Int. J. of GEOMATE, June, 2015, Vol. 8, No. 2 (Sl. No. 16), pp. 1293-1299
Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

# OPTIMIZING WATER UTILIZATION FROM A WINDPUMP-DRIP IRRIGATION SYSTEM FOR HIGH-VALUE CROP PRODUCTION

Nguyen Thanh Nghi[1], Helen F. Gavino[2] and Manuel Jose C. Regalado[3]
[1] Center for Agricultural Energy and Machinery, Nong Lam University - Ho Chi Minh City, Vietnam
[2]Central Luzon State University (CLSU), Philippines
[3]Philippine Rice Research Institute, Philippines

**ABSTRACT:** Although the windmill has been used for water pumping for many centuries, its development and application is limited due to high investment cost. Using windmill instead of diesel engine to drive a water pump reduces dependence on fossil fuel and mitigates greenhouse gas emissions. Thus, this study was conducted to optimize water use from a windpump coupled to a drip irrigation system. Performance of the windpump-drip irrigation system was also evaluated based on technical and economic feasibility. Water from the windmill combined with suction pump and piston pump was applied to vegetable crops in a 0.18-ha area through a drip irrigation system. Results showed that average daily discharge of the windpump was 9.2 $m^3$/day (24 hours) at 1.6 m/s daily wind speed. It varied from 0.7 at 1.6 m/s to 22.1 $m^3$/day at 2.7 m/s. Overall efficiency of the windmill-suction pump system varied from 23.1 to 6.1% corresponding to wind speed of 1.7 to 4.3 m/s, respectively. With total available water supply from the windpump and rainfall of 17.1 $m^3$/day, optimum service area of the system would be 0.81 ha, 0.95 ha, 0.65 ha, and 0.32 ha for tomato, eggplant, onion, and rice crops, respectively. Economic analysis showed that with three tomato crops per year in 0.81 ha, annual net income would be PhP38,960. Financial rate of return was 19% with a payback period of 9 years. Thus, the investment for the windpump-drip irrigation system would be feasible only for high-value crops

*Keywords: drip irrigation, high-value crops, optimized water utilization, windpump*

## 1. INTRODUCTION

Windmills have been used for pumping water (windpump) for many centuries, at least 3,000 years (Burton et al., 2001). In recent years, there has been a revival of interest in wind energy and attempts are underway all over the world to introduce cost-effective wind energy conversion systems for this renewable and environmentally benign energy source. Using windmill instead of diesel engine to drive a water pump reduces dependence on fossil fuel and provides opportunities for mitigating greenhouse gases. However, the development and application of windpump in the Philippines is limited due to its high investment cost. Thus, to be adapted widely, the windpump should be evaluated based on its technical and economic feasibility. In this study, the limited amount of water pumped from the windpump was used for high-value crop irrigation through a drip irrigation system because one of the drip system is water saving. This study was conducted to optimize water utilization from the windpump coupled to a drip irrigation system. The specific objectives were as follows: (1) to characterize the potential wind energy and water supply of the windpump; (2) to evaluate the performance of the windpump coupled to a drip irrigation system; (3) to optimize water utilization for irrigation and household use and validate the optimization scheme; and (4) to determine the technical and economic viability of the windpump-drip irrigation system

## 2. MATERIALS AND METHODS

Based on the proposed specific objectives, the study was implemented with the following steps: 1) Site description; 2) Description of the windpump-drip irrigation system; 3) Characterization of the potential wind energy and the water supply; 4) Test and evaluation of the windpump-drip system; 5) Optimization of the water utilization for irrigation; and 6) Technical and economic viability of using the windpump-drip irrigation system.

### 2.1 Site Description

The The study site is located at a rain-fed area in Barangay Magaspac, Gerona, Tarlac, which has two distinct seasons: wet season from May to October and dry season from November to April. It has a soil type of sandy loam with 69% of sand, 23.5% of silt, and 6.8% of clay. The sample of the aquifer has a low uniformity coefficient ($C_u$ = 2.44) and coefficient of curvature ($C_c$ = 0.73) which indicates that the sand is uniform. With less than 5% of fine particle, the well belongs to a well-graded sand. The water table depth at the shallow tubewell fluctuated from 0.39 m in wet season to 2.5 m in dry season.

### 2.2 Description of the Windpump-drip Irrigation System

The windpump-drip irrigation system (Fig. 1) has the following main components: windmill, water pump, water tank, and drip system.

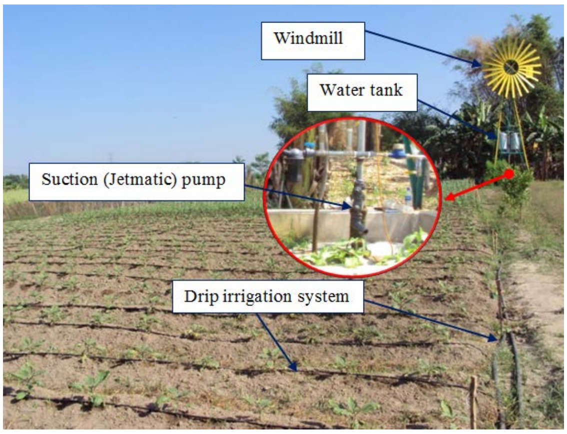


Figure 1 Windpump-drip irrigation system

The windmill was multi-bladed type with 24 blades. A 4.5 m diameter rotor was placed at 10 m height. Two (2) pumps were considered for the test: suction pump ("Jetmatic" pump) with 95 mm diameter and piston pump with 45 mm diameter. Two 0.7 $m^3$ water tanks were installed at 4.3 m height to temporarily store water for irrigation and household use.

The drip irrigation system was designed and installed for an area of 0.18 ha with 1.0 m lateral spacing and 0.3 m drip spacing (Agulto, 2011). Overall discharge of the system which consisted of five (5) manifolds was 6,000 $m^3$/hr. The mainline was PVC pipe with a diameter of 25.4 mm. 16 mm diameter drip line composed of low pressure drippers with discharge of 1.0 liter/hr.

### 2.3 Characterization of Potential Wind Energy and Water Supply

Potential wind energy at the study site was assessed using 5-year record of wind speed taken from CLSU-PAGASA Agromet station. Likewise, actual wind speed monitoring was also done at the study site from April to July 2012. Wind speed was measured at a height of 7 m using three cup-anemometer with accuracy of 0.1 m/s. The wind speed data at 7 m height was converted to values corresponding to the height of 10 m which is the height of the anemometer at the CLSU-PAGASA Agromet station. Probability density distribution of wind speed at both study site and CLSU-PGASA Agromet station was analyzed based on Weibull distribution, which is expressed by the following formula:

$$p\left(\frac{u}{U}\right) = k\Gamma\left(1+\frac{1}{k}\right)\left\{\frac{u}{U}\Gamma\left(1+\frac{1}{k}\right)\right\}^{k-1} e^{-\left\{\frac{u}{U}\Gamma\left(1+\frac{1}{k}\right)\right\}^{k}} \quad (1)$$

where: u = unsteady wind speed component
U = mean value of wind speed at 10-meter height
k = factor that determine the shape of the curve
$\Gamma\left(1+\frac{1}{k}\right)$ = the value of the Gamma function

The power that can be extracted from the wind is determined by the area of the rotor, and the speed of the wind. The following equation was used to calculate the power available from the wind (Burton et al., 2001, and Gourieres, 1982):

$$P_{wind} = \frac{1}{2}\rho A V^3 \quad (2)$$

where: $P_{wind}$ = wind power, kW
ρ = air density, kg/$m^3$
A = rotor area, $m^2$
V = wind speed at 10-meter height, m/s

Water supply from the windpump system was predicted using the functional relationship between daily wind speed and daily discharge of the pump. Total potential water supply included water supply from the windpump and rainfall. Fluctuation of total water supply, due to the fluctuating wind speed and rainfall, was a basis for making an action plan to optimize the use of water supply.

### 2.4 Test and Evaluation of the Windpump-drip System

In order to finally decide on the type of pump to be installed, two types of pump were tested: (1) suction pump and (2) piston pump. Standard test procedures as used by Molla et al. (1993) were followed to collect data. The parameters that were evaluated to compare the performance of the system were pump rod load, torque at the shaft of the rotor, power output, water pump power, and efficiency.

Simultaneously, the drip irrigation system coupled to the windpump was also evaluated. Data gathered during the test runs were wind speed, pump discharge, distribution uniformity, coefficient of uniformity, discharge of emitter, and water application rate. Functional relationship between wind speed and discharge of the windpump was determined to predict water supply based on wind speed data.

### 2.5 Optimization of the Water Utilization for Irrigation

The objective of this task was to optimize the water utilization for irrigation based on data of water supply. Optimization of the system about water utilization was conducted using linear programming (LP) as a tool. Objective function was to maximize net income per year (PhP/yr) subject to the constraints such as availability of water supply, area to be planted, water consumption of crop, and cost and price of crop production.

The objective function:

$$\text{Maximize } (\sum Yp_i*X_i*P_i*N_i - \sum Cp_i*X_i*N_i) \quad (3)$$

where: $Yp_i$ = potential yield of crop i, t/ha
$Xi_i$ = planted area of crop i, ha
$P_i$ = price of production of crop i, PhP/kg
$N_i$ = number of crop i per year
$Cp_i$ = cost of production of crop i, PhP/ha

Subject to the constraints of water demand of crop and available water supply which is described by the function:

$$\sum 10Wd_i * X_i * C_w \leq W_s$$

where: $Wd_i$ = water demand of crop i, mm/day
$X_i$ = as previously described
$W_s$ = available water supply, $m^3$/day
$C_w$ = wetted area ratio

In the objective function, $X_i$ is variable which changes to maximize net income per year with satisfaction of constraints of total water demand of planted crop equally or less than water supply. In this study, values of i range from one to four which stands for tomato, eggplant, onion, and rice, respectively.

### 2.6 Technical and Economic Viability of Using the System

Technical viability was evaluated based on performance of the system. Data were gathered during six months of the experiment based on its actual operating condition. Parameters used to determine technical viability include efficiency of rotor of the windmill, overall efficiency of windpump system, distribution uniformity and uniformity coefficient of the drip system.

Economic feasibility was evaluated based on total costs and total benefits derived from application and use of the system for irrigation. Economic variables used for evaluation include capital, maintenance, water cost, and yearly mortgage payment. Internal Rate of Return (IRR) was used for evaluation of economic feasibility. In addition, payback period and net present value were also computed and used as a condition for evaluating feasibility of investment on the system.

## 3. RESULTS AND DISCUSSION

### 3.1 Potential Wind Energy at the Study Site

Mean daily wind speed from April to July 2012 varied from 0.1 m/s to 2.7 m/s. Computed average daily wind speed was 1.6 m/s (Table 1). Wind speed varied from month to month, the highest in April (2.1 m/s) and the lowest (1.2 m/s) in May. Using Weibull distribution method, results showed that probability of wind speed at 2.2 m/s (cut-in wind speed) was from 32% to 35%. It means that the windpump functioned from 32 to 35% of the time at the study site. The highest probability density distribution at wind speed of 1.2 m/s was 62% and 68% for study site and CLSU-PAGASA Agromet station, respectively.

Table 1 Weibull parameters of mean daily wind speed from April to July 2012

| Parameter | Apr | May | Jun | Jul | Mean |
|---|---|---|---|---|---|
| Mean wind speed, m/s | 2.1 | 1.4 | 1.6 | 1.2 | 1.6 |
| Std., m/s | 1.16 | 1.27 | 1.29 | 1.08 | 1.20 |
| Weibull shape factor (k) | 1.87 | 1.13 | 1.24 | 1.15 | 1.35 |
| Gamma function (Γ) | 0.89 | 0.96 | 0.94 | 0.95 | 0.93 |

With the size of the windmill, the potential wind energy, shown in Figure 2, indicated that it ranges from 9.5 W at 1.0 m $s^{-1}$ to 171.2 W at 2.6 m/s.

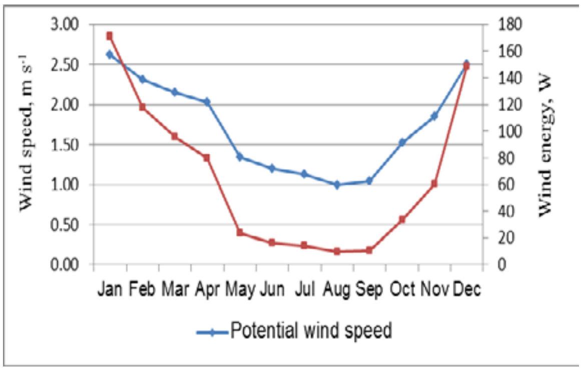


Figure 2 Potential wind speed and wind energy

### 3.2 Performance Evaluation of the Windpump System

Discharge comparison of the two pumps was shown in Figure 3. Discharge of suction pump was significantly higher than that of piston pump. During the experiment, with average daily wind speed of 1.6 m/s, discharge of suction pump was 9.2 $m^3$/day meanwhile it was 3.67 $m^3$/day for piston pump. Although average daily wind speed was lower than cut-in wind speed (2.2 m/s), wind speed was higher than that at 32% of the time based on result of Weibull distribution analysis.

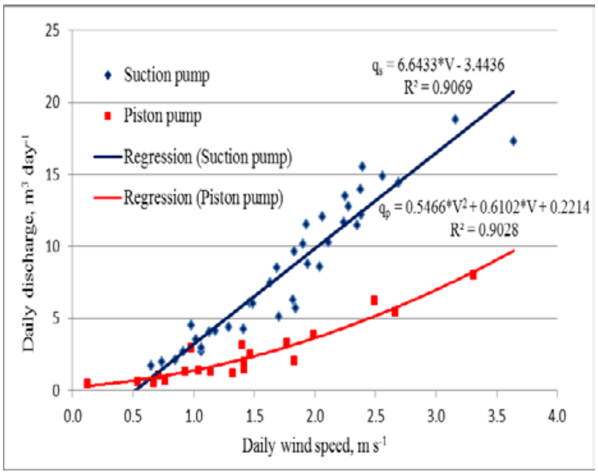


Figure 3 Discharge of the suction and piston pumps

Comparison of efficiency of rotor, windmill with suction pump, and windmill with piston pump is presented in Figure 4. Average efficiency of windmill was 20.8%, ranging from 10.1% at 4.1 m/s wind speed to 33.3% at 1.7 m/s wind speed. Efficiency of windmill-suction pump was higher than that of windmill-piston pump at all levels of wind speed. Average efficiencies of windmill-suction pump and windmill-piston pump was 13.0% and 6.7%, respectively.

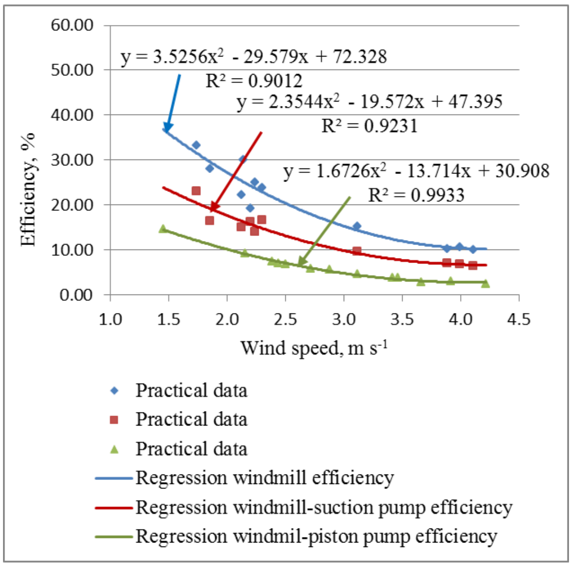


Figure 4 Efficiency of the system with different pumps

### 3.3 Potential Water Supply

The comparative test showed that efficiency and discharge of suction pump was higher than that of piston pump. Thus, functional relationship between wind speed and discharge of suction pump was used to determine available water supply from the windpump system. Daily discharge of the windpump system varies, ranging from 3.2 to 14.0 $m^3$/day, corresponding to daily wind speeds from 1.0 to 2.6 m/s. The highest is in January while the lowest is in August. Amount of water supply from rainfall was predicted based on 5-year recorded data from CLSU – PAGASA Agromet station and analyzed in frequency analysis. Total available water supply was determined by summing up amount of water from the windpump system and rainfall. This served as the basis in determining service area of the windpump coupled to a drip irrigation system in the optimization program.

### 3.4 Use of Water from the Windpump System

#### *3.4.1 Irrigation for Crop Production*

The main priority of water utilization from the windpump system is for irrigation of crops. In this study, tomato and eggplant crops were planted in an area of 558 $m^2$ and 1,242 $m^2$, respectively. Variety of tomato planted was D. Max with three-month life span and Morena for eggplant with six-month life span. Row spacing is 100 cm for both tomato and eggplant. Hill spacing is, however, 30 cm for tomato and 60 cm for eggplant. Daily amount of water applied for crops is shown in Figure 5.

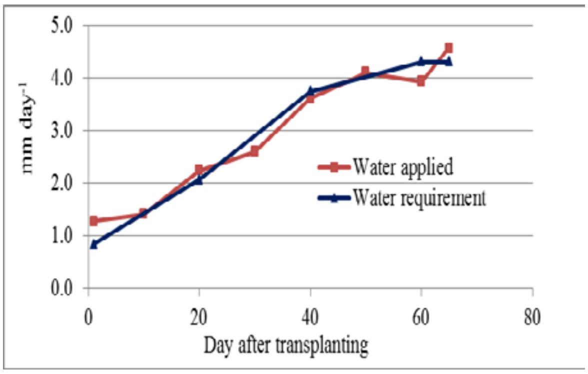


Figure 5 Water application for crops

Water applied for crops was increased from 1.3 mm/day to 4.6 mm/day because plants need more during their growing period (Stanley et al., 2004). As shown in the graph (Fig. 5), crops were applied with less amount of water than the requirement because discharge of the windpump decreased due to light wind during these days. Although average daily discharge of the system is 9.2 $m^3$/day which was not uniform by the time crops suffered from lack of water for some days. Thus, the system should be designed with water tank which can store water to supply crops for at least two days.

*3.4.2 Domestic Water Supply*

The windpump system was installed in an area where there was no domestic water supply system. Thus, the system also supplied water for household use besides irrigation purpose. According to actual data monitored from April to July, average daily amount of water used for one household with three members was 0.46 $m^3$/day (= 153 L/person/day). With average daily discharge of 9.2 $m^3$/day and based on water use of households in the area, the windpump system could supply enough water for 15 households (assuming four members per household).

### 3.5 Optimization of Water Utilization for Irrigation

*3.5.1 Optimization Scheme*

Water from the windpump were prioritized for irrigation, household, and storage in that order. Optimization scheme considered was for one (1) year so that the analysis would be on an annual scale. The basic assumption that in order to maximize the benefit in the area and the use of the windpump-drip system, off-season vegetable crops (tomato, eggplant, and onion) were selected especially when water availability was lowest and rice crop when there was enough rainfall to support the water requirement of the crop.

Result of optimization shows that net income of PhP291,615.72 per year is maximum value when mono-tomato crop is planted, with area of 0.81 hectare. At this point, peak water requirement of the crop is 17.1 $m^3$/day which satisfies the constraint of available water supply less than or equal to 17.1 $m^3$/day. Due to the variable total water supply and water requirement of crop, the transplanting schedule was determined to maximize the service area. Three tomato crops would be planted in March, July, and November. Amount of surplus water supply for the crop irrigated using the drip system, especially in rainy season, would be used for other crops or households based on the action plan.

*3.5.2 Validation of the Optimization Scheme*

The optimization scheme was validated by using the actual crop production data of tomato and eggplant crops, which were planted during experiment period, for optimization program. The data of water consumption, water cost, yield, price of production, and production cost were collected from the scale experimental model, 0.0558 hectare for tomato crop and 0.1242 hectare for eggplant crop. These data were converted to the equivalent area based on the optimizing result, 0.81 hectare for tomato crop and 0.95 hectare for eggplant.

Results show that maximum net income was met for mono-tomato crop. It is similar to result of optimization with the assumed data. However, net income was lower due to lower yield of tomato on off-season, from 11.0 to 7.54 t/ha. For the converted area, 0.81 hectare of tomato and 0.95 hectare for eggplant, (Table 2), daily water applied (16.2 $m^3$/day for tomato and 16.7 $m^3$/day for eggplant) was less than the total water supply from the windpump and rainfall (17.1 $m^3$/day). Thus, the constraint of available water supply is satisfied.

Table 2. Validation of optimization scheme.

| Parameter | Tomato | Eggplant |
|---|---|---|
| Area, ha | 0.81 | 0.95 |
| Number of crop/yr | 3 | 2 |
| Water applied, mm/day | 5.0 | 4.4 |
| Water applied, $m^3$/day | 16.2 | 16.7 |
| Labor and material cost, PhP/yr | 532,553 | 289,405 |
| Gross income, PhP | 709,069 | 401,724 |
| Net income, PhP | 176,515 | 112,318 |

*3.5.3 Action Plan based on the Results of Optimization*

Surplus water supply was computed from total water supply and water requirement of main crop which was irrigated using drip system. Amount of surplus water supply fluctuated in year. More surplus water supply was in rainy season, from May to October. In the action plan, four selected crops (rice, string bean, pechay, and tomato) would be planted aside from the area irrigated by drip system. The planting calendar, area and expected income for these crops were planned based on the amount of surplus water supply (Table 3). These crops will consume 70.1% of the amount of surplus water from the system while the rest (29.9%) will be used in household. The total net income from using the surplus water from the system is PhP61,009.68 per year. Besides net income from the crop, income from the total amount of water used for household (1,899.5 $m^3$) is PhP3,343.24 per year.

Table 3 Planting calendar and expected income

| Crop | Crop duration | Area, ha | Expected income, PhP |
|---|---|---|---|
| String bean | Feb. to Apr. | 0.18 | 7,848.00 |
| | Sep. to Nov. | 0.32 | 13,952.00 |
| Pechay | Apr. to May | 0.16 | 6,976.00 |
| Rice | May to Sep. | 0.26 | 9,422.85 |
| Tomato | Sep. to Dec. | 0.19 | 22,810.83 |
| Total | | | 61,009.68 |

### 3.6 Economic Analysis of Using the System

The initial investment cost includes costs of windpump and drip irrigation system. Fixed cost included the costs of depreciation, repair and maintenance, and interest costs based on amount of investment. Depreciation cost depended on the useful life of the system which was considered to be 20 years for windmill and tube-well, and 5 years for water pump and drip system. Interest rate was 8%. Variable cost including costs of labor and materials used for crop production were proportionate to hectarage (Maghirang, 2007).

Net income is PhP38,906.61 per year if tomato crop is planted on of 0.81 ha. Meanwhile, it is negative PhP40,120.69 per year if eggplant crop is planted on of 0.95 ha. Internal rate of return and payback period of the project for tomato crop were 18.6% and 9.4 years, respectively. Meanwhile, they were indeterminate for eggplant crop. Thus, the investment on the windpump-drip system was feasible for only high value crops, such as tomato crop, which produce high net income.

### 3.7 Technical Viability

The windmill has been well functioning during the observation period from March to August, 2012. The rotor could start to function at the cut-in wind speed of 2.2 m/s which matched with the design. However, the windmill does not have the cut-out wind speed at which the rotor does not face the wind direction. The drip irrigation system worked well with the distribution uniformity of 90.0% and coefficient of uniformity of 91.7% (Ngigi, 2008, and Priyanjith et al., 2002).

As result, maximum discharge of suction pump was 2.3 $m^3$/hr, corresponding to mean wind speed at 4.3 m/s. Meanwhile, maximum pumping rate of the piston pump was 0.93 $m^3$/hr at wind speed of 4.1 m/s. Average efficiency of the windmill is 20.8%. The highest efficiency is 33.3% at wind speed of 1.7 m/s and the lowest efficiency is 10.1% at 4.1 m/s wind speed. Compared to the high level of efficiency (30%) for the multi-blade windmill (Molla et al., 1993), this level of efficiency of the rotor is acceptable. Meanwhile, the overall efficiencies of the windmill-suction pump and the windmill-piston pump are 13.0% and 6.7%, respectively.

## 4. CONCLUSION

Compared to fossil fuel, wind is a “free” renewable energy and its use is environmentally-friendly. By using the windpump-drip irrigation system, water requirement of crops would be supplied without consuming fossil fuel. The total water supply from the windpump and rainfall varied in a year because of the fluctuating wind speed and rainfall. At the same level of wind speed, the discharge of the suction pump was higher than that of the piston pump because the former has bigger suction diameter than the latter. Thus, the efficiency of the suction pump combined with the windmill was higher than that of the piston pump. The investment on the windpump-drip irrigation system is feasible if high value crops, such as tomato, are selected.

## 5. RECOMMENDATIONS

Based on results of the study and observations made during the test period, recommendations for further study are as follows:

1. The tail vane structure of the windmill should be redesigned so that the rotor will skip strong wind. Observation showed that the system worked well with maximum rotor speed of 50 rpm.
2. Based on result of optimization, to store surplus water from irrigation for household use, system should be matched with water tank that has capacity of 4.5 $m^3$ corresponding to about 25 200-liter oil drums.
3. Economic evaluation of using the system should be continuously studied for other high value crops, such as chili and bitter gourd, both during wet and dry seasons.

## 6. ACKNOWLEDGEMENT

The authors would like to thank the Philippine Rice Research Institute, Department of Agriculture High Value Crops Development Program (DA HVCDP) and DA Regional Field Unit III for providing financial support for the study as a component of the DA-PhilRice project “Windmill-Pump Irrigation Technology Adoption for Improved Rainfed Agricultural Productivity and Profitability in Gerona, Tarlac.” The technical support of Engr. Elmer Bautista, Leo Moliñawe and James Bruno of the PhilRice Rice Engineering and Mechanization Division as well as the facilitation done by Ms. Maria Cristina Barcita, Budget Officer of the DA HVCDP for the conduct of the study at the Magaspac, Gerona project site are also gratefully acknowledged.

## 7. REFERENCES

[1] Agulto IC. 2011. Drip Irrigation System Design Procedure (lecture). Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines.

[2] Burton T, Sharpe D, Jenkins N, Bossanyi E. 2001. Wind Energy: Handbook. John Willey & Sons, Ltd., UK.

[3] Gourieres DL. 1982. Wind Power Plants: Theory

and Design. Oxford, England.

[4] Maghirang RG, Guevarra LD, Rodulfo G S. 2007. Vegetable Production Guide. University of the Philippines Los Baños, College, Laguna, Philippines.

[5] Molla S, Clark RN. 1993. Analysis Of Two Mechanical Wind Pumping Systems. Alternative Energy Institute, West Texas A&M University, Texas, USA.

[6] Ngigi S N. 2008. Technical Evaluation and Development of Low-head Drip Irrigation Systems in Kenya. Columbia University, Kenya.

[7] Priyanjith KJKT, Kuruppuarachchi DSP, Gunathilaka HAW. 2002. Field Evaluation of Irrigation System for Small Scale Banana (Musa) Orchards. Wayamba Universtyof Sri Lanka, Sri Lanka.

[9] Stanley C D, Clark GA. 2004. Water Requirement for Drip-irrigated Tomato Production in Southwest Florida. University of Florida, USA.

*Int. J. of GEOMATE, June, 2015, Vol. 8, No. 2 (Sl. No. 16), pp. 1293-1299.*
MS No. 4118 received on June 30, 2014 and reviewed under GEOMATE publication policies.


**Corresponding Author: Nguyen Thanh Nghi**