

Crop water use (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 (Alauddin 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:

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

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

Where, HA_{Pd} (ha) and HA_{Corn} (ha) are harvested areas of paddy and corn, respectively, *Kcpaddy-i* and *Kccorn-i* are crop coefficients of paddy and corn, respectively, and *ETo*j *(mm)* and *EFFRFj* (mm) are references evapotranspiration and effective rainfall, respectively.

2.4 Crop water productivity 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, Crop water productivity (*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.

2.5 Total factor productivity 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) (Tang et al., 2016). The first step is the analysis of each of the crops 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 (Xu, 2012; Toma et al., 2017) as stated by the following equations based on Färe et al. (1994). Additionally, in this paper, we used the words growth and changed interchangeably.

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

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

Total factor productivity change (TFPC) = EFC× 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 (Goodridge, 2007; Koehuan et al., 2019a; Koehuan et al., 2019b).

3 Results and discussion

3.1 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 the 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 main 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 volume of water compared to paddies. On average, main 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 ($p < 0.005$), 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} (m^3)	31112557.01	25798236.36	209418.17	92297832.51	0.000
CWU_{Corn} (m^3)	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 16 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 capricious production. 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.

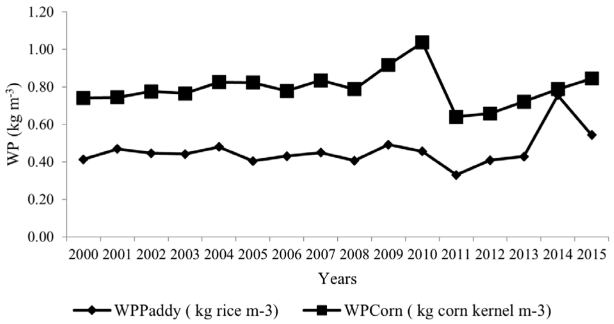
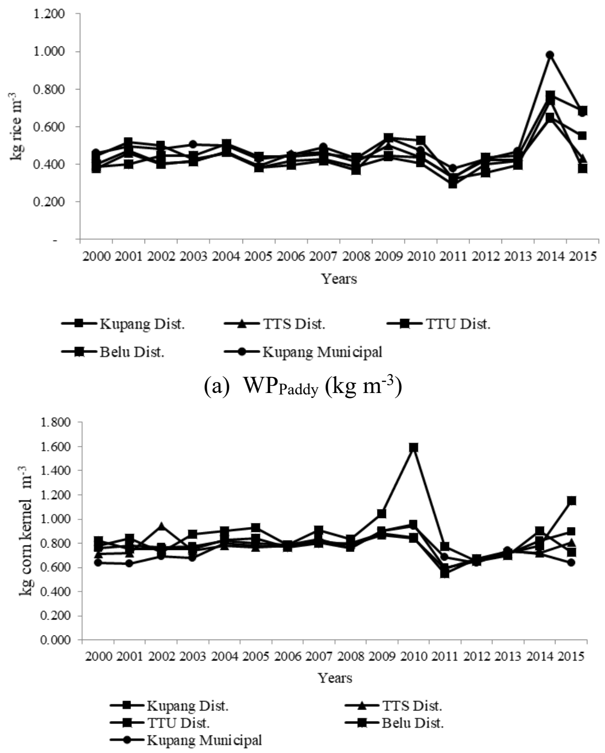


Figure 1. Annually main food water productivity of West Timor

During 2000 and 2015, crop water productivity of paddy and corn per 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 WP_{Paddy} 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 WP_{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 Sharma et al. (2015) and surpassed the experience of subsistence farmers of Tanzania (0.100–0.600 kg m^{-3}) (Makurira et al., 2011).



(a) WP_{Paddy} (kg m^{-3})

(b) WP_{Corn} (kg m^{-3})

Figure 2. Considering inter-district estimations

Considering inter-district estimations of WPPaddy and WPCorn, 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 WPPaddy.TTU district experienced a more varied value of WPCorn 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.

3.3 Paddy water total factor productivity growth

The data envelopment analysis – Malmquist Index (DEA-MI) approach to determine total factor productivity (TFP) growth has the ultimate advantage of providing information regarding the influence of efficiency change (EFC) and technology change (TEC). This linear mathematical programming also releases the strict function from which it enables to use of 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.

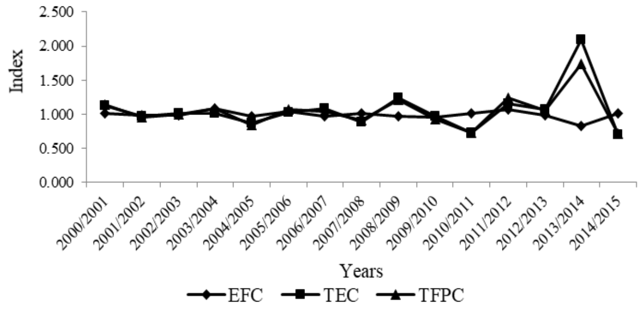


Figure 3. Mean annual WP_{Paddy}TFP growth from 2000-2015

Paddy water total factor productivity (PWTFP) growth in West Timor from 2000 to 2015, as depicted in Figure 3, showed a fluctuating trend, especially from 2013 to 2015. The mean annual PWTFP growth was 1.041, with a mean annual growth of efficiency change (EFC) of 0.992 and a mean annual growth of technology change (TEC) of 1.062. The highest PWTFP 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 with the current production technology, there was an opportunity for farmers in West Timor to increase a maximum of 17% of rice production or the average of 0.80% of rice production without additional water input. Likewise, 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 PWTFP and TEC gained high and low indexes, showing that technology changes determine PWTFP 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.

Despite that on average technology changes outnumbering efficiency changes and dominating the growth of PWTFP growth, based on chain indices, there was an increase in EFC and a decrease in both TEC and PWTFP. 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 PWTFP index were 0.622 and 0.626, respectively, which indicates the downfall of 37.81% of technology growth and 37.38% of PWTFP growth.

Table 2 Chain indices of paddy water total factor productivity 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 of efficiency change (EFC) 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 product innovation. Furthermore, the downfall of TEC results in a reduction of PWTFP 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 PWTFP growth. Belu district had the highest PWTFP growth and efficiency change of 1.039 and 1.012, respectively, in contrast with the TTU district, which had the lowest PWTFP 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.

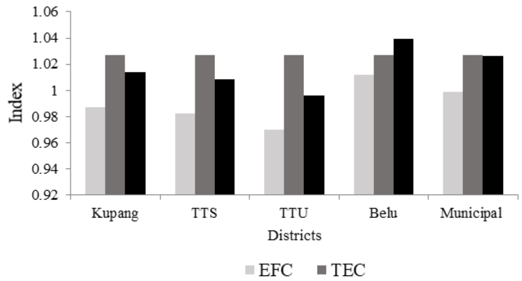


Figure 4. Districts' mean paddy water total factor productivity growth

3.4 Corn water total factor productivity growth

About the mean Corn Water Total Factor Productivity (CWTFP) growth, Figure 5 shows a fluctuation trend, especially in the last 7 years.

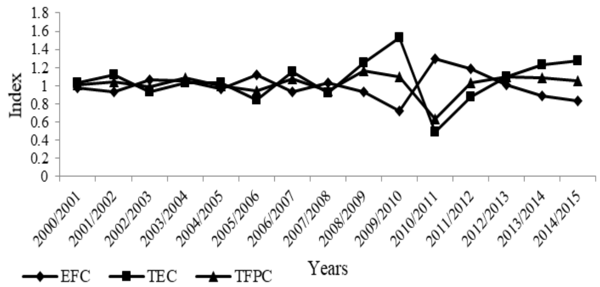


Figure 5 Mean annually corn water total factor productivity growth

CWTFP growth reached a peak in 2008/2009 and hit the lowest point in 2010/2011. The mean annual CWTFP growth was 1.008, which consisted of an efficiency change (EFC) of 0.985 and a technology change (TEC) 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. There was a possibility to increase 1.50% corn production without the increasing of water input. Moreover, technology changes generated the growth of CWTFP growth rather than efficiency changes.

Table 3 Chain indices of corn water total factor productivity 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

Concerning chain indices of CWTFP growth during the last 16 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 CWTFP. 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 dryland 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.

Regarding district performances, Figure 6 shows that the inter-districts Corn water total factor productivity (CWTFP) growth had a slight variation from 0.995 to 1.023. The CWTFP 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 CWTFP growth of 2.3%, while the TTU district had the lowest growth of -0.46%. The highest improvement of CWTFP was in the Belu district compared to other districts; this was due to farmers in this district being efficient at using water to increase corn production. Despite the 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.

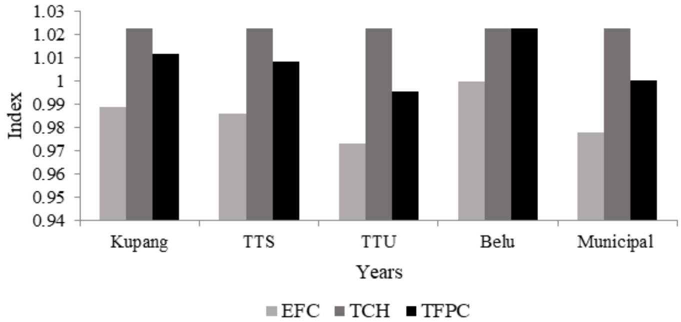


Figure 6. Districts' mean corn water total factor productivity growth

The average CWPTFP growth and its components of EFC and TEC were different from what resulted from the parametric method. According to Koehuan et al. (2019a), the results from a stochastic frontier analysis-Malmquiat index (SFA-MI) with Translog production function were the average CWTFP index was 0.996 with the average index of EFC was 0.996 and the average index of TEC was 1.000. During the period there was a decrease in TFP growth by 5.95%, EFC by 0.56%, and TEC by 5.42%. In terms of district performance, Kupang municipal had a better CWTFP growth.

3.5 Main food water total factor productivity growth

The main 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 Total Factor Productivity (FWTFP) growth depicted in Figure 7 highlights that there was a fluctuation, particularly in the last 7 years. From 2000-2015, FWTFP 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 FWTFP growth was 1.014, with an average EFC of 0.994 and TEC of 1.020.

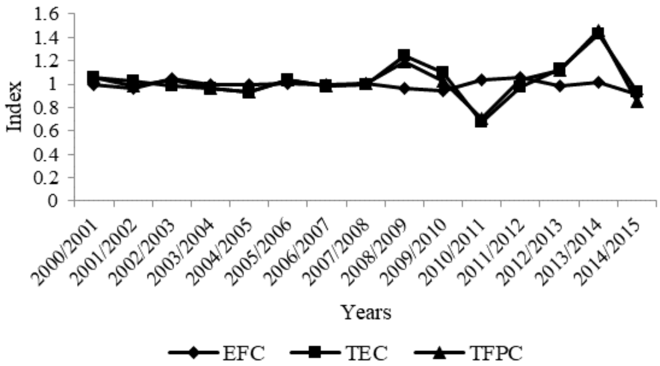


Figure 7 Mean annually main food water total factor productivity growth

There was a similar result when TEC and FWTFP 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 FWTFP. It is important to note that FWTFP growth and its component of EFC and TEC showed a fluctuated index in which EFC was more stable than TEC and FWTFP. Farmers in West Timor were efficient in using water for food production and on average there was a chance to increase 0,60% food production without additional water input. Moreover, the fluctuation of FWTFP and TEC 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.

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. Fuglie (2010) conducted an agricultural TFP growth of Indonesia using Tornqvist-Thiel indices showed that during 2002-2006 the average Indonesian agricultural TFP growth was 2.95 that constructed from output index of 4.31 and input index of 1.36.

Table 4 Chain indices of food water total factor productivity 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 FWTFP growth during the last 16 years, there was an alarming decrease of FWTFP growth by 19.16%, which was constructed by decreasing the efficiency and technology changes by 8.03% and 12.10% respectively. The lowest growth of FWTFP of -32.95% was in 2010/2011, in which TEC was at the lowest index of -35.73% and EFC index of 4.32%. The highest growth of FWTFP of 38.16% was in 2013/2014, with the highest 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 FWTFP 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. The chain indices of FWTFP is presented in Table 4.

Regarding district performance, as depicted in Figure 8, Food Water Total Factor Productivity (FWTFP) growth varied from 0.986 to 1.032, with an average of 1.014. Kupang municipal had the highest FWTFP growth while the TTU district had the lowest FWTFP growth. All districts had an EFC of 1.000, except for the 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.

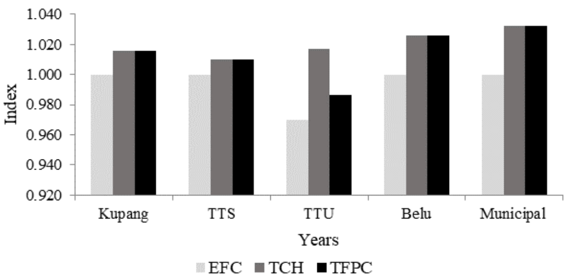


Figure 8 Districts WP_{Food} TFP growth

The recent study by Koehuan et al. (2019b) showed that the parametric Stochastic frontier analysis – Malmquist index (SFA-MI) with Translog production function showed a similar result. The average FWTFP growth was 1.015 with the EFC was 1.000 and TEC was 1.015. During the same period, there was an increase of FWTFP and TEC of 1.59%, and there is no change of EFC. Kupang Municipal had the highest FWTFP growth compared to other districts. Both results indicate that SFA-MI with the Translog production function method and DEA-MI with the MIMO method showed a common result.

Additionally, this study confirmed that in traditional dryland farming in semi-arid regions, technology changes (TEC) play an essential role in FWTFP growth. Interestingly, even though Kupang municipal has the smallest food cultivation area and production, it leads in the FWTFP growth during the period of analysis. This result might be explained by the fact that food 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, water productivity of paddy and corn (WP_{Paddy} 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) on average was showed an increase with a small change of efficiency (EFC) and an increase 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 was a considerable decrease in PWTFP and TEC compared to the base year of 2000. Paddy farmers in the Belu district had a better growth of PWTFP. The average growth of Corn Water Total Factor Productivity (CWTFP) and TEC was increased with a slight decrease in 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 increase 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 the Belu district have a better ability to use water for corn production.

Based on non-parametric DEA-MI in MISO analysis the growth of FWTFP on average was an increase due to a 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 was a decrease of FWTFP, EFC, and TEC by 19.16%, 8.03%, and 12.10% respectively. Kupang municipality has a 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 be coupled with the changing of a food production environment, therefore to enhance the water productivity growth, it is strongly advised by the improvement of paddy and corn production technology while maintaining the level of efficiency.

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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