

Atmometer-based furrow irrigation for sweetpotato (*Ipomoea batatas*)

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Abstract: The study focused on the development of water management technology for sweetpotato utilizing atmometer for scheduling. Shallow tube well irrigation systems were installed to implement the technology. Experimental sites were located at San Felipe, Zambales in rainfed lowland and lahar-laden area. Four treatments with three replications were implemented such as T₀ - rainfed condition (control), T₁ - every 7 days, T₂ - every 14 days, and T₃ - every 21 days irrigation. 15 square meter plot sizes were separated with two meter-alley and laid out in a randomized complete block design. Data were tested in analysis of variance using Statistical Analysis for Agricultural Research (STAR). Results of the study showed that in lahar-laden area T₁ and T₂ produced significantly higher yield compared to T₀. T₁ and T₂ with 13.87 kg and 13.36 kg/30 samples, respectively. However, T₃ with 9.89 kg, had no significant difference with the control with 8.01 kg. These were attributed to more significant number of large storage roots under the irrigation treatments. Herbage weight was also found to be significantly higher in T₂ with 500.83 gram/plant. In lowland condition, irrigation treatments had no significant effect compared to control. However, presence of weevils were observed under control plots. On the other hand, shallow-tube wells and atmometer use could possibly increase income of 23.51% to 37.28%, with a pay-back period of 0.74 to 3.20 years.

Keywords: atmometer, climate change, lahar-laden, lowland, sweetpotato irrigation, water productivity

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1 Introduction

The agriculture sector highly affected by weather conditions is in the course adapting to climate change effects (ADB, 2009; Iizumi et al., 2019; Karimi et al., 2020). For a developing country like Philippines, major crops and staple food production must be secured, as it affects households especially the farmers (Ravago et al., 2017). Mostly, with climate change, water supply becomes limiting (Mehran et al., 2017) which challenges farm management. Thus, the need to strategize farming system involving water management and crop diversification (ADB, 2009).

Sweetpotato is one of the staple foods that has a

great potential of addressing food security in the midst of climate change (Mari et al., 2022; Sapakhova et al., 2023). Moreover, its economic viability is very competitive ranking fifth value in production with P1.054 million (PSA, 2021). Considered the seventh most important food globally, this crop is being planted in many countries for various purposes (Kays, 2005).

Philippines had been producing sweetpotato for food, flour or starch and feeds. According to PSA (2018), Bicol Region is the biggest producer with 41.86 thousand metric tons or 27.2% of total sweetpotato production in the second quarter of 2018.

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This was followed by Central Luzon and Eastern Visayas with 20.4% and 16.0% of total produce, respectively. However, decline in the production occurred (PSA, 2018) and is still observed recently (PSA, 2023). The effects of climate change seemed to show off especially in terms of water availability. It was noted that in Bicol region, the decreased yield was due to insufficient water supply during tuber formation (PSA, 2018). On the other hand, Eastern Visayas experienced continuous rainfall during tuber formation which lowered the production. This indicates that water is an important limiting factor in sweetpotato production, especially here in the country (PSA, 2018).

Sweetpotato had the ability to adapt to a period of drought stress (Siqinbatu et al., 2014). However, the yield response of the crop differs with differing soil moisture conditions, with decreasing yield as the soil water tension is increased (Felix et al., 2015). Ekanayake and Collins (2004) observed that decreasing water applied showed decreasing fresh root yield. In addition, ten weeks onwards (root development) are critical periods of increased water use since fluctuating soil moisture will reduce yield and cause cracking of roots (Traynor, 2005). Thus, water management involving irrigation scheduling with levels of water to be applied is essential (Felix et al., 2012).

Irrigation techniques for crops have been continuously developed for optimum yield and resource management. For sweetpotato, many irrigation systems had been adopted (Önder et al., 2015). Surface and pressurized irrigation like sprinkler and drip systems had also been adopted (Nasare et al., 2009; Gajanayake et al., 2013). Some of these techniques involved soil-based moisture monitoring and weather-related crop water use monitoring. Tensiometers are utilized to monitor soil moisture and would indicate when and how long to irrigate (Traynor, 2005). Others incorporated automation with the use of soil moisture sensors (Millón et al., 2019; Divya Dhatri et al., 2009; Pramanik et al., 2022). Irrigation time can also be scheduled using evapotranspiration gages like atmometers (Mahbub and Elliot, 2003; Gleason et al.,

2013; Villaroman et al., 2018; Ines et al., 2023). These techniques can be effective considering local conditions like crop related management and local weather conditions. In the country, such technologies are not yet widely adopted. Moreover, the availability of water supply poses a challenge (Lapong and Fujihara, 2008) in implementing water management at farm level. Thus, a need to establish crop water management technique that considers climate related factors, considering the threat of water insufficiency in the next decade (Ranada, 2015).

Small-scale irrigation system like small farm reservoir (SFR) and shallow tube well (STW) have proved to have addressed water scarcity issues and potentially capable of sustaining small-holder farmers' income (Payen et al., 2012; Jusoh et al., 2013). Partnered with applicable water management technology, farmers may be well prepared to adapt to the possible scenarios brought about by climate change. Thus, this project had address the current gaps aforementioned.

Generally, this study aimed to develop an improved water management for sweetpotato production in the rainfed lowland and lahar –laden areas. Specifically, the study aimed to: (1) establish small-irrigation systems for pilot areas under rainfed lowland, and lahar laden areas; and (2) utilize atmometer in irrigation scheduling for sweetpotato employing furrow irrigation.

2 Materials and methods

2.1 Establishment of Small-Scale Irrigation System (SSIS)

Six sites were established for this project namely; (1) three lahar-laden sites (Moncada, Tarlac; San Marcelino, Zambales; and San Felipe, Zambales) and (2) three rainfed lowland sites (Moncada, Tarlac; San Felipe, Zambales and Concepcion, Tarlac). Rainfed here refers to areas not covered by relatively large irrigation structures such as the National Irrigation Systems, Communal Irrigation Systems and Privately Owned Irrigation Systems. Field inspection and site validation were conducted to determine the type of

SSIS to be installed.

2.1.1 Field inspection and site validation

Upon stakeholders' consultation, possible sites for establishing technology demonstration have been determined. The selected sites were visited and factors like water availability, accessibility, and farmer receptivity were checked. There was a total of four newly installed shallow-tube wells; two in Tarlac (Moncada) and two in Zambales (San Marcelino and San Felipe). Some experimental sites were selected since there were already existing irrigation source. As in the case of Concepcion, Tarlac and San Felipe, Zambales.

Based on characterization, the soil physical characteristics in Moncada, Tarlac falls under heavy soils while, in the San Marcelino and San Felipe Zambales were light textured soils. These can be specially helpful in crop establishment. Based on ocular inspection, the selected areas relatively have shallow ground water table, as evidently observed presence of other STWs in nearby farms. This also validated the shallow groundwater as shown in the map by National Water Resources Council (1982a, 1982b). Thus, the PAES 610 (2016) and PAES 615 (2016) (Groundwater Irrigation Shallow-Tube Well) was used in establishing the small scale-irrigation system in the experimental/demonstration sites.

2.1.2 Participatory trial demonstration

This was conducted alongside the conduct of atmometer-based irrigation scheduling. Data on discharge was gathered as basis for implementing irrigation. The fuel consumption, as well as other production expenses was also estimated for cost and return. Operation of the engine was conducted by the farmers, in coordination with the researcher for the timing of irrigation.

2.2 Atmometer-Based irrigation scheduling

To estimate the crop water need or irrigation water requirement, crop evapotranspiration was determined. From there, the net irrigation depth was computed.

2.2.1 Determination of evapotranspiration and sweetpotato actual evapotranspiration

Instead of using Modified Penman-Monteith and

other models, reference evapotranspiration (ET_{ref}) was determined through direct measurement from the atmometer instrument. Atmometer with a data logger was used and manually read at least once a week for checking prior irrigation. Crop evapotranspiration (ET_{CROP}) was estimated based on the formula form PAES 602 (2016):

$$ET_{CROP} = ET_{REF} \times K_C \quad (1)$$

where:

ET_{CROP} – sweetpotato evapotranspiration (mm day⁻¹);

ET_{REF} – reference evapotranspiration (mm day⁻¹, from the atmometer);

K_C – crop coefficient for sweetpotato.

Based on FAO (2018), the sweetpotato has the following crop coefficient, which were considered during the irrigation activities. The K_C in initial stage is 0.2~0.4, the K_C in middle stage is 1.15, and the K_C in end stage is 0.65.

The 'VSP6' (Super Bureau) with 90 days expected harvest was used in this study. Initial stage where from 0 to 30 days after transplanting (DAT); middle stage is from 31 to 60 DAT, and end stage is up to harvesting. The last irrigation for sweetpotato was 2-3 weeks prior harvest.

2.2.2 Irrigation water requirement

The amount of water applied is the total crop evapotranspiration, neglecting percolation and seepage. Since the experimental plots are relatively small (about 15 square metres per plot), irrigation hose were used. The timing of irrigation was based on the treatments of 7-, 14-, and 21-days interval, and no irrigation (rainfed). These were based on farmer's practice. In lahar-laden area, especially in San Felipe, Zambales, they do not irrigate their sweetpotato field. In Concepcion, Tarlac they irrigate their field once a week or when they visually assessed those crops needed irrigation. Others also practiced twice irrigation for the whole crop duration.

2.2.3 Experimentation and data analysis

Plants were raised according to the general recommendation of sweetpotato production. The experiment was laid out in a randomized complete

block design (RCBD), with three replications. Each plots were separated by bunds of two metres from each side. Treatments employed were as follows:

T₀ - Rainfed condition (Control)

T₁ - 7 days interval

T₂ - 14 days interval

T₃ - 21 days interval

The number of roots, weight of roots, and herbage weight were collected. Roots were also qualified into small, medium and large roots by visual inspection. The data were tested by analysis of variance in RCBD. T-tests were run to further check and compare each irrigation schedule with the rainfed condition (no irrigation).

2.3 System evaluation

The crop yield, in relation to water use, and related costs of the irrigation system as well as the technology introduced was analyzed. Cost and return analysis, and pay-back period were determined to evaluate the systems' cost-benefit aspect.

3 Results and discussion

3.1 Establishment of Small-Scale Irrigation System (SSIS)

Shallow-tube wells (STW) irrigation system was established in the selected sites of San Marcelino and San Felipe Zambales; and Moncada, Tarlac. All of the sites have relatively shallow water table and thus, STWs were recommended to be installed in the selected sites. Some sites in San Felipe, Zambales (lowland) and Concepcion, Tarlac (lowland) had existing irrigation systems. Soils in Moncada, Tarlac were categorized under heavy soils. On the other hand, Zambales especially in lahar-laden areas of San Marcelino and San Felipe have light-textured soils. However, soil in rainfed lowland at San Felipe, Zambales are medium textured. Medium and heavy textured soils tend to form soil clods during tillage, while light textured soils are relatively loose upon tillage. With respect to the water discharge of the newly installed irrigation systems, discharge observed

from idle (minimum) to full position of engine had 3.68 to more than 16.0 liters per seconds (lps). Depending on the engine setting, the discharge also varies. Less than one to more than two hectares can be serviceable with the discharge of the STW (PNS/BAFS, 2017).

3.2 Evapotranspiration based on atmometer

Evapotranspiration (*ET*) based on atmometer is a "semi-direct" measurement of water consumption. The instrument has a canvass which mimics the vegetation surfaces (Figure 1). In this study, the atmometer has a digital logger which automatically records the water lost within the cropping period. Estimated daily evapotranspiration in San Felipe, Zambales recorded from February 4, 2021 to May 18, 2021 (Figure 1). It could be observed that the evapotranspiration increases at the middle stage of the crop (critical stage of tuber formation). The determined sweetpotato *ET* were the basis of irrigation in each of the treatment. The sweetpotato *ET* was approximately 389.59 mm for 104 days growth period. These observations were the basis in conducting the experiment on sweetpotato irrigation.

3.3 Atmometer-Based irrigation scheduling

The experiment was not fully implemented in the sites of San Marcelino, Zambales and Moncada, Tarlac. The unforeseen pandemic, has practically stopped the implementation of the project. During the lockdown, the experiment was left to the custody of the farmer cooperator, who was not yet equipped to undertake processes. When community quarantine was lowered, travel to sites were possible. Storage roots were harvested; however, the plants were already over matured. On the other hand, the experimental site established in Concepcion, Tarlac was unsuccessful. This was because the crop was established at the later part of dry season already. Thus, rainfall occurrences were already observed throughout the crop growth duration, which constantly saturated the soil.

For this experiment, the results taken from the experimental sites of San Felipe (lahar-laden and lowland) were gathered, and analyzed. The analysis of variance revealed that all the parameters considered in

evaluating each treatment was not significantly different. Thus, t-test was run to compare the control (rainfed or no irrigation) to other treatments.

3.3.1 Lahar-Laden condition

3.3.3.1 Total weight of storage roots

Table 1 shows the total weight of storage roots under lahar-laden condition. Results have shown that compared to control, irrigation in every 7 days and 14 days with the use of atmometer have significantly different total storage roots weight. These results suggest that every 7- and 14-days irrigation may outperform the crops under rainfed condition in lahar-laden condition, by about 25.1%-26.8%. The results of

this study were similar to what was observed in the study of Saqib et al. (2017) and Nedunchezhiyan et al. (2012), wherein storage root weight increase with irrigation frequency of shorter irrigation intervals. In this study, the difference in the total weight of storage roots can be attributed to the significant differences in the weight of large roots. T₁ and T₂ have heavier large roots compared to T₀. While there is increase of 10.5% yield in T₃ compared to T₀ which is not significant. The 21 days irrigation interval might have caused fluctuations in soil moisture, which affects yield (Gajanayake et al., 2014).

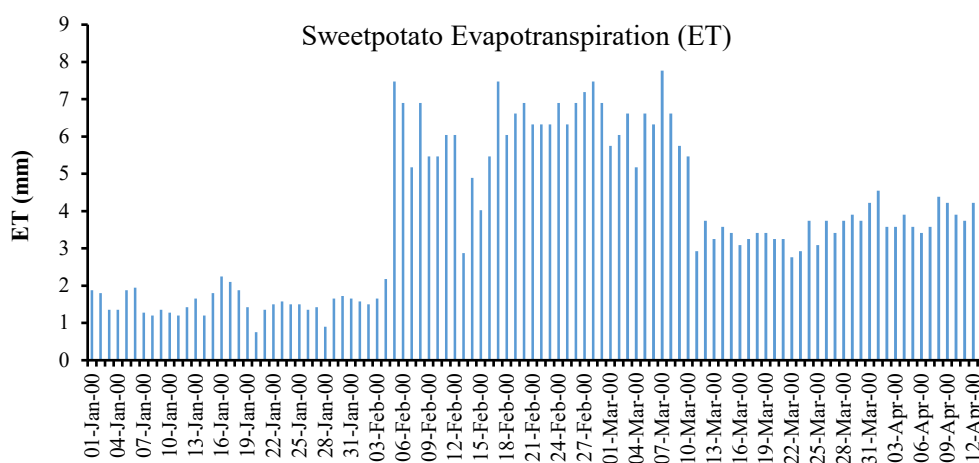


Figure 1 (left) Atmometer (right) Estimated evapotranspiration of sweetpotato in San Felipe, Zambales (From planting to harvesting)

Table 1 Total weight of storage roots under lahar-laden condition

Treatment	Number of roots per plant		
	Small	Medium	Large
T ₀ - Rainfed condition or no irrigation (control)	1.53	0.90	1.27
T ₁ - 7 days interval	0.87 ^{ns}	1.27 ^{ns}	1.43 *
T ₂ - 14 days interval	1.47 ^{ns}	0.73 ^{ns}	1.07 *
T ₃ - 21 days interval	1.20 ^{ns}	0.80 ^{ns}	1.30 ^{ns}

Note: Computed based on 30 samples, ns - not significant and * - significant compared to control at 0.05 level of significance. Sizes were visually observed.

3.3.3.2 Number of storage roots

Table 2 shows that there are significantly more large storage roots in T₁ and T₂ (7- and 14-days interval) compared to those under rainfed condition. This could also be an attributing factor as to why storage total weight of storage roots under T₁ and T₂ were significantly higher than in rainfed condition. Having more large roots implies larger diameter of roots which

increased with irrigation frequency (Nedunchezhiyan et al., 2012) and increased soil moisture level (Gajanayake et al., 2013). On the other hand, number of roots under T₃ (21 days interval) is not significantly different from those observed under no irrigation or rainfed condition. This could mean that irrigation timing could be critical in sweetpotato, as it affects storage root number and production efficiency

(Gajanayake et al., 2013). In addition, it is important to note that there is only one variety (VSP6) tested in this study, which other varieties could have responded differently (Lewthwaite and Triggs, 2012; Gajanayake et al., 2013).

Compared to control, the herbage weight is not significantly different in T₁ and T₃, but has significant difference in T₂ (Table 3). Herbage weight affected the storage root yield (Ahmed et al., 2012). Moreover, the

nutritional yield increased iron, zinc and beta carotene for orange fleshed sweetpotato (*Ipomoea batata* var. Bophelo) with more irrigation as a result of the study by Nyathi et al. (2019). On the other hand, the harvest index of each treatment is not significantly different compared to control. Harvest index observed were comparable to the study of Caruana and Cagasan (2020).

Table 2 Number of storage roots per plant under lahar-laden condition

Treatment	Total weight of storage roots (kg)	Difference in control (%)	Small (kg)	Medium (kg)	Large (kg)
T ₀ - Rainfed condition or no irrigation (control)	8.01	-	2.44	2.98	2.59
T ₁ - 7 days interval	13.87 *	26.8	2.97 ^{ns}	2.72 ^{ns}	8.19 *
T ₂ - 14 days interval	13.36 *	25.1	2.62 ^{ns}	3.59 ^{ns}	7.16 *
T ₃ - 21 days interval	9.89 ^{ns}	10.5	2.16 ^{ns}	2.52 ^{ns}	5.22 ^{ns}

Note: Computed based on 30 samples, ns - not significant and * - significant compared to control at 0.05 level of significance. Sizes were visually observed.

Table 3 Herbage weight (grams) under lahar-laden condition

Treatment	Average herbage weight (grams/plant)	Harvest index (Root weight/Herbage weight + Root weight)
T ₀ - Rainfed condition or no irrigation (control)	363.67 ^{ns}	0.4180
T ₁ - 7 days interval	404.67 ^{ns}	0.5157 ^{ns}
T ₂ - 14 days interval	500.83 *	0.4382 ^{ns}
T ₃ - 21 days interval	404.67 ^{ns}	0.4224 ^{ns}

Note: Computed based on 30 samples, ns - not significant and * - significant compared to control at 0.05 level of significance

Table 4 Average weight per storage roots (grams/root) under lahar-laden condition

Treatment	Small (grams/root)	Medium (grams/root)	Large (grams/root)
T ₀ - Rainfed condition or no irrigation (control)	50.83	119.20	258.50
T ₁ - 7 days interval	46.33 ^{ns}	129.29 ^{ns}	314.88 *
T ₂ - 14 days interval	51.27 ^{ns}	119.67 ^{ns}	298.13 ^{ns}
T ₃ - 21 days interval	39.18 *	114.32 ^{ns}	306.76 ^{ns}

Note: Computed based on 30 samples, ns - not significant and * - significant compared to control at 0.05 level of significance. Sizes were visually observed.

3.3.3.3 Weight per storage root.

Table 4 shows that the average weight per storage root under each irrigated treatments generally have no significant differences compared to those under rainfed condition. Exception is observed under T₁ in which large storage roots were significantly heavier compared to those of rainfed condition. On the other hand, small storage roots under T₃ is significantly

lighter compared to that of control. This may mean the level and timing of irrigation may have caused varying response in terms of quantity and quality of sweetpotato (Saqib et al., 2017; Nedunchezhiyan et al., 2012). Size is one descriptor of sweetpotato classification for marketing based on PNS/BAFS (2010), and this may influence marketability of the product (Duque et al., 2022; Arancibia et al., 2014).

With these results, evaluation based on water productivity and cost and return analysis are essential.

3.3.3.4 Water productivity

Water productivity as shown in Table 5 was analyzed in order to determine the water use efficiency of the atmometer irrigation scheduling. It can be observed that T₂ has relatively higher water productivity of 30.0 kg per cubic meter of water applied. This was followed by T₃ and T₁ with 26.62 and 26.55 kg per cubic meter, respectively. This means that every 14 days irrigation would result to a more efficient use of water resources, compared to other irrigation schedule. This is applicable to the lahar-laden area, especially in Zambales. The results on water productivity or water use efficiency of sweetpotato was found out to be increasing with increasing irrigation depth of up to 75%

Table 5 Water productivity at each irrigation schedule using atmometer

Treatment	T ₁ - 7 days interval	T ₂ - 14 days interval	T ₃ - 21 days interval
Total water applied (m ³)	1.97	1.87	1.65
Total yield (kg)	52.43	56.04	43.89
Water productivity (kg m. ⁻³)	26.55	30.00	26.62

Note: Reference data from lahar-laden condition in considering a 45 square meter area

3.3.3.5 System evaluation - cost and return analysis

If the cost of atmometer and shallow tube-well irrigation and pump set will not be considered, there would be possible increase in income by up to 23.51% – 37.28% (Table 6). However, if capital outlay from these pieces of equipment will be considered, there is a decrease in the net income within one cropping season. Such decrease would be due to initial investment of the irrigation equipment, as what is also observed by Hoque et al. (2016). In this study, the return of investment would reach about 31.25% to 67.16%. And the payback period would be 1.49 - 3.20 for one cropping season in a year, or 0.74 to 1.60 years for two cropping seasons. The 21 days irrigation interval may not be economical since is caused a decrease in net income compared to control. However, these values are estimation from the experimental area. Jabet et al. (2016) found that payback period decreases with increasing farm size. However, Mupaso et al. (2014) reported that irrigation technology may not be

evapotranspiration, from 16 to 20 kilograms per cubic meter (Delazari et al., 2018). The water productivity in this study was relatively higher compared to the aforementioned study probably because the plants did not experience water stress. On the other hand, Nedunchezhiyan et al. (2012) found that increased water supply had decreasing water use efficiency. It can be noted that their study had three, five, and seven irrigation frequency, which could be comparable to four and seven time irrigation in this study. Evaluation of resource use like water productivity is important in assessing technology adopted (Maisiri et al., 2005; Mergesa and Abdulahi, 2015 as cited by Mari et al. (2022). On the other hand, cost and return analysis would also be essential in determining socio-economic potential of the production (Lirag, 2019), which comes with the technology adopted.

the sole determinant of economic and financial viability. Resource use, socio-economic and environmental factors might also be essential in investing irrigation infrastructure (Khan et al., 2010).

3.3.2 Lowland condition

Under lowland condition, there is no significant differences in each irrigation treatment compared to control (data not shown). Similarly, the total weight of storage roots in each sizes total number of storage roots and the average weight per root also showed that there is no significant differences in the yield response of sweetpotato between each of the irrigation treatment and the control. The results of the experiment under this locations were different to those under lahar-laden condition. This is probably because rainfall occurred at the time of planting, thereby, water input may be sufficient enough for the whole growth of sweetpotato. Solis et al. (2014) as cited by Mari et al. (2022) reported that root yield is affected by soil moisture moisture status in the first 30 days after planting. It can

also be noted that the area planted have been practiced with organic farming for five years already. Water retention in the soil may have been improved due to addition of organic matter (Bhadha et al., 2017). It was however observed that weevil infestation occurred

under rainfed condition with 2.70% infestation. Cracked or dry soil may allow entry of weevils which affected storage roots (Kyereko et al., 2019). This situation may possibly cause poor quality tubers which influences profitability (Lirag, 2019).

Table 6 Cost and return analysis using atmometer-based irrigation scheduling

Treatment	T ₀ - Rainfed or no irrigation (control)	T ₁ - 7 days interval	T ₂ - 14 days interval	T ₃ - 21 days interval
Capital outlay <i>STW and atmometer</i>	-	180,000.00	180,000.00	180,000.00
Total production cost <i>materials and labor, inclusive of irrigation cost</i>	62,460.00	79,891.00	77,604.00	77,180.00
Gross income	210025.00	262150.00	280175.00	219425.00
Net income <i>without capital outlay</i>	147565.00	182258.81	202570.70	142244.20
Percent (%) increase in net income		23.51	37.28	-3.61
Net income <i>with capital outlay</i>	147565.00	92258.81	112570.70	52244.20
Return on investment (%) <i>without capital outlay</i>	236.26	228.13	261.03	184.30
Return on investment (%) <i>with capital outlay</i>		54.30	67.16	31.25
Payback period <i>one cropping season</i>		1.84	1.49	3.20
<i>two cropping seasons</i>		0.92	0.74	1.60

Note: Values are estimation based on a hectare of sweetpotato field. And atmometer could cover a 10-kilometer radius area and could service several farmers in a barangay. In this estimation 10 farmers.

4 Conclusion and recommendations

The shallow-tube well irrigation systems were established in both lahar-laden and rainfed lowland areas where the groundwater table is relatively shallow, and existing STWs are observed in the area. On the other hand, atmometer-based irrigation scheduling can be implemented in irrigating sweetpotato field especially in lahar-laden area. However, irrigation in lowland area may not be necessary especially if the field was irrigated during or right after transplanting. For validation of the results, pilot testing may be conducted to several farms with large production areas. Every 7- and 14-days irrigation are advised to be implemented. In lahar laden areas, irrigation is necessary for better plant survival. Furthermore, returns might also be improved. Other ways of irrigation management like use of drip or sprinkler may also be adopted. Assessment on the quality (including physico-chemical properties) of storage roots and other morphological properties of sweetpotato can also be looked into for future studies.

In addition, other varieties of sweetpotato can also be tested in terms of their response to irrigation.

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