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Portable Minapadi Model and Its Performance for Urban Farming

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Abstract

The conversion of agricultural land to non-agricultural uses has threatened the food supply of urban areas. While there are many unused open spaces in the areas that would have the potential to produce certain foods that are regularly consumed. It is then necessary to introduce cultivation techniques that match the area's conditions and operable by the people with no, or less experience in farming. This study aims to come up with a portable Minapadi (paddy and fish) culture deemed suitable for urban farming and identify its performance to produce rice as well as fish. The model was tested for one season (99 days) with the main parameters observed being water balances, rice and fish production and revenue. Applying automatic irrigation without using electricity, the irrigation water consumption was 738 mm with an efficiency of 54%. Land and water productivity were 3.62 tons/ha and 0.96 kg/m³, respectively. The fish survival rate was 85% with total production of 3.34 kg and feed efficiency of 2.74. This model earned IDR7,054.94/m³ for rice and IDR36,989.82/m³ for fish with total revenue of IDR44,044.76/m³. These results confirmed that this minapadi model has potential application to support the development of urban agriculture.

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1. Introduction

The conversion of agricultural land to non-agricultural land is a problem. For example, in the period 1994-2003 in Tangerang district there was a conversion of 5407 hectares of agricultural land at a rate of 2.44% per year, which caused a loss of rice production per hectare of converted land of 3,588.11 tons per year (Kadir, 2005). In another case, the conversion of agricultural land due to the construction of the West Java International Airport in Kertajati, Majalengka Regency, West Java had

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a negative impact on the socio-economic life of farmer households indicated by decreased household income, reduced employment opportunities and decreased rice production (Hidayat et al., 2017). From both above, it can be said that the conversion of agricultural land can threaten food availability in urban areas. This statement triggers an effort to maintain food security, especially in fulfilling independent nutrition at least at the family level. Urban farming is one of the solutions to realize this.

Urban farming is not a new concept in modern agriculture. Moreover, urban agriculture has many positives besides maintaining food security. A study conducted in Tasikmalaya city showed that urban agriculture has a positive influence on sustainable agriculture in the city where the study was conducted by taking 100 samples of urban farming actors in 10 sub-districts in Tasikmalaya city (Sugihartini et al., 2023). In addition, urban agriculture has considerable benefits to the community including fulfilling nutritional needs, increasing family income, environmental aesthetics and becoming green open space in urban areas (Santoso & Widya, 2014).

IPB University has developed an urban farming device called the nonpowered automatic fertigator (FONi). FONi was created based on the idea of applying the concept of evapotranspirative irrigation which is used to meet the water needs of plants without using electrical power consisting of a series of plant pots connected to each other and connected to a water supply tank while maintaining the water level that forms a connected vessel system (Muharomah et al., 2024). FONi technology has been tested several times. Subagio, (2023) tested this technology on cabbage cultivation. The results of the research conducted show that FONi technology can produce a cabbage crop harvest of 1,754 grams in the greenhouse and 3,531 grams outside the greenhouse. Syafriyandi et al., (2023) used FONi technology for the cultivation of three vegetable crops namely water-lettuce, choy-sum and spinach with land productivity of 9.60 kg/m2; 12.30 kg/m2 and 25.10 kg/m2 respectively and water productivity of 29.00 kg/m3; 12.30 kg/m3; and 52.40 kg/m3 respectively. Safitri, (2024) conducted a rice planting test with the SRI-Salibu method using FONi technology with three harvests, namely at 117 days after planting (DAP) with land productivity of 2.41 tons/ha; at 177 DAP with land productivity of 8.85 tons/ha and at 233 DAP with land productivity of 4.38 tons/ha. FONi technology has also been disseminated and used for community service purposes. Muharomah et al., (2023) tested FONi technology in Tasikmalaya city, especially in two different locations, namely Madrasah AL-Manshur and the field laboratory of Siliwangi University campus. The results of the trial showed that FONi technology can produce sustainable organic vegetables, especially in meeting consumer needs.

Another agricultural concept that has been applied is integrated rice and fish cultivation or better known as Minapadi. Minapadi is a way of raising fish in between rice plants as an interlude between two rice growing seasons or raising fish as a substitute for secondary crops in rice fields (Syuraihanah et al., 2024). The minapadi concept has been proven to provide benefits. Nurhayati et al., (2016) revealed that in Ciparay, West Java, the concept of minapadi can provide good economic and social results for the community in optimizing land use. Another study conducted by Lestari & Rifai, (2017)

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showed that the concept of minapadi can provide quite abundant results, namely as much as 3 quintals of grain and 4 quintals of catfish carried out in Desa Payaman, Nganjuk District.

Both agricultural concepts have proven to have a positive impact on the community. Therefore, a combination of the two is needed. This study aims to come up with a portable Minapadi (paddy and fish) culture deemed suitable for urban farming and identify its performance to produce rice as well as fish. This research is an initial research and concept for further development.

2. Research Methodology

2.1 Location and Time

The planting test was conducted from May 27, 2024, to September 3, 2024. The research was conducted in several places, namely the field laboratory located on Carang Pulang, Dramaga, Bogor Regency, Solid and Hazardous Waste Laboratory, Department of Civil and Environmental Engineering, IPB University and Wisma Wageningen, Department of Civil and Environmental Engineering, IPB University.

2.2 Design of the Minapadi Model

The FONi System for Minapadi Model was designed and constructed to consist of four fiberglass boxes: first control box, second control box, rice control box and fish control box. The fiberglass boxes are 2000 mm x 1000 mm x 400 mm with lateral supports in the middle of their vertical span as recommended by Julianto et al., (2024). The first control box contained 10 polybags (the diameter of polybags is 30 cm) of rice plants and 15 fish, the second control box providing 10 polybags of rice plants and 15 fish, rice control box containing 10 polybags of rice plants and fish control box containing 30 fish. An automatic weather station was installed to obtain weather data, and two water meters were installed to measure the volume of irrigation and drainage through the system. A control bucket was installed to automatically regulate water usage from the reservoir. The water level is practically set and maintained at 17.5 cm from the bottom of the basin. The plan and mechanism of water level control mechanism can be seen in Figure 1, Figure 2 and Figure 3.

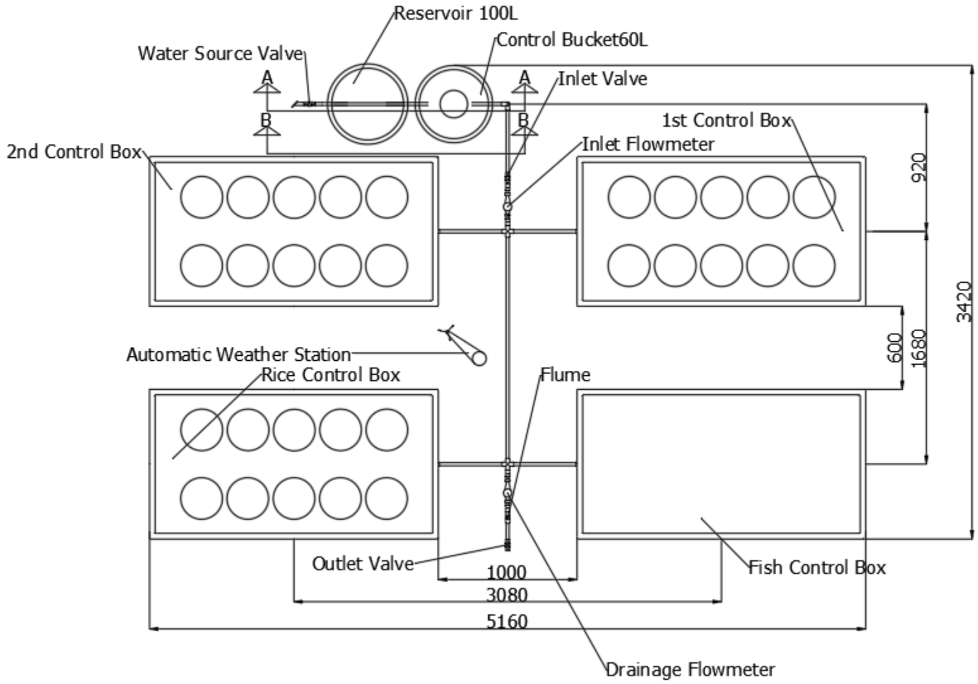

Figure 1. Plan of FONi system for minapadi model.

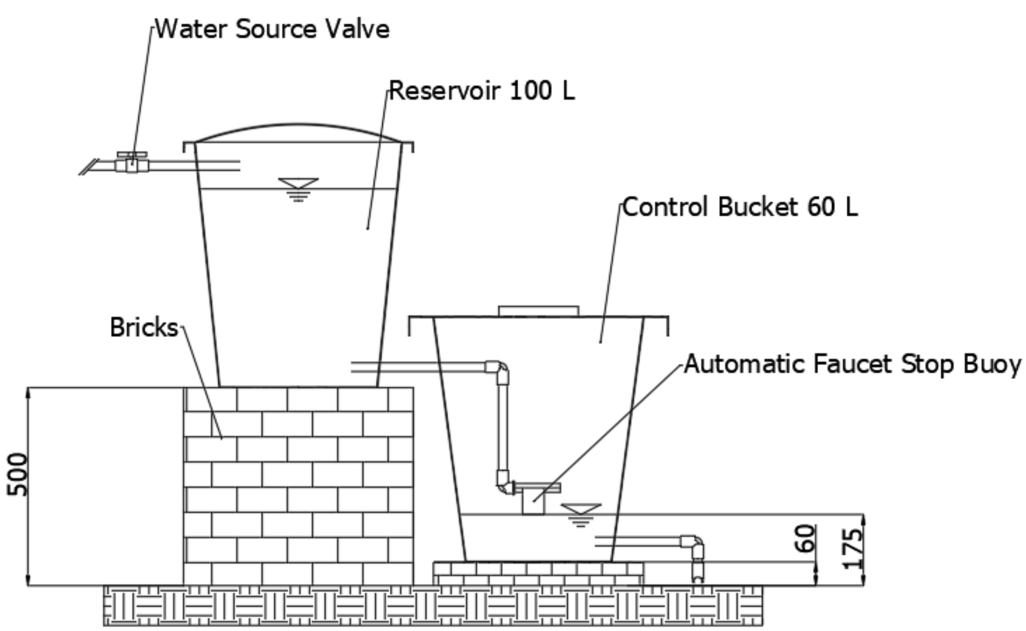

Figure 2. Section A-A explains the water level control mechanism.

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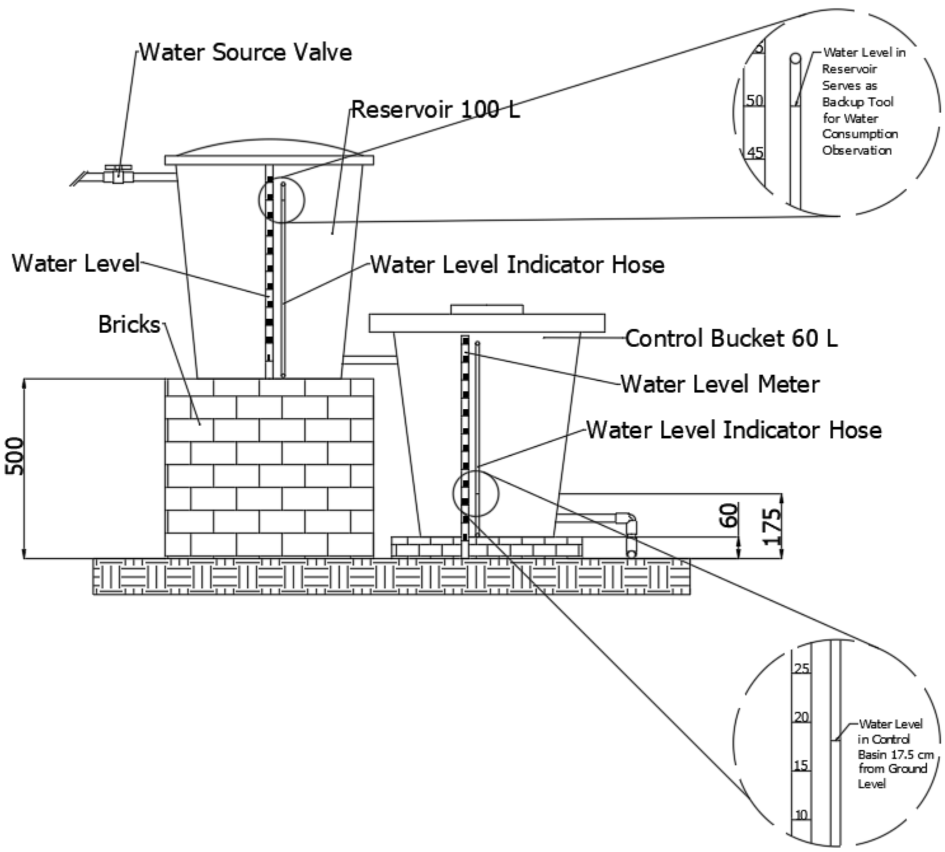

Figure 3. Section B-B explains how to read water levels.

2.3 Rice and Fish Cultures

The crop used was IPB 9G rice variety. The rice plants were seeded in the greenhouse using seedling trays where one cup seedling tray was planted with 4-5 seeds. Seedlings that grow on the seedling tray will be transplanted to polybags with planting media in the form of a mixture of native soil with manufactured planting media. One polybag is filled with about 4-5 seedling trays. Polybags will be placed in a box along with fish to resemble the conditions of minapadi in real rice fields. About every 3-4 days, fertilization is carried out with solid organic fertilizer and liquid organic fertilizer given in combination directly into the polybag. Every five days, the height of the plants will be measured using a ruler from the ground level of the polybag. At the end of the growing season, the rice grain will be weighed and dried to determine its water content and to determine the weight of harvested dry grain (HDG) to calculate water productivity and land productivity. In addition, the estimated number of grains is calculated by random sampling where one polybag is taken from each Box and the number of grains is counted. The grains in the polybag will be partially taken and then counted and weighed to get the grain weight. The HDG weight will be divided by the grain weight to predict the number of grains at harvest.

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The fish used are red tilapia (Oreochromis sp.) with an average weight of 30 grams. Red tilapia will be acclimatized for approximately 15 minutes before being released into the boxes. The fish are fed twice a day in the morning and evening with the amount of feed given depending on the needs of the fish. Weight at harvest, fish population and feed utilization were recorded to calculate aquaculture harvest parameters.

2.4 Water Balance and Rice Production Anlaysis

The calculation of water balance involves irrigation water, rainwater, drainage water, actual evapotranspiration and the difference in water level in the system. The water balance can be calculated with Equation 1.

$$Ir + R = D + ETa + \Delta WL \quad (1)$$

The variables *Ir* is irrigation water (mm), *R* is rain (mm), *D* is drainage (mm), *ETa* is actual evapotranspiration (mm) and *ΔWL* is the change in water level in the control basin (mm). The calculation results of each variable in Equation 1 were used to analyze crop consumption and productivity. Plant productivity is divided into two, namely water productivity and land productivity. Water productivity is divided into two, namely physical and economic water productivity (Molden et al., 2010). In this case, physical water productivity is how much crop yield is obtained from physical water consumption activities (such as evapotranspiration) while economic water productivity is how much crop yield is obtained from spending on irrigation activities (such as irrigation water use), both of which can be calculated by Equation 2 and Equation 3.

$$WP_P = \frac{W_{MDG}}{vETa} \quad (2)$$

$$WP_E = \frac{W_{MDG}}{vIr} \quad (3)$$

$$CIWE = \frac{vETa}{vIr} \times 100\% \quad (4)$$

The variable WP_P is physical water productivity (kg/m^3), WP_E is economic water productivity (kg/m^3), W_{MDG} is the weight of milled dry grain or MDG (kg), *vETa* is the actual evapotranspiration volume (m^3), vIr is the irrigation volume (m^3) and *CIWE* is the crop irrigation water efficiency (%). The actual evapotranspiration volume is the amount of actual evapotranspiration multiplied by the embedded soil area (polybag area). The calculation of W_{MDG} can follow Equation 5.

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$$W_{MDG} = W_{HDG} - W_{HDG} \times (WC_{HDG} - WC_{MDG}) \quad (5)$$

The variables W_{MDG} is the weight of MDG (kg), W_{HDG} is the weight of HDG (kg), WC_{HDG} is the water content of HDG (%) and WC_{MDG} is the water content of MDG (%). The calculation of the water content of harvested dry grain follows Badan Standardisasi Nasional, (2020) as presented in Equation 6.

$$WC_{HDG} = \frac{B - C}{B - A} \times 100\% \quad (6)$$

The variable WC_{HDG} is the water content of HDG (%), B is the weight of grain and cup (gram), C is the weight of grain after drying and cup (gram), A is the weight of cup (gram). Meanwhile, land productivity can be calculated with Equation 7.

$$LP = \frac{W_{MDG}}{A_{Land}} \quad (7)$$

The variable LP is land productivity, W_{MDG} is the weight of MDG (tons), A_{Land} is the land area (ha).

2.5 Fish Production Analysis

Analysis of aquaculture harvest products includes several calculations of harvest parameters, namely absolute weight growth, specific growth rate, feed efficiency, feed conversion and survival which can be calculated using Equation 8, Equation 9, Equation 10, Equation 11 and Equation 12 (Effendie, 1997; Renaldi et al., 2024; Zonneveld et al., 1991).

$$Wa = Wt - Wo \quad (8)$$

$$SGR = \frac{\ln Wt - \ln Wo}{t} \times 100\% \quad (9)$$

$$FE = \frac{(Wt + Wd) - Wo}{f} \times 100\% \quad (10)$$

$$FCR = \frac{f}{(Wt + Wd) - Wo} \quad (11)$$

$$SR = \frac{\sum Nt}{\sum No} \times 100\% \quad (12)$$

The variable *Wa* is the absolute weight growth (grams), *Wt* is the mean weight at the end of observation (grams), *Wo* is the mean weight at the beginning of observation (grams). In this study, the average weight of fish is practically considered to be 30 grams. This is because fish weight selection was carried out at the beginning of the study with an accuracy level of 1 gram. Variable *SGR* is specific growth rate (%), t is observation time (days), *FE* is feed efficiency (%), *Wd* is dead fish weight (grams), *f* is feed weight (grams), *FCR* is feed conversion factor, *SR* is survival rate (%), *Nt* is final fish count (fish), *No* is initial fish count (fish).

3. Results and Discussion

3.1 Water Balance

The calculation and analysis of the water balance was done by measuring irrigation, rain and drainage water. Changes in water level were assumed to be absent because the water level is regulated and controlled by an automatic buoy on the control bucket. This analysis used Equation 1 to obtain actual evapotranspiration. Irrigation water and rainwater are considered as water variables entering the system, while drainage and actual evapotranspiration are considered as water variables leaving the system. Irrigation and drainage are obtained from meter readings divided by the total area of the basin used so that irrigation and drainage have the same unit length, which also applies to rain and evapotranspiration. Calculations were carried out daily and accumulated during the observation day (99 DAP) with the accumulated value of water entering and leaving the system can be seen in Figure 4.

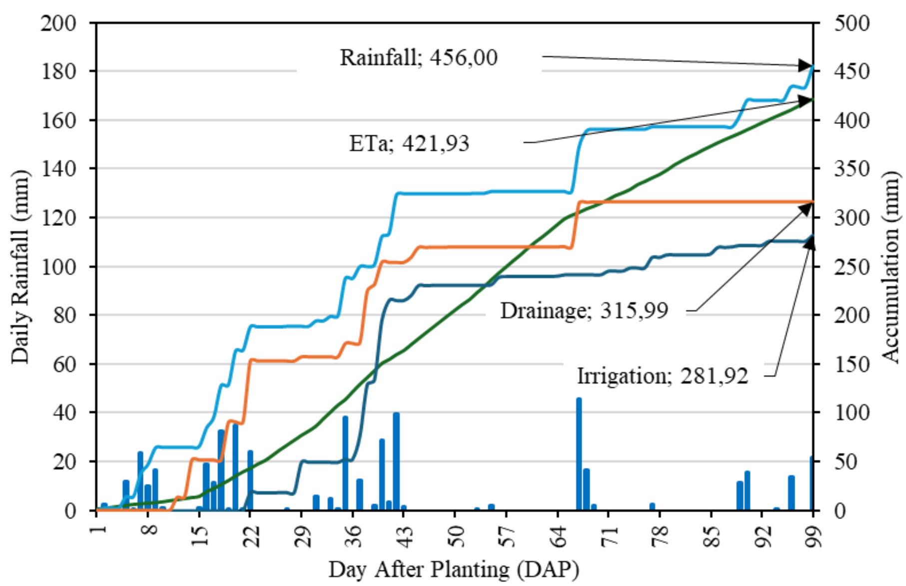

Figure 4. Water components recorded in the system used.

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Figure 4 shows the accumulation of irrigation, rain, drainage and actual evapotranspiration. At 67 DAP, the highest rainfall of 45.5 mm was recorded which was proportional to the increase in drainage. The total accumulation of water entering the system was 737.92 mm and the accumulation of water leaving the system was 737.92 mm, which means that it can practically be said that there is no excess or deficit of water in the system.

3.2 Rice Production

Crop height growth was measured periodically at five days intervals. Measurement of crop height was conducted using a ruler by measuring the height of the plant from the surface of the polybag soil to the top of the rice plant. The results of crop height measurement can be seen in Figure 5.

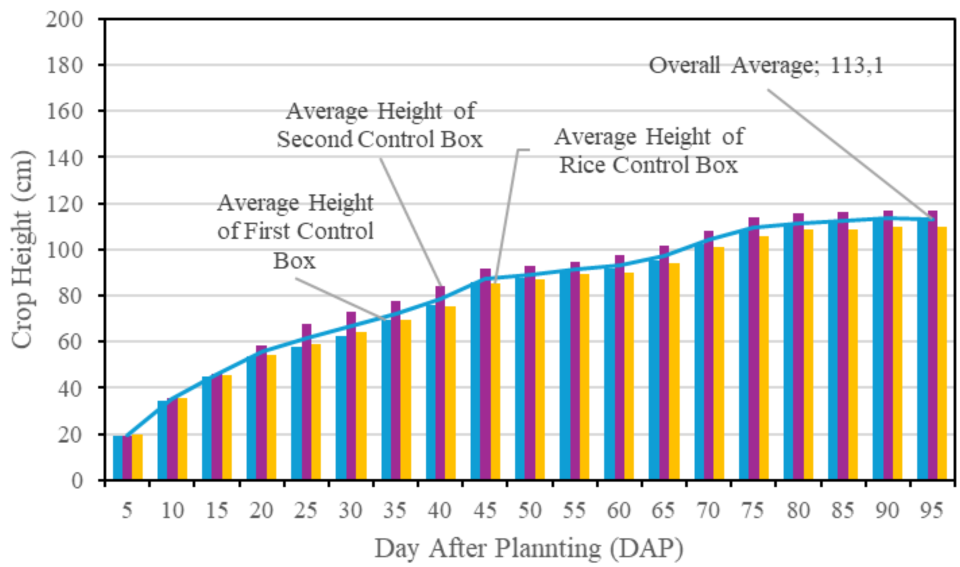

Figure 5. Average crop height.

The mean plant height presented in Figure 5 shows the differences between the three planted boxes. The mean height of the three basins on the last day of plant height measurement was 113.1 cm with second control box being the box that had the highest mean plant height at 116.8 cm, exceeding the overall mean plant height. The lowest height was in the rice control box which had a mean plant height of only 110.0 cm.

The number of grains was calculated by random sampling. The selected samples were counted and weighed to obtain the grain weight. The average weight of one grain was 0.03 grams with the distribution of HDG yields between first control box, second control box and rice control box being 825.00 grams; 886.00 grams and 749.00 grams respectively with a total HDG yield of 2,460 grams. When the weight of one grain is divided by the weight of HDG harvest, the estimated number of grains per box is 30,043 grains, 32,265 grains and 27,276 grains with the total number of grains from all boxes is 89,584 grains. Based on these results, the highest HDG yield is in second control box both in terms of weight of the harvest and the number of estimated grains obtained. based on the plant height and the weight of the HDG harvest, it can be said that second control box has the best performance in terms of producing biomass.

Calculation of HDG water content was done to calculate MDG weight as described in Equation 5. The average moisture content of HDG is 24.39%, while the water content of MDG is 12.75% (Wijaya et al., 2024). Therefore, the weight MDG obtained is 2,170 grams or 0.00217 tons. In this study, the planted land area is the polybag area of 2.89 m², while the total land area is assumed to be the area of boxes planted with rice, namely first control box, second control box and rice control box with a total area of 6.00 m² or equivalent to 0.0006 ha. Thus, land productivity in this system is 3.62 tons/ha. As a comparison, research conducted by Jauhari et al., (2020) using the Inpago 8 variety resulted in land productivity of 5.52 tons/ha. In water productivity, a comparison was made into two scenarios. The calculation of water productivity is based on irrigation volume and actual evapotranspiration volume. The actual evapotranspiration volume is the actual evapotranspiration value accumulated multiplied by the planted land area (polybag area). These two scenarios illustrate the economic and physical productivity of water, where the values of the two scenarios are compared with the results of previous (Subari et al., 2012; Fuadi et al., 2016; Nabipour et al., 2024; Mondal et al., 2024). The results of the comparison can be seen in Figure 6 and Figure 7.

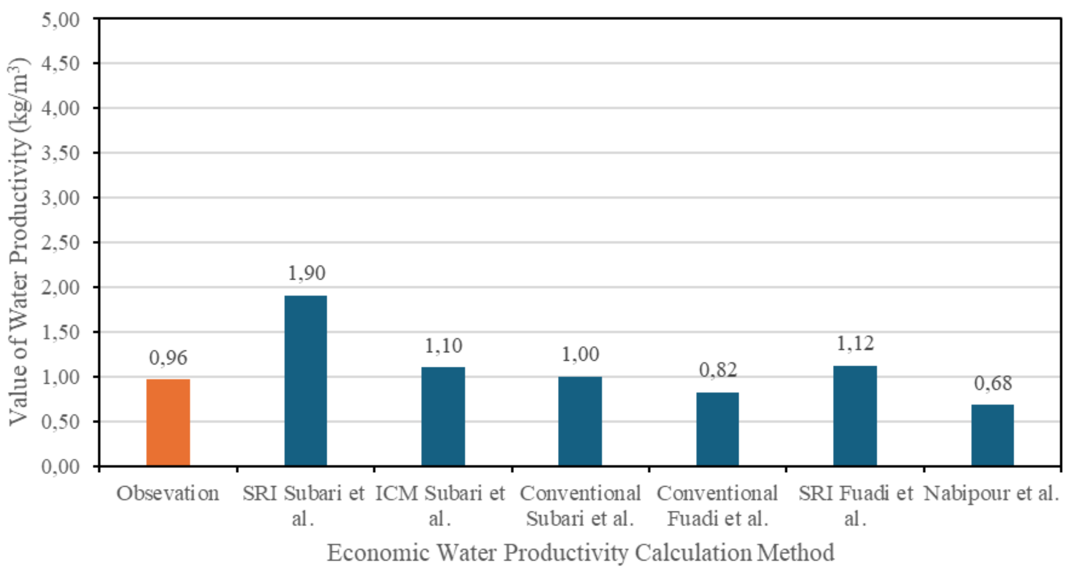

Figure 6. Economic water productivity.

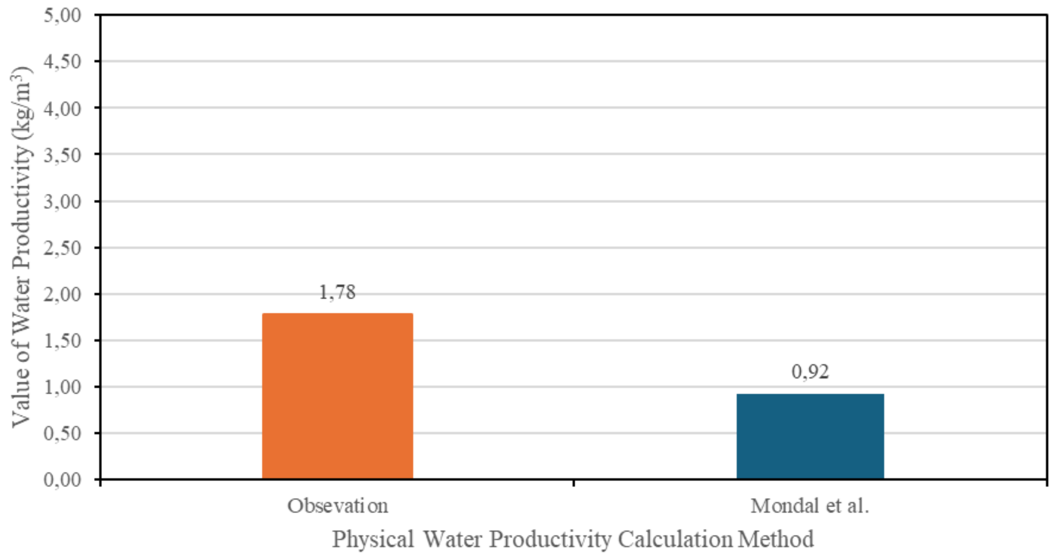

Figure 7. Physical water productivity.

Figure 6 shows the economic water productivity by irrigation use where the observed water productivity is 0.96 kg/m^3. This value is quite competitive when compared to water productivity from several other references. In the SRI method, the value of water productivity is indeed quite high, this is supported by research conducted by Nugroho & Prayogo, (2016) and Wayayok et al., (2014) which states that indeed the SRI method can increase production by at least 50% with a reduction in water use by 50%. Like economic water productivity, the physical water productivity presented in Figure 7 also shows similar results. The physical water productivity involving actual evapotranspiration is 1.78 kg/m^3. Accumulatively, the water supply from irrigation reached 2.25 m^3 and the volume of crop evapotranspiration activity was 1.22 m^3. This indicates that the crop water efficiency is 54.00%.

3.3 Fish Production

The harvest of aquaculture products was recorded to have a total harvest weight of 3,337.00 grams consisting of 857.00 grams of harvest in the first control box, 1,091.00 grams of harvest in the second control box and 1,389.00 grams of harvest in the fish control box with absolute weight growth of 35.92 grams; 53.92 grams and 25.56 grams and specific growth rate of 0.80%; 1.04% and 0.62% respectively. A total of nine fish deaths were recorded which occurred at 8 DAP, 12 DAP, 13 DAP, 21 DAP, 61 DAP, 91 DAP and 92 DAP. Therefore, at harvest time the total remaining fish was 51 fish with a survival rate of 85%. The overall weight of the fish at the beginning of cultivation was 1,800 grams. The weight of fish per fish is considered the same as 30 grams. The total weight of the harvest is 3,337 grams with a total feed usage of 4,949.50 grams where the distribution of feed usage can be seen in Figure 8. If the initial population is considered the same as the population at harvest, namely 51 fish, then the total weight of the initial cultivation is 1,530 grams. Then, the feed conversion ratio value of the cultivation

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results in the system is 2.74, which means that 2.74 kg of feed is needed to get 1.00 kg of fish and feed efficiency is 36.51%. As a comparison, research conducted by (Renaldi et al., 2024) obtained the FCR value of 1.23.

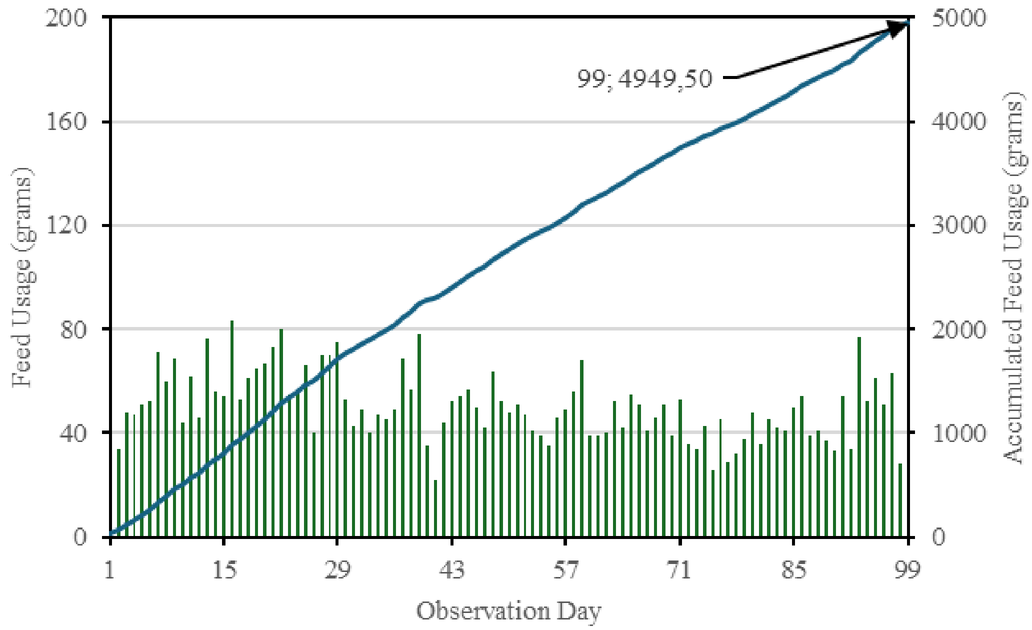

Figure 8. Accumulated feed usage.

3.4 Revenue of the Rice and Fish Productions

Calculation of water productivity based on the weight of milled dry grain as described in Equation 2, the price of milled dry grain in Indonesia in 2024 is worth an average of IDR7,320.48/kg (Badan Pusat Statistik, 2025). If we multiply the water productivity of irrigation use by the average price of dry milled grain in Indonesia, it can be said that economically there is revenue of IDR7,054.94/m^3. Yield of red tilapia fish is 3.34 kg and the selling price of tilapia in the Bogor area is assumed to be IDR25,000/kg (Hadiroseyani et al., 2023) and the use of water for fish farming is assumed to be the same as the amount of irrigation water, it can be said that the economic production of fish farming produces revenue of IDR 36,989.82/m^3. By combining the income from the milled dry grain and red tilapia harvest, the total income from the system used is IDR44,044.76/m^3. As a comparison of income between systems, the productivity values presented in Figure 6 were multiplied by the price of milled dry grain according to the year of observation with the assumption that all prices follow the average price in Indonesia in 2012, 2016 and 2024. The system income comparison can be seen in Figure 9.

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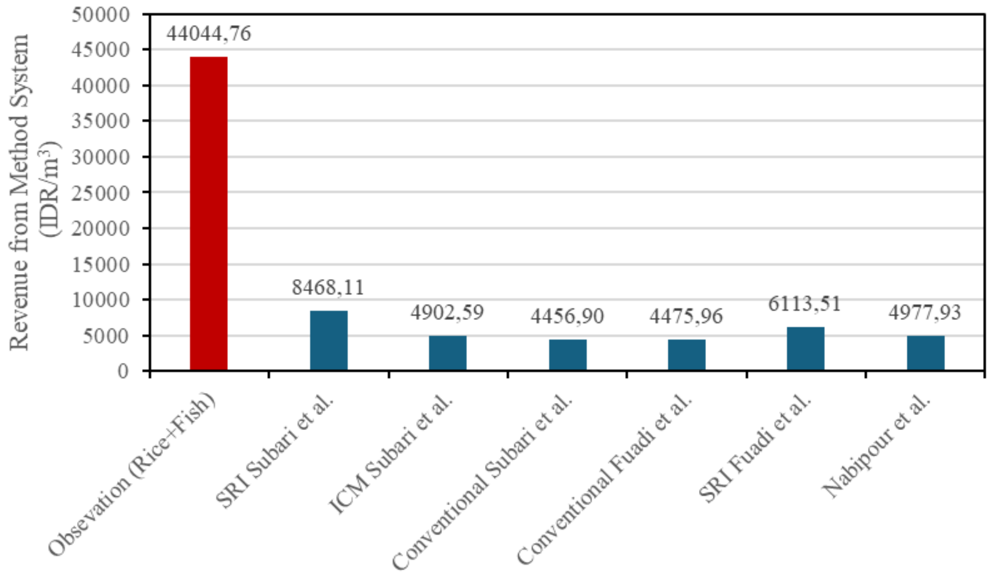

Figure 9. Revenue comparison chart.

Based on Figure 9, the amount of revenue generated from the piloted system is the highest compared to the comparator. This can happen because the income presented is a combination of rice and fish. This indicates that the income from integrated farming is indeed proven to increase income.

4. Conclusion

This research shows that the minapadi system based on the nonpowered automatic fertigator (FONi) can increase water use efficiency, rice productivity, and fish farming yields in urban agriculture. The water balance in this system was balanced with a total accumulation of incoming and outgoing water of 737.92 mm, and water use efficiency reached 54%. The resulting land productivity reached 3.62 tons/ha, with water productivity based on irrigation of 0.96 kg/m^3 and based on evapotranspiration of 1.78 kg/m^3. Fish farming in this system recorded an 85% survival rate, with a total harvest of 3.34 kg and feed efficiency (*FCR*) of 2.74. Economically, this system generated higher income than the conventional method, with an economic value of grain of IDR7,054.94/m^3 and fish of IDR36,989.82/m^3, bringing the total income to IDR44,044.76/m^3. With these results, the integration of FONi technology in the minapadi system is proven to be effective in increasing water efficiency, agricultural and fisheries productivity, and income, so it has the potential to be a sustainable agricultural solution on limited urban land.

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