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Estimating Evapotranspiration and Crop Coefficient of Vegetable Crops Using Pot Micro-lysimeters

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Irrigation for crop production constitutes the most part of agricultural water worldwide. As most of the water withdrawn by agriculture is lost through crop evapotranspiration (ET_C), efficient water management requires accurate and reliable estimation of ET_C. To date, available methods for estimating ET_C require expensive devices and extensive meteorological information, which become a problem in areas with no instruments and with limited data. The present study aimed to evaluate the performance of a technique to estimate ET_C and crop coefficient (K_C) of selected vegetable crops (lettuce, mustard, onion, bush bean, and "pechay") using small plastic pots as micro-lysimeters under screen house conditions. Daily rainfall, reference crop evapotranspiration (ET_O), and ET_C were recorded. Correlation analysis between ET_O and ET_C showed a significant positive correlation in lettuce (R = 0.736), pechay (R = 0.687), onion (R = 0.761), and mustard (R = 0.467). The K_C values of vegetable crops were obtained and the K_C curve for each crop was generated by plotting the K_C with respect to the stages of growth. Comparison between K_C curves of crops obtained using the present technique with the generalized K_C curve by the FAO-56 Penman-Monteith (FAO56PM), the standard method for estimating ET_C and K_C, revealed a significant positive correlation in mustard (R = 0.998), onion (R = 0.982), and bush bean (R = 0.800) – suggesting that the K_C curves of most crops obtained by using the present technique is comparable with the standard generalized K_C curve by the FAO56PM. Taken together, these findings suggest that the present technique provided a close approximation of the water requirements of the crops tested. Since the technique is relatively simple and requires minimum input parameters for estimating ET_C and K_C compared to the standard method, the technique may be used as an alternative in remote areas where meteorological information is limited, as well as in places where urban agriculture is commonly practiced.

Keywords: evapotranspiration, micro-lysimeter, vegetable crops coefficient, water management

INTRODUCTION

The importance of water is indisputable in all forms of agriculture. Proper management of water resources is, therefore, necessary to ensure successful agricultural production with optimum output productivity. With the impending threats of climate change and natural resource degradation, efficient water resource management will play a crucial role in addressing important economic, environmental, and social concerns in the future. Issues concerning supply, quality, allocation, technological innovations, use efficiency, economic feasibility, benefit/cost measurement, and changing social demands of water will be of increasing importance to policy-makers and research institutions at different levels. Since 80–90% of total freshwater used by humans is allotted to agriculture and may reach as high as 95% in some less economically

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developed countries, improving on-farm water use efficiency can contribute not just in increasing water availability for agriculture but also in alleviating problems on water scarcity (Rijsberman 2004; Morison *et al.* 2007; FAO 2017).

When there is insufficiency in the water supply to meet water demand, water scarcity takes place (FAO 2012). Apart from climate change and natural resource depletion, other culprits compounding water scarcity problems are anthropogenic in nature – such as inequitable access, increasing human population growth, urbanization, and misuse of water resources (Homer-Dixon 1993). To cope with water scarcity, the FAO (2012) presented a list of strategies and policies in which a large part is agriculture-related. Indeed, improving agricultural productivity without compromising environmental conservation and stewardship will be helpful in addressing water scarcity, since agriculture is considered to be the largest water user globally (FAO 2017).

As most of the water withdrawn by agriculture is lost through evaporation and transpiration, irrigation for crop production constitutes the most part of agricultural water worldwide. In the Philippines, agricultural irrigation accounts for 82% of the overall freshwater withdrawals (Morison *et al.* 2007; FAO 2011). Hence, efficient and scientific utilization of water for irrigation is necessary to effectively address the increasing cost and shortage of irrigation water. To do this, irrigation systems must be made with the goal of minimizing water wastage. This, in conjunction with efficient fertigation systems to avoid fertilizer wastage, is a requirement for optimum crop production.

The interaction of various climatic parameters that determine crop water use and water supply from rain dictates the water requirement for crop production. Development of strategies to optimize water use for crop production and effective water management practices will need comprehensive meteorological information to be gathered, processed, and analyzed (Smith 2000). Also known as evapotranspiration, crop water use is composed of soil evaporation and plant transpiration from the Earth's land surface to the atmosphere (Al-Kaisi 2000; Tukimat *et al.* 2012). Efficient agricultural water management plus proper budgeting and planning of water consumption and long-term water resources require accurate and reliable estimation of ET_C (Tukimat *et al.* 2012; Zeleke and Wade 2012). In agricultural production, ET_C determines the amount of water to be applied through artificial means or irrigation (Zeleke and Wade 2012).

There are several methods for estimating ET_C developed by hydrologists. Each has its concept and developed for a specific regional climate (Burnash 1995). These methods can be described as empirical such as those developed by Thornthwaite (1948) and Blaney and Criddle (1950), as well as physical-based [*e.g.* Penman (1948), Monteith (1981), FAO's Penman-Monteith method by Allen *et al.* (1998)]. Generally, ET_C may be obtained directly with the aid of lysimeters and through indirect estimation methods (Villanova *et al.* 2006). The above-mentioned differ in terms of accuracy and data requirement. Since many of these methods were region-specific, they only work best in the condition and region they were developed for but often fail to estimate potential ET_C in other climatic conditions (Tukimat *et al.* 2012; Zeleke and Wade 2012).

The FAO-56 Penman-Monteith (FAO56PM) approach is considered to be the standard method for ET_C estimation and K_C determination in the present (Allen *et al.* 1998; Maina *et al.* 2012). Having gained acceptance from the international scientific community, the FAO56PM model is known for its precisely better results when compared to other models in various regions of the world and its good approximation to accurate lysimeter observations (Mohawesh 2011; Maina *et al.* 2012). However, despite its reliability, the FAO56PM requires extensive meteorological information, data, and parameters, which pose a problem in places where data is scarce and unavailable. For most regular meteorological stations, only temperature and rainfall are measured while other meteorological parameters essential for ET_C estimation are not available (Tukimat *et al.* 2012). The magnitude of the problem increases in remote areas with no weather stations for recording the required meteorological data and parameters. Therefore, a much simpler and parameter-less alternative that can deliver reliable results in estimating crop water requirements is desirable.

An experimental technique that directly measures crop water use involves the use of lysimeters. These devices are composed of tanks or containers that permit the measurement of soil-water balance. Measurements obtained using lysimeters can determine K_C value along the crop cycle. Several studies had been carried out to obtain ET_C using lysimeters, which could either be of the weighing or the percolation type (Howell 2005). Lysimeters of different sizes, ways of operation, designs, and shapes have long been used to determine water use in a variety of crops (Fisher 2004; Piccinni *et al.* 2009; Abdullahi *et al.* 2013; Abedinpour 2015; Gebler *et al.* 2015). Lysimeter measurements had been found to be in agreement with the FAO56PM in some studies, making it an efficient and accurate method for determining crop water use (López-Urrea *et al.* 2006; Vaughan *et al.* 2007). Despite the above-mentioned advantages, the instruments *per se*, their installation, and their operation are very expensive and are impractical to use in some areas. For this reason, many researchers resorted to using simple, low cost, and even self-made lysimeters (Fisher 2004; Panda *et al.* 2014; Facchi *et al.* 2016). However, most of these lysimeters involve measurement of ET_C of several plant units or a group of plants and are suitable only to some plant species like grasses, rice, and corn. In the Philippines, lysimeter studies are limited and most of which are conducted at the International Rice Research Institute's sophisticated lysimeter facility (Abubakary *et al.* 2013; Sandhu *et al.* 2016; Cal *et al.* 2018).

To date, there are no published lysimeter studies conducted to measure ET_C of individual plants in the Philippines. Lysimeters that can measure plant water use individually will be suitable for vegetable crops, especially in the practice of container/urban gardening, which is gaining popularity nowadays in the age of climate change, increased urbanization, population growth, and pandemics. This study was conducted to evaluate the performance of a technique to measure ET_C and K_C of selected vegetable crops using small plastic pots as percolation micro-lysimeters and a drip irrigation set-up for its water application under screenhouse conditions. The technique evaluated in the present study may help to properly manage water use in crop production in places where urban/container agriculture is commonly practiced.

MATERIALS AND METHODS

Study Site

The study was conducted at the Agricultural and Biosystems Engineering Complex, Mindanao State University – General Santos City (6.0720° N, 125.1253° E). The preparation and set up of the experimental field were carried out for a period of five months. The actual field experiments were performed from January–April 2012.

General Santos City is located in the southern part of the Philippines and has a tropical wet and dry climate with an average annual rainfall of 959.9 mm, an average annual relative humidity of 79%, and daily mean temperature of 27.9 °C (PAGASA 2012).

Experimental Area

The area covered 8 m^2 and was fully enclosed by a fence to protect the setup from stray animals and unauthorized persons. Equipped with a drip irrigation system, the setup was composed of the main tank, monitoring drums, a network of plastic pipes to supply water to the potted plants, a Class A evaporation pan, a rain gauge, and plastic pot containers that served as micro-lysimeters. The perspective plan of the drip irrigation system is shown in Figure 1A.

The experimental setup was placed inside the screen house and was covered with orchid nets to prevent damages on experimental crops caused by insect and pest infestations. Also, the evaporating pan and rain gauge were placed inside the screen house to ensure that the equipment had similar environmental conditions with the potted plants. To neutralize the filtering effect of the net, the Class A evaporation pan was painted blue as pans with dark colors may lose more water than white pans due to the difference in reflectivity (Ali 2018). The experimental layout is shown in Figure 1C. Photos of the actual setup and the devices used in the study are shown in Figure 2.

Experimental Crops

The crops tested in the study were Lollo Rossa lettuce (*Lactuca sativa* L.), mustard (*Brassica juncea* L.), spring onion (*Allium fistulosum* L.), bush bean (*Phaseolus vulgaris* L.), and pechay (*Brassica rapa* subsp. *chinensis*). Lollo Rossa is a loose-leaf type of lettuce with frilly magenta leaves and can be harvested 55 days after planting (DAP) (McLaughlin 2010). Mustard has a rosette of large light or dark green leaves and is considered a hardy leaf vegetable. Mustard greens can be harvested 30–40 DAP (Albert 2008). Bush beans grow compactly and may reach up to 2 ft tall. Bush beans require well-drained soil and produce in about 50–55 d (Stillman *et al.* 2020). Characterized with a distinct white stem consisting of leaf bases, spring onions have slightly enlarged bulbs with straight hollow leaves. Spring onions require constant moisture in the soil as they have small root systems and typically reach maturity at 56–70 DAP (Burt 1999). Pechay is an erect, biennial herb with numerous soft, thin, light green, and broad to oblong-ovate leaves that are spreading and arranged spirally. Pechay grows rapidly, requires adequate moisture, and can be harvested 30–40 DAP (Jimenez *et al.* 2000).

Except for bush beans, which were directly planted to the pots, the seedlings of vegetable crops were first grown in a nursery box and transplanted later to the experimental pots when they were ready and sturdy enough to be exposed to direct sunlight. A ratio of 1:4 vermicompost to ordinary garden soil was used in all experimental pots to supply enough nutrients to the plants.

Experimental Pots (Micro-lysimeters)

The small plastic pots served as micro-lysimeters. A schematic diagram of the experimental pot depicting its setup and structure is shown in Figure 1B. Twelve (12) pots were used for each type of crop being studied (Figure 1C). Each pot micro-lysimeter was made up of a cylindrical plastic pail with a diameter of 10 in provided with a drainage pipe at the bottom, a 1-gal container for drainage collection, and a measuring cup. Water was

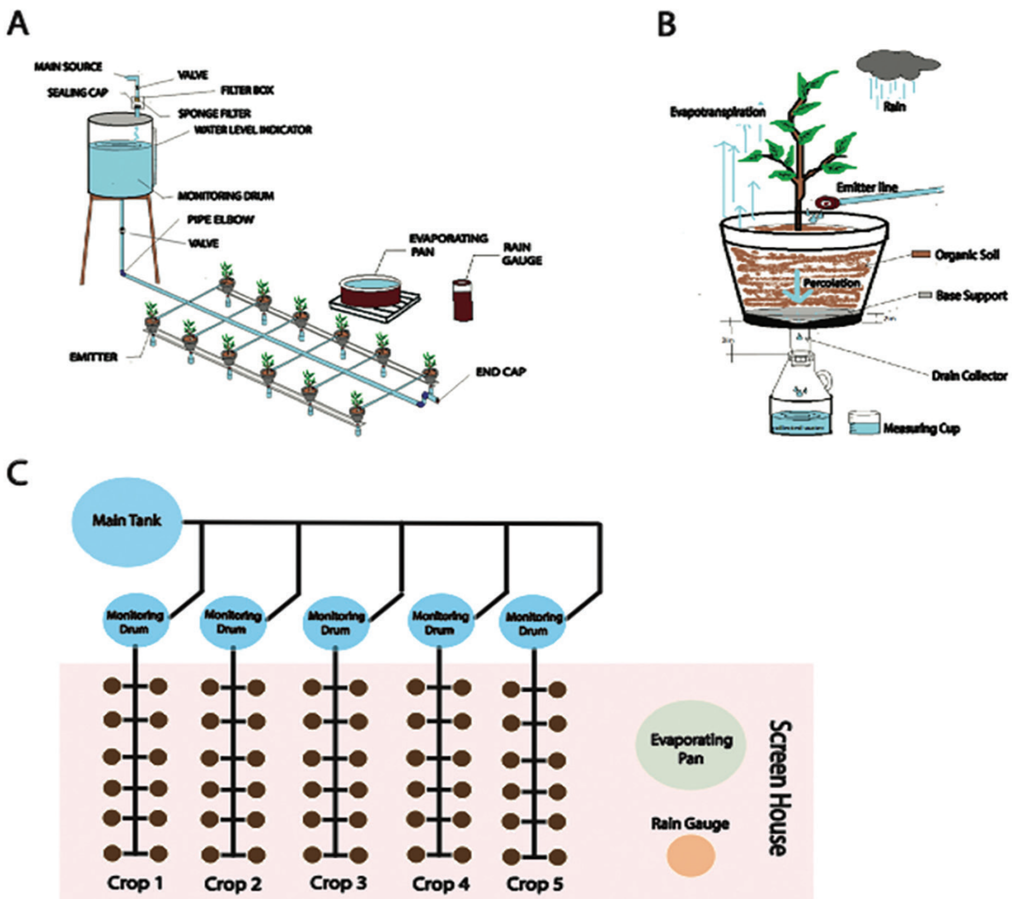

Figure 1. (A) perspective plan of the drip irrigation system, (B) the schematic diagram of the small plastic pot micro-lysimeter, and the (C) experimental layout.

supplied to the plants in the pot through the emitters and any excess water was collected at the bottom of each pot. The collected water was regularly monitored and transferred to the measuring cup for measurement. The volume of water supplied to the plants in the pot and the water drainage from the pot were measured every time to estimate the actual water consumption. To prevent weeds from competing with nutrients and water consumption of the crops, regular weeding was carried out. The actual water consumption of the crop (evapotranspiration, ET_C) was determined by accounting the amount of water added to the pot and the drainage collected on a daily basis.

Data Gathering

Daily measurements of evaporation (E_{pan}) and rainfall were recorded from the evaporation pan and rain gauge installed in the experimental area, respectively. By taking into account the aforementioned parameters, the K_C was estimated using the equation (Allen *et al.* 1998):

$$K_C = \frac{ET_c}{ET_o} \quad (1)$$

The ET_C was based on the calculations of the water balance of the system. This was estimated daily by using the plastic pots as micro-lysimeters. In this way, water provided by irrigation (Q), stored by the substrate (W), and drained (D) was calculated daily:

$$ET_C = Q + R - D \quad (2)$$

where Q is the discharge (water applied to plants in the experimental pot), R is rainfall, and D is the drainage. During the experiment, the soil was maintained at field capacity since the vegetable crops were continuously supplied with water using drip irrigation. Hence, the effect of stored water (W) in the soil was no longer included in Equation 2.

The ET_O can be estimated using the E_{pan}. By observing the loss of water from the pan and using empirical coefficients to relate pan evaporation to ET_O, Allen *et al.* (1998) reported the practical value of pans and the use of pans to successfully estimate the ET_O. Here, the ET_O was estimated on the basis of atmospheric demand measured with the studied devices and empirical equation (Allen *et al.* 1998):

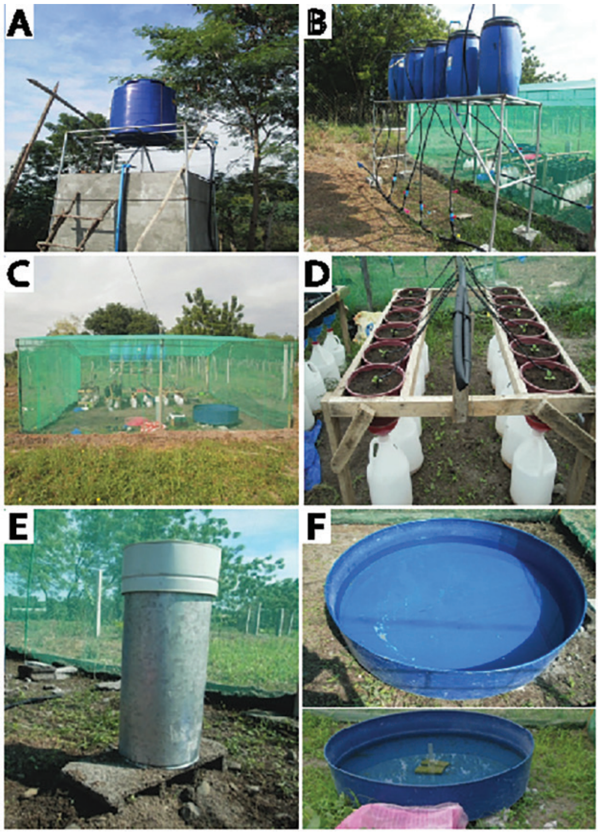

Figure 2. Photos of the actual setup: (A) main tank, (B) monitoring drums, (C) screen house, (D) plastic pot micro-lysimeters, (E) rain gauge, and (F) modified evaporation pan

$$ET_O = K_{pan} \; x \; E_{pan} \tag{3}$$

where K_{pan} (0.7) is the pan coefficient and E_{pan} is the pan evaporation. Since the climate in General Santos City is dry, the K_{pan} of 0.7 was used as a rough estimate for Class A evaporation pan for dry (arid and semi-arid) conditions (Smajstrla *et al.* 2000).

The methodological framework of the study is shown in Figure 3.

Statistical Analysis

The relationships between variables examined in the study were evaluated using Pearson correlation and the data were analyzed using MS Excel 2011 Version 14.4.0. The tests of significance were performed by using StatPlus:mac LE Version v7 and a significance threshold of 0.05 was used.

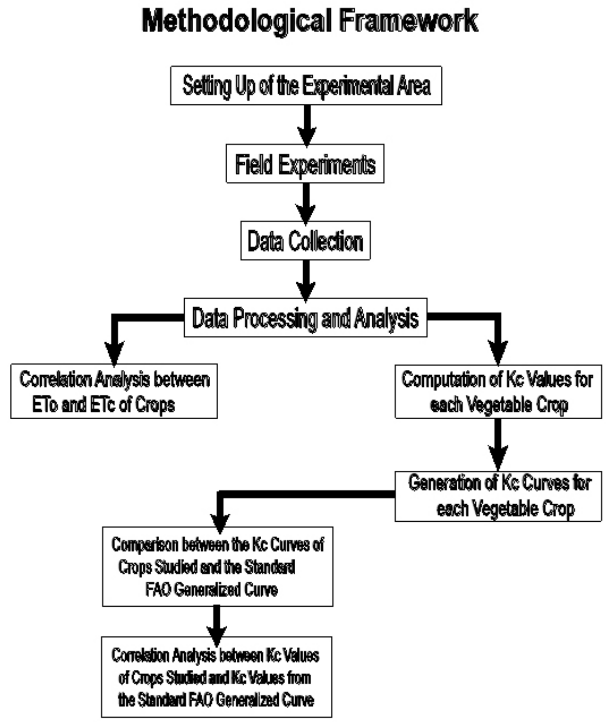

Figure 3. Methodological framework of the study.

RESULTS AND DISCUSSION

Daily Rainfall, ET_O, and ET_C Rates of Vegetable Crops Tested

The daily ET_O, ET_C, and rainfall during the growth periods of vegetable crops tested in this study are shown in Figure 4. The graph shows a similar trend of ET_O and ET_C in that an increase in ET_O recorded a corresponding increase in ET_C of the vegetable crops studied. During the early stages of growth, it was observed that the ET_C values of all vegetable crops were lower than the ET_O. According to Allen *et al.* (1998), the majority of the water lost during the early stage of plant growth is due to evaporation from the soil surface. Subsequently, transpiration becomes the main source of water loss once the plant has well developed and its canopy shades most of the ground area.

Unlike onion and bush bean with their ET_C lower than the ET_O during the period covered, there was a subsequent gradual increase in the ET_C of lettuce, mustard, and pechay with ET_C surpassing the ET_O at 31, 23, and 29 DAP, respectively. These differences may be attributed to the different physiological and physical characteristics of the vegetable crops tested in the study. As crop type or characteristics is also considered one of the factors affecting ET_C, alongside crop variety and development stage, the differences between the characteristics of vegetable crops tested in the present study likely explain the variations in the pattern of ET_C of the vegetable crops.

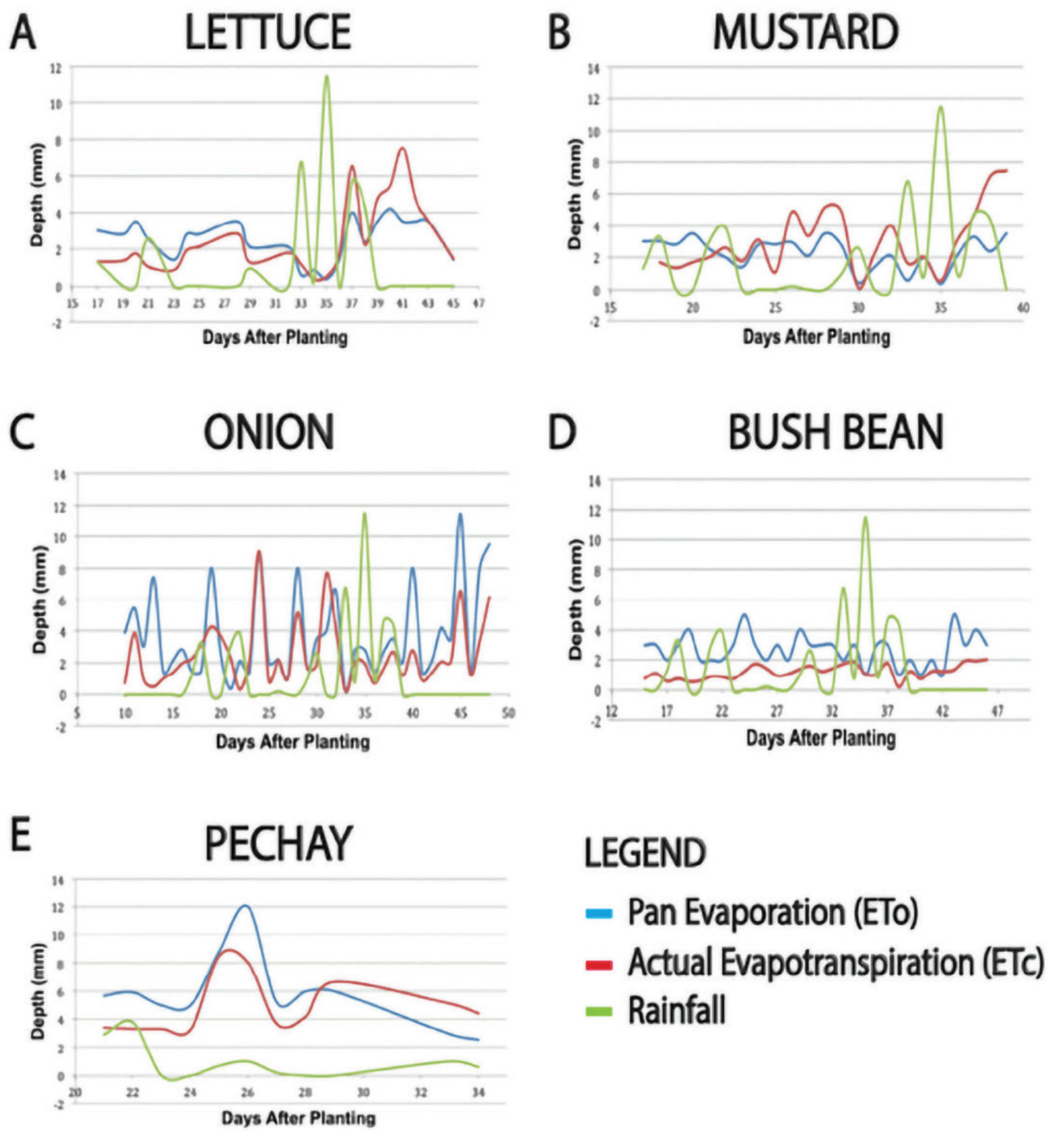

Figure 4. Daily rainfall, Reference Crop Evapotranspiration (ET_O, mm/day) and Actual Crop Evapotranspiration (ET_C, mm/day) of vegetable crops at different days after planting.

According to Rind *et al.* (1990), the ET_C is a function of leaf area (transpiring surface) because, under similar atmospheric demand, the ET_C will be higher in crops with larger leaf area indices. Morphologically, lettuce, mustard, and pechay have broader and wider leaves than the onion and bush bean. Thus, these crops have a greater surface area for transpiration and can cover a much bigger area of the soil below them than do onion and bush bean. Moreover, it is also possible that the bush beans had not attained their full development yet during the conduct of the experiment; hence, the canopies were not big enough to optimally cover the soil below them. For onion plants, the very narrow, hollow-tubed leaves and the consistently wet ground may have caused their ET_C to be always lower than ET_O during the entire period.

In the present study, the rainfall also appeared to influence the ET_C and ET_O as there seemed to be a drop in both at times when rainfall was high. This inverse relationship between precipitation and ET_C has also been reported previously. There was a reported decrease in regional transpiration caused by higher precipitation associated with reduced sunshine duration and increased cloud cover (Moller and Stanhill 2007).

Since ET_O and ET_C occur simultaneously (Allen *et al.* 1998), the correlation between the two variables was examined in the present study. As shown in Figure 5, correlation analysis revealed a significant positive correlation between ET_O and ET_C of lettuce [$R(20) = 0.736$, $P < 0.05$], pechay [$R(9) = 0.687$, $P < 0.05$], onion [$R(21) = 0.761$, $P < 0.05$] and mustard [$R(21) = 0.467$,

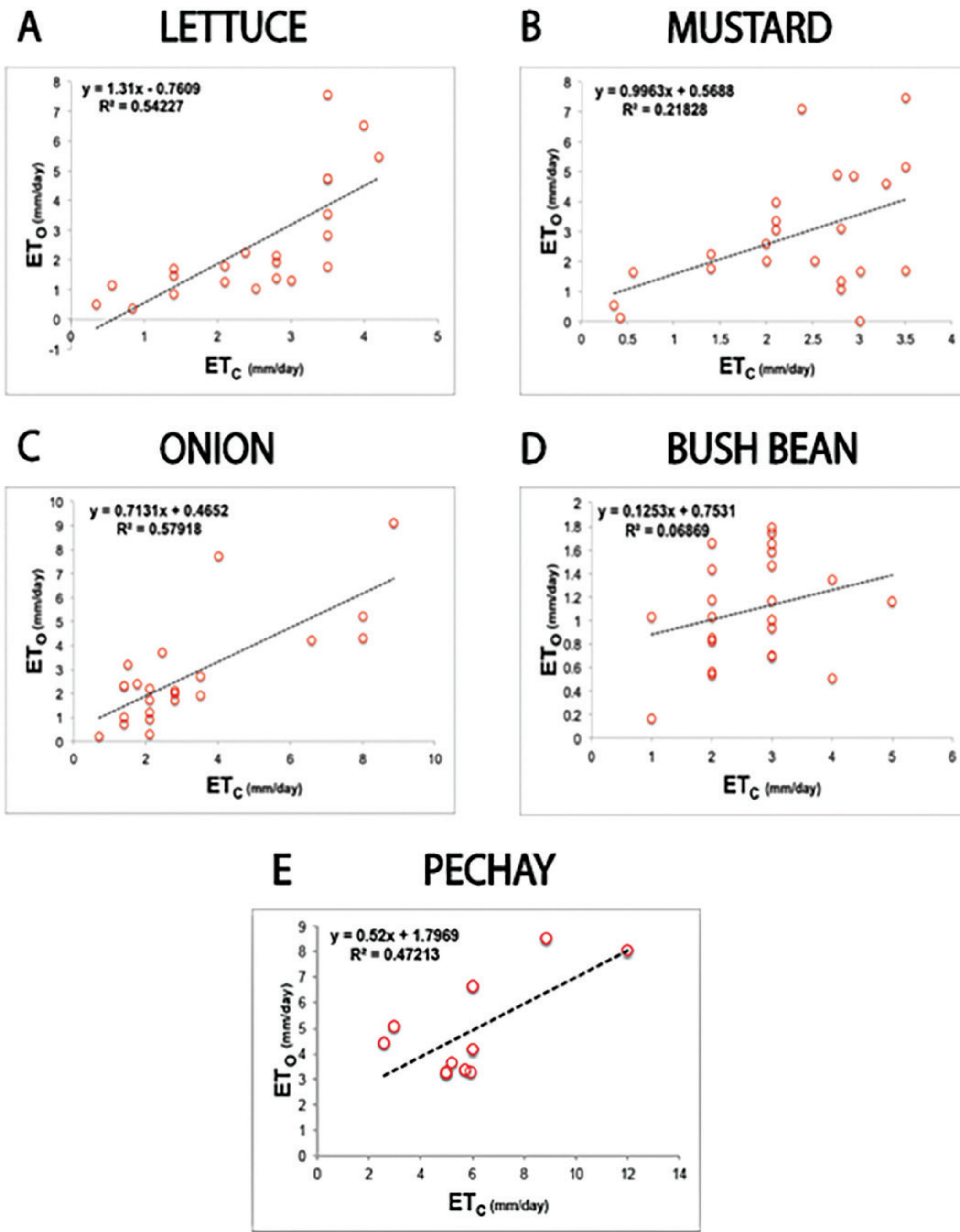

Figure 5. Correlation between reference crop evapotranspiration (ET_O, mm/day) and actual crop evapotranspiration (ET_C, mm/day) of vegetable crops tested in the study.

$P < 0.05$]. However, in the bush bean, although a weak positive correlation was observed [R(21) = 0.262], the said relationship is not significant ($P > 0.05$). The difference in the results, albeit positively correlated, may be attributed to the difference in the species and stage of development of crops tested in the present study. As aforementioned, the varying canopies of different crops at different stages of growth influence the ET_C (Al-Kaisi 2000).

Comparison of K_C Curves of Crops from the Experiment with the FAO K_c Generalized Curve

A single K_C value integrates the effects of both plant transpiration and soil evaporation and incorporates the characteristics of the crop and the average soil evaporation (Allen *et al.* 1998). Simply put, K_C is the ratio of ET_C to ET_O and is used to predict potential evapotranspiration in crops (Savva and Frenken 2002). In the present study, after computing the K_C of vegetable crops at different stages using Equation 1, the values obtained were then compared with the K_C values of the generalized K_C curve for the single K_C approach by the FAO (Allen *et al.* 1998). Only the average K_C values of vegetable crops at the initial, development, and mid-mature stages were taken and compared with the FAO's generalized K_C curve covering the initial until the mid-mature stages only. The photos depicting the vegetable crops at different stages of growth are shown in Figure 6. The K_C curves for each crop tested in the study along with the FAO values from the generalized coefficient curve are shown in Figure 7. As observed, the K_C values of all crops are in agreement with the FAO values from the generalized coefficient curve. The K_C values were lowest during the initial stage of growth of lettuce (> 20 DAP), mustard (> 21 DAP), onion (> 20 DAP), bush bean (> 24 DAP), and pechay (> 20 DAP). The K_C values subsequently increased during the development stages of lettuce (21–34 DAP), mustard (22–35 DAP), onion (21–30 DAP), bush bean (25–39 DAP), and pechay (21–30 DAP). Within the period covered, the crop water requirements were highest during the mid-mature stages of growth of lettuce (35–45 DAP), mustard (36–40 DAP), onion (31–47 DAP), bush bean (40–47 DAP), and pechay (30–35 DAP).

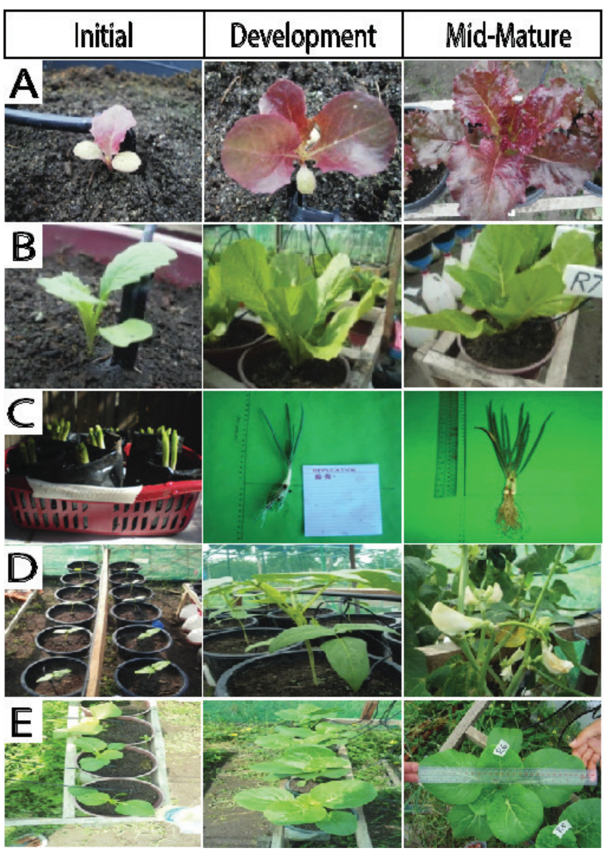

Figure 6. Photos of (A) lettuce, (B) mustard, (C) onion, (D) bush bean, and (E) pechay at initial, development, and mid-mature stages of growth.

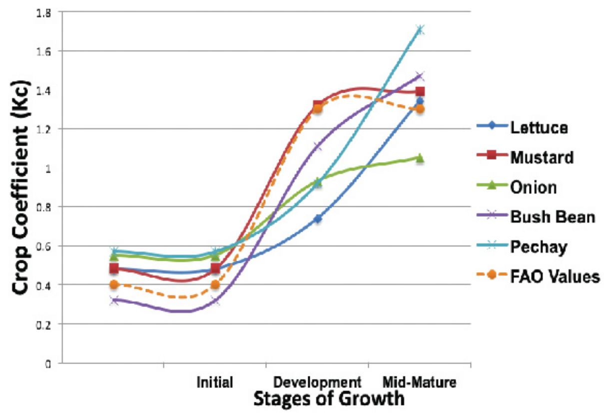

Figure 7. Comparison between the K_C curves of vegetable crops obtained using the simple technique and the K_C values from FAO's generalized curve for single K_C.

Figure 8 shows the correlation between K_C values of vegetable crops from the experiment and the K_C values from the FAO generalized curve. Subjecting the K_C values of crops from the experiment and the FAO values to correlation analysis revealed a significant positive correlation between the two variables for mustard (R = 0.998, $P < 0.05$), onion (R = 0.982, $P < 0.05$), and bush bean (R = 0.800, $P < 0.05$). Although there was a positive relationship between the two variables for lettuce (R = 0.797) and pechay (R = 0.800), the results were not significant ($P > 0.05$). These results are consistent with the K_C curves of lettuce and pechay as shown in Figure 7, which appear to be still increasing and had not yet reached the peak or plateau that corresponds to the middle stage as projected by the FAO's generalized coefficient curve. The results suggest that while mustard, onion, and bush bean had attained the middle stage based on their K_C, the K_C of lettuce and pechay were still on the rise and had not reached full maturity yet. Since the duration of different crop development stages set by FAO varies in different planting periods and climatic regions (Allen *et al.* 1998), there is still a need to determine the duration of crop development stages set for each type of crop to determine the accurate K_C of crops at different stages of growth under General Santos City conditions. Nevertheless, the K_C values of vegetable crops fell within the range of K_C of crops in previous reports (Allen *et al.* 1998; MAFF-BC 2011; Qassim and Ashcroft 2012), suggesting that the simple technique used in the present study provided a close estimate of the water requirements of the vegetable crops tested.

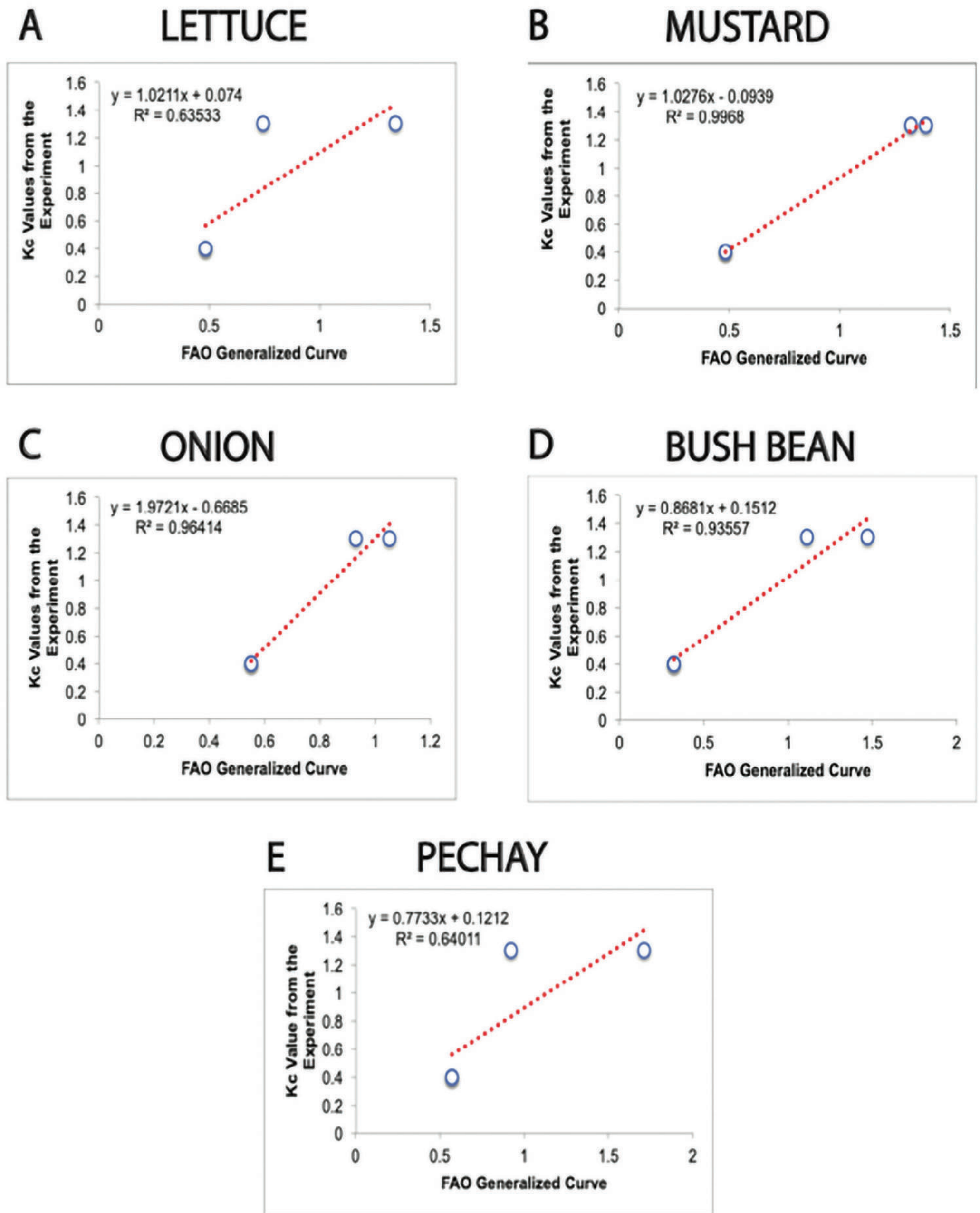

Figure 8. Correlation between the K_C values of vegetable crops from the experiment and the K_C values from the FAO generalized curve.

SUMMARY AND CONCLUSION

The study evaluated the performance of a technique to estimate ET_C and K_C of selected vegetable crops under General Santos City conditions. Results showed that the K_C curves of crops followed the trend of the generalized K_C curve by the FAO, which were supported by the strong positive correlation between the K_C of some crops in the study and the generalized FAO K_C values. Taken together, these findings suggest that the technique used in the present study provided a close approximation of ET_C and K_C of selected vegetable crops. Since the technique is relatively simple, inexpensive, and requisitive of minimum input parameters in determining the crop water consumptive use and K_C values compared to the standard method, it may be used as an alternative especially in remote areas where meteorological stations, weather instruments, and similar facilities are not available as well as in places where urban/container agriculture is commonly practiced. The technique, however, needs to be further validated using other vegetable crops in different climatic and environmental conditions. Also, as the present study had very limited parameters, conducting similar studies with extensive meteorological parameters as inputs for the estimation of ET_C using FAO56PM and the CROPWAT program will be very helpful in validating the technique. Finally, it is recommended to perform further studies covering all stages of growth to obtain the K_C from the initial stage until the senescence stage of crops.

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STATEMENT ON CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

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