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Nutrient Uptake and Fiber Yield of Abaca (*Musa textilis* var. *Laylay*) as Affected by Shade, Irrigation and Fertilizer Application

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ABSTRACT

Abaca, being a shallow rooted plant and a gross feeder, is able to exploit a limited zone soil. Hence, a careful evaluation of its nutrient uptake is needed, particularly under reduced light condition, irrigation, and NPK fertilization. These field trials were performed to investigate the effect of different shade conditions, irrigation, and fertilizer application on NPK plant uptake and fiber yield of abaca. Light infiltration was reduced by 30%, 40%, and 50% of full sunlight using polypropylene shade nets. Irrigation was applied at a rate of 5 liters plant^{-1} application^{-1} day^{-1}. Placement application of N, P_2O_5, K_2O using complete fertilizer was done at 14 grams plant^{-1} quarter^{-1} for the first six months and was increased to 40 grams plant^{-1} quarter^{-1} for the next six months after planting. Results showed that shade ($p \leq 0.01$) and irrigation-fertilization ($p \leq 0.05$) significantly influenced NPK plant uptake, root and leaf uptake rates of abaca from seedling stage until flagleaf stage. The amount of NPK absorbed was proportional to the amount of growth made as influenced by shade and irrigation-fertilization at different stages of plant growth. The abaca grown in 0% shade was negatively affected by high radiation causing photoinhibition and photooxidative damage of the crop at seedling and early vegetative stages that significantly affected NPK uptake rates and fiber yield. The combination of irrigation and fertilization could further enhance fiber yield to as much as 41% but this was not enough to offset the effects of shade on the growth performance and NPK plant uptake of abaca which significantly ($p<0.01$) increased fiber yield to as much as 165%.

Key Words: nutrient uptake rates, photoinhibition, photooxidative damage, fiber crop, shade, irrigation-fertilization

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INTRODUCTION

Abaca (*Musa textilis* Née), closely related to edible banana, is grown primarily for its fibers which are utilized by the pulp, cordage and fibercraft industries. The Philippines supplied 84% of the global production which is equivalent to an average fiber production of 68,982 tons yr^{-1} from 1999 to 2008, where the Eastern Visayas region (islands of Leyte, Biliran, Samar and Pana-on) was the major abaca producer that supplied the bulk of the product contributing an annual average of 25,517 tons or 38.5% of the total production (FIDA, 2010). The average annual fiber yield in Eastern Visayas is 913 kg ha^{-1}, which is above the national annual average of 610 kg ha^{-1} (PCARRD, 2003) but far behind the potential yield of 2,000 kg of fiber ha^{-1} (Armecin *et al.*, 2011). It is evident that a lot more is still to be done to improve the production level of abaca.

In Leyte Island, abaca-based agroecosystems are concentrated in mountainous areas where abaca is usually planted in the shade beneath tall trees or coconuts (Armecin and Gabon, 2008). Intensive abaca cultivation in these areas has been done for years without applying any fertilizer as supplement to the crop (Lacuna-Richman, 2002). Armecin *et al.* (2011) reported that abaca biomass ranged from 0.8 tons ha^{-1} to 33.2 tons ha^{-1} while Sinon *et al.* (2011) estimated that 2% of the total biomass is removed from the production area during harvest in the form of fiber. Furthermore, Halos (2008) cited that 280 kg N, 30 kg P, and 517 kg K will be lost per 100 tons of fresh abaca biomass harvested, which could be considered as potential risk of nutrient depletion due to crop removal. This would lead to the depletion of the nutrient reserve in the soil that would cause significant reduction of the fiber yield if not properly managed and understood.

Nitrogen (N), phosphorus (P), and potassium (K) are essential macronutrients which play an important role in plant development. In abaca-based agroecosystems, NPK limitations strongly affect competition between plants species, as species vary in their ability to cope with low NPK availability in the soil. Armecin *et al.* (2011) reported that in coconut-abaca cropping system, abaca growth was suppressed not only due to exhaustive belowground (nutrient) but also aboveground (light) competition. Thus, in integrating abaca under multi-strata production systems, one has to consider radiation interception and the efficiency with which radiation energy is used to produce photosynthates since this plays a crucial role in the growth of tree-crop stands (Balster and Marshall, 2000; Will *et al.*, 2001; Allen *et al.*, 2004; Kemanian *et al.*, 2004). Likewise, if shading is viewed as a way to cool the leaves and reduce the vapour pressure deficit, differences in surface air temperature among shaded abaca plants with reference to abaca grown in full sunlight is another factor that might affect nutrient uptake (Turner and Lahav, 1985).

Abaca, being a shallow rooted plant and a gross feeder, is able to exploit a limited zone soil, but a careful evaluation of its nutrient uptake is needed, particularly under reduced light condition, irrigation, and NPK fertilization. Hence, these field trials were performed to investigate the effect of different shade conditions, irrigation, and fertilizer application on NPK plant uptake and fiber yield of abaca. Likewise, the study aimed to give a broad representation on the pattern of NPK root and leaf uptake rates at various stages of crop growth.

MATERIALS AND METHODS

Biophysical and climatic conditions of the study site

The study site was located in an abaca farmer's area in Barangay Catmon, Ormoc City, Philippines 11^0 04' 52.4" N and 124^0 34' 29.5" E on an alluvial terrace with an elevation of 44.5 meters above mean sea level and a slope of 0-3%. The site was previously planted to sugarcane (*Saccharum officinarum*) and then left under fallow for ten years. Constant grazing caused grasses to dominate the vegetation structure of the site. The soil is classified a Haplic Alisol (IUSS Working Group WRB, 2006), whose clay fraction is dominated by kaolinite and halloysite and contains significant amounts of goethite and hematite with more than 60% P retention capacity (Asio, 1996; Asio *et al.*, 1998).

The pH values for the 0-30 cm and 30-60 cm soil depths were 5.16 and 5.14, respectively. These pH values indicate strongly acid conditions (Soil Conservation Society of America, 1982). Bulk density ranged from 1.06 g cm^{-3} to 1.11 g cm^{-3} with very minor variations in the values indicating high porosity of the soil. Furthermore, results revealed that there were no significant differences in the total N between different treatments and soil depths. Available P was much higher in the top soil (0-30 cm) than in the sub-surface soil (30-60 cm).

Climatic data were collected from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) weather station at the Visayas State University. Average daily air temperature was between 27°C and 28°C while average annual temperature was 27.3°C during the time of the experiment which is within the range of the long-term average of Leyte. Incident rainfall was 1018 mm, well below the average.

Propagation of planting materials at the nursery

Tissue cultured abaca plantlet was individually potted in a soil-filled polyethylene bag (10cm x 15cm) and placed in sealed recovery chamber for one month until new leaves (at most 3) had developed. The chamber was partially opened (1 section week^{-1}) one month after potting to acclimatize the seedlings from the outside climatic conditions. Seedlings were watered every second day. No fertilizer was applied to guarantee uniform nutritional status of the planting material prior to out-planting. Due to the rapid growth of the seedlings, re-bagging was done (15cm x 25cm polyethylene bags) two months after potting to provide more space for root development. The seedlings were hauled to the temporary nursery constructed at the middle of the study site a month after re-bagging. The process allows the planting materials to adjust to on-site climatic condition prior to out-planting. This was done for another three months where watering was minimized and light infiltration was increased (by step-wise removing the shade materials) every week. During this period, the seedlings were evaluated and classified according to plant height, girth and number of leaves. These data were basis for selecting and distributing the seedlings to treatment plots to guarantee uniform morphological characteristics of planting material.

Experimental design

The design of the experiment was a 4x4 factorial combination of shade and irrigation-fertilizer application. Tissue-cultured abaca seedlings (var. Laylay) were planted in a split-plot randomized block design with four replications. The dimension of each main plot (shade) was 30m x 30m. Since there were four sub-plots (i.e., irrigation and fertilizer application), a total of 64 plots were established with a dimension of 12.5m x12.5m plot^{-1}. The planting distance used was 2.5m x 2.5m (square method) that corresponded to a total of 36 abaca seedlings plot^{-1}

Shading, irrigation, fertilizer application and crop management

Three different shade nets made of polypropylene (Bayview Fishing Supply and General Merchandise, Manila, Philippines) were used: B-double (4mm x 5mm mesh size), A-double (3.5mm x 2.5mm mesh size) and dry nets (2mm x 2mm mesh size) that permitted 70%, 60%, and 50% of full sunlight, respectively. The nets were installed at an initial height of 3.66 meters and were increased to 6 meters seven months after planting (MAP).

A drip irrigation system was improvized by installing 288 20-litre water containers. One container was properly leveled and installed at the center of four abaca plants to attain uniform distribution of water among plants. Since there was no available information on the evaporative demand of the crop in the field, irrigation was applied during the dry period when soil moisture was below 26% as determined using the gravimetric method. During the first two months after planting (MAP), the abaca plants were irrigated at a rate of 5 liters per plant per application per day. The frequency of irrigation was applied two times at seedling stage (1-3 MAP), three times at the early vegetative stage (4-6 MAP), four times at the late vegetative stage (7-9 MAP), and five times at flagleaf stage (10-12 MAP). The reason for increasing the frequency of watering was due to an increase of emergence of new suckers.

A fertilizer recommended rate of 43 kg N, P_2O_5 and K_2O per hectare for each of the fertilized plots using complete (14-14-14) fertilizer was used. This was applied in five different periods of crop growth. At planting, a blanket application of 5 grams N, P_2O_5 and K_2O per plant was done. At three and six months after planting, a placement application of 10 grams per plant was applied. This was increased to 28 grams per plant at nine and twelve months after planting. During the conduct of the study, there was no available and published data on the critical nutritional level of abaca plant; hence, the National Abaca Research Center and Fiber Development Authority recommendations were used. Monthly weeding was done when the surrounding vegetation of the plantation threatened to interfere with the growth of the abaca plants. Suckers were pruned bimonthly starting one MAP until six MAP to control overproduction which could eventually affect the physiological performance of the mother (sample) plant.

Destructive harvesting and preparation of plant tissue samples

Destructive harvesting was conducted every three months. Four sample plants per treatment per replication were excavated. Biomass samples were separated into plant organs (i.e., roots, corm, leaf sheath or pseudo stem, leaf stalks, leaves) and fresh weight was determined for each plant organ. Tissue samples were collected per organ and were decontaminated with tap water to remove all soil particles and other extraneous materials and finally washed with distilled water. Samples were oven-dried at 60 ^{0}C for 24 hours or until constant dry weight was reached.

Preparation of ash solution and determination of NPK concentrations

The dried samples were ground in a Wiley mill into a particle size of less than 1 mm (20 mesh screen). One gram of thoroughly mixed ground tissue samples of different plant organs were incinerated in a muffle furnace for about 8 hours at 550 °C temperature. Ash samples were dissolved in a 1.0 N hydrochloric acid solution and filtered through a Whatman #42 filter paper into a volumetric flask. The ash solutions produced per plant organ were used to quantify K using an atomic absorption spectrophotometer. P concentration was determined colorimetrically using ascorbic acid as reducing reagent. This was done at the Central Analytical Laboratory Services, PhilRootcrops Complex, Visayas State University. On the other hand, 0.2 g of thoroughly mixed ground tissue samples of different plant organs were prepared for total N determination. These were digested and quantified using a micro-Kjeldahl distilling apparatus at the Soil and Plant Tissue Laboratory Services, Department of Agronomy and Soil Science, Visayas State University.

The effects of treatments upon the nutrient plant uptake (N_{uptake}) were computed using the formula (Pearcy *et al., 1989*):

$$\mathbf{N_{uptake}} = \frac{(M_2 - M_1)}{(W_{p2} - W_{p1})} \qquad (1)$$

Where: M_1 = weight of nutrient in the plant at harvest 1 (mg)
M_2= weight of nutrient in the plant at harvest 2 (mg)
W_{p1}= dry weight of plant at harvest 1 (g)
W_{p2}= dry weight of plant at harvest 2 (g)

While, the root and leaf uptake rates were calculated using the formula (*Turner* and *Lahav*, 1986) as follows:

$$\mathbf{R_r} = \frac{(\ln W_{r2} - \ln W_{r1})}{(t_2 - t_1)} \times \frac{(M_2 - M_1)}{(W_{r2} - W_{r1})} \qquad (2)$$

$$\mathbf{R_l} = \frac{(\ln W_{l2} - \ln W_{l1})}{(t_2 - t_1)} \times \frac{(M_2 - M_1)}{(W_{l2} - W_{l1})} \qquad (3)$$

Where: R_r = root mean uptake over the period during destructive sampling (mg $g^{-1}_{\text{root dry matter}}$ d^{-1})
R_l = leaf mean uptake over the period during destructive sampling (mg $g^{-1}_{\text{leaves dry matter}}$ d^{-1})
W_{r1}= dry weight of roots at time t_1 (g)
W_{r2}= dry weight of roots at time t_2 (g)
W_{l1}= dry weight of leaves at time t_1 (g)
W_{l2} = dry weight of leaves at time t_2 (g)
M_1= weight of nutrient in the plant at time t_1 (mg)
M_2= weight of nutrient in the plant at time t_2 (mg)

Statistical analyses

All data were tested for normality and homogeneity using PROC Univariate of Statistical Analysis System version 9.1 (SAS, 2003). PROC GLM procedure was initially performed to check for effects of shade and irrigation-fertilizer application and their interactions on abaca plant nutrient uptake, root and leaf uptake rate. The final models for each response variable were analyzed but including only those significant main factors and two-factor interaction effects for each stage of growth. Duncan multiple range test (DMRT) and least squares differences (LSD) were carried out to compare treatment means of independent variables with significant variations at probability <0.05.

RESULTS

Soil characteristics and nutrient status

The results of the soil profile examination revealed that both soil profiles were characterized by Ap-Bw-Bt_1-Bt_2 horizon sequence to a depth of 1 meter. This indicates an accumulation of silicate clay that has formed in the horizon or has moved into it by illuviation or either both. Soil textures ranged from clay loam on the surface to silty clay loam in the subsoil. The soil structure was strong to moderate coarse granular structure in the A horizon and a strong to moderate sub-angular blocky structure in the lower horizon. Ants, millipedes and centipedes were observed in the surface horizon and earthworms, adult and larvae termites were noted in the subsurface horizon of both profiles during the examination. High intensity root development occurred in the upper 0-20 cm soil depth of both profiles evaluated. Bulk density ranged from 1.05 g cm^{-3} to 1.12 g cm^{-3} with very minor variations in the values indicating high porosity of the soil.

Table 1 presents the average values of selected soil chemical properties of the study site. The pH values for the 0-30 cm and 30-60 cm soil depths were 5.23 and 5.14, respectively, indicating strong acid condition (Soil Conservation Society of America, 1982). There was very little variation in the pH values among main treatments suggesting no effect of the treatments on the soil property. Furthermore, results revealed that there were no significant differences in the total N between different treatments and soil depths. Available P was much higher in the surface (0-30 cm) soil than in the sub-surface (30-60 cm) while exchangeable K was generally much lower in the surface than in the sub-surface horizon.

Table 1. Mean values of selected soil properties for the 0-30 cm and 30-60 cm soil depths

Soil Properties	**Soil Depth (cm)**	
	0-30	**30-60**
pH (KCl)	5.16±0.39	5.14±0.04
Organic matter (%)	2.83±0.23	1.32±0.03
Total N (g kg^{-1})	1.53±0.03	1.05±0.04
Available P (mg kg^{-1})	30.67±2.72	4.17±0.97
Exchangeable K ($cmol_c$ kg^{-1})	0.52±0.04	0.55±0.04
Bulk density (g cm^{-3})	1.11±0.00	1.06±0.01

NPK plant uptake

Effects of shade on NPK plant uptake

Statistical analysis results showed that shade significantly influenced ($p \leq 0.01$) NPK uptake of abaca from seedling stage until flagleaf stage (Table 2). Analysis of variance further revealed that the amount of NPK absorbed was influenced by the amount of growth made during the different developmental phases of the crop. This was strongly substantiated by the results obtained from morphological (i.e., plant height and base girth) and physiological (i.e., dry matter) measurements. Data showed that abaca planted under shade treatments were consistently taller, bigger, and produced higher biomass compared to plants grown in full sunlight (0% shade) which were usually shorter, smaller and produced lower biomass from seedling stage to flagleaf stage. However, the link between the dry matter production and nutrient uptake significantly differed from one element to another as the plant started to develop from seedling stage until harvest (flagleaf stage).

Table 2. NPK plant uptake (mg $g^{-1}_{\text{dry matter}}$) at different developmental stages of abaca as affected by shade across irrigation (I)-fertilization (F) treatments

Nutrients	**Shade Treatments**	**Stages of Plant Growth**			
		Seedling	Early vegetative	Late vegetative	Flagleaf
Nitrogen	0% shade (control)	5.42 ± 0.70^{c}	8.99 ± 0.83^{b}	7.55 ± 0.94^{a}	2.26 ± 1.88^{c}
	30% shade	7.86 ± 0.70^{b}	11.52 ± 0.83^{ab}	3.47 ± 0.94^{b}	4.95 ± 1.88^{bc}
	40% shade	7.73 ± 0.70^{b}	13.84 ± 0.83^{a}	1.11 ± 0.94^{b}	14.75 ± 1.88^{a}
	50% shade	10.55 ± 0.70^{a}	12.79 ± 0.83^{a}	7.73 ± 0.94^{a}	7.42 ± 1.88^{b}
Phosphorus	0% shade (control)	1.54 ± 0.05^{b}	2.12 ± 0.10^{c}	1.52 ± 0.16^{a}	0.41 ± 0.31^{c}
	30% shade	1.88 ± 0.05^{a}	2.09 ± 0.10^{c}	1.28 ± 0.16^{ab}	1.54 ± 0.31^{b}
	40% shade	1.81 ± 0.05^{a}	2.58 ± 0.10^{b}	0.63 ± 0.16^{c}	2.01 ± 0.31^{b}
	50% shade	1.93 ± 0.05^{a}	2.86 ± 0.10^{a}	0.84 ± 0.16^{bc}	3.16 ± 0.31^{a}
Potassium	0% shade (control)	12.11 ± 1.18^{c}	29.98 ± 3.03^{a}	46.56 ± 3.38^{a}	3.98 ± 2.64^{bc}
	30% shade	19.07 ± 1.18^{b}	22.03 ± 3.03^{ab}	46.90 ± 3.38^{a}	5.56 ± 2.64^{a}
	40% shade	28.55 ± 1.18^{a}	17.09 ± 3.03^{b}	51.77 ± 3.38^{a}	3.92 ± 2.64^{c}
	50% shade	21.87 ± 1.18^{b}	3.23 ± 3.03^{c}	48.51 ± 3.38^{a}	4.87 ± 2.64^{ab}

Note: least square means in each cell within the column of a specific stage of plant growth with different letter superscripts (a-c) are significantly different at $p<0.05$, n=16

As can be seen in Table 2, K uptake of abaca planted in 40% and 50% shade considerably decreased during the early vegetative stage. This was due to the strong wind (typhoon) that toppled down most of the sample plants grown in 40% and 50% shade. The data obtained from morphological measurements revealed that abaca planted in 40% (158.18±7.73 cm) and 50% (186.96±7.73 cm) shade were notably taller compared to those grown in 30% (155.69±7.73 cm) and 0% (112.19±7.73 cm) shade. Hence, the plants were susceptible to lodging which significantly damaged the roots and leaves of the crop during the typhoon that occurred towards the end of the seedling stage (June 20, 2008). This drastically reduced K plant uptake particularly on sample plants grown in 50% shade at early vegetative stage.

Effects of irrigation-fertilization on NPK plant uptake

Fertilizer application significantly influenced ($p \leq 0.05$) N and P uptake of abaca during the early and late vegetative stages of plant growth. Meanwhile, NPK fertilization positively affected ($p \leq 0.01$) K uptake during the seedling and late vegetative stages. Analysis of variance showed that supplemental irrigation had no significant influence on NPK uptake (Table 3). This was probably due to the fact that the incident rainfall during the period of the experiment was sufficient for the crop growth and development. However, the result could behave differently during long drought periods like El Niño or in areas where water is a major problem.

Table 3. NPK plant uptake (mg $g_{\text{dry matter}}$) at different developmental stages of abaca as affected by irrigation (I)-fertilization (F) across shade treatments

Nutrients	**Irrigation-Fertilization Treatments**	**Stages of Plant Growth**			
		Seedling	Early vegetative	Late vegetative	Flagleaf
Nitrogen	Without I and F (control)	6.69 ± 0.70^{a}	10.16 ± 0.83^{a}	2.81 ± 0.94^{b}	8.34 ± 1.88^{a}
	Without I, with F	8.66 ± 0.70^{a}	12.85 ± 0.83^{a}	4.79 ± 0.94^{ab}	8.65 ± 1.88^{a}
	With I, without F	6.94 ± 0.70^{a}	11.04 ± 0.83^{a}	6.47 ± 0.94^{a}	4.74 ± 1.88^{a}
	With I and F	9.28 ± 0.70^{a}	12.95 ± 0.83^{a}	5.79 ± 0.94^{ab}	7.64 ± 1.88^{a}
Phosphorus	Without I and F (control)	2.00 ± 0.05^{a}	2.08 ± 0.10^{c}	1.10 ± 0.16^{a}	1.94 ± 0.31^{a}
	Without I, with F	1.60 ± 0.05^{c}	2.31 ± 0.10^{bc}	1.11 ± 0.16^{a}	1.22 ± 0.31^{a}
	With I, without F	1.80 ± 0.05^{b}	2.71 ± 0.10^{a}	0.93 ± 0.16^{a}	1.69 ± 0.31^{a}
	With I and F	1.77 ± 0.05^{b}	2.54 ± 0.10^{ab}	1.14 ± 0.16^{a}	2.26 ± 0.31^{a}
Potassium	Without I and F (control)	17.43 ± 1.18^{b}	19.89 ± 3.03^{a}	44.42 ± 3.38^{a}	5.98 ± 2.64^{a}
	Without I, with F	20.84 ± 1.18^{b}	12.50 ± 3.03^{a}	47.07 ± 3.38^{a}	3.08 ± 2.64^{a}
	With I, without F	18.07 ± 1.18^{b}	21.46 ± 3.03^{a}	48.80 ± 3.38^{a}	3.44 ± 2.64^{a}
	With I and F	25.26 ± 1.18^{a}	18.47 ± 3.03^{a}	53.45 ± 3.38^{a}	1.99 ± 2.64^{a}

Note: least square means in each cell within the column of a specific stage of plant growth with different letter superscripts (a-c) are significantly different at $p<0.05$, n=16

It is worth mentioning that sample plants treated with NPK fertilizer and/or combination of irrigation-fertilization significantly and positively enhanced plant height. The abaca plants grown in plots with fertilizer application (158.81±7.73 cm) and with combination of irrigation-fertilization (170.99±7.73 cm) were considerably taller compared to those plants without irrigation and fertilizer application (133.05±7.73 cm) at seedling stage. For this reason, most of the abaca plants in fertilized and irrigated-fertilized plots were toppled down during the typhoon. Similarly, this significantly affected K plant uptake during the early vegetative stage.

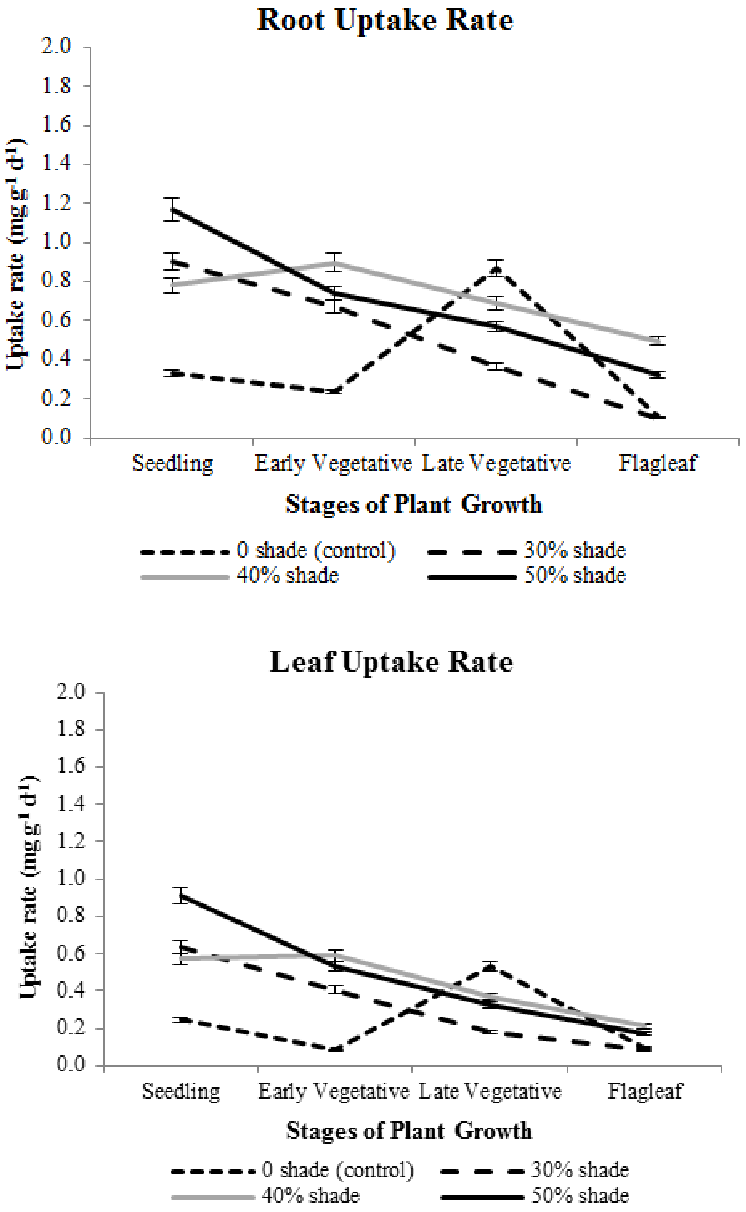

Fig. 1. Nitrogen root and leaf uptake rates of abaca (mg $g^{-1}_{\text{dry matter}}$ d^{-1}) at different developmental stages as affected by shade across irrigation-fertilization treatments

NPK root and leaf uptake rates

Effects of shade on N root and leaf uptake rates

Figure 1 shows that shade significantly ($p \leq 0.01$) influenced N root and leaf uptake rates of abaca as the crop started to develop from seedling to flagleaf stage. The N root and leaf uptake rates decreased as the plant developmental stages evolved independent of the effects of shade.

Furthermore, N root and leaf uptake rates were affected by high radiation that was evident on abaca plants grown in 0% shade. It was observed that the leaves got sunburned (photooxidative damage) at the seedling stage that reduced the number of functional leaves per plant at the early vegetative stage. This significantly influenced the N root (probability=0.0130) and leaf (probability=0.0012) uptake rate of the plant at the aforementioned stage of crop growth.

At late vegetative stage, abaca plants grown in full sunlight (0% shade) were able to recover and tended to improve both N root and leaf uptake rates. This has changed the usual pattern of N root and leaf uptake rates of the crop. However, the increase in N uptake (Table 2) was not enough to exceed or even equal the productivity (i.e., fiber yield) of abaca grown in the 50% shade treatment (Table 4).

Effects of irrigation-fertilization on N root and leaf uptake rates

As expected, the application of NPK fertilizer considerably improved ($p \leq 0.05$) N root and leaf uptake rates of abaca. This was evident during the seedling and early vegetative stages of plant growth (Figure 2). Analysis of variance showed that irrigation had no significant influence on N root and leaf uptake rates.

As can be seen in Figures 1 and 2, the pattern of N root and leaf uptake rates among abaca planted in shade treatments were similar to the sample plants grown under irrigation and fertilizer application treatments. This indicates that N concentration in both roots and leaves of the crop decreases as the plant grows and eventually reached its maturity.

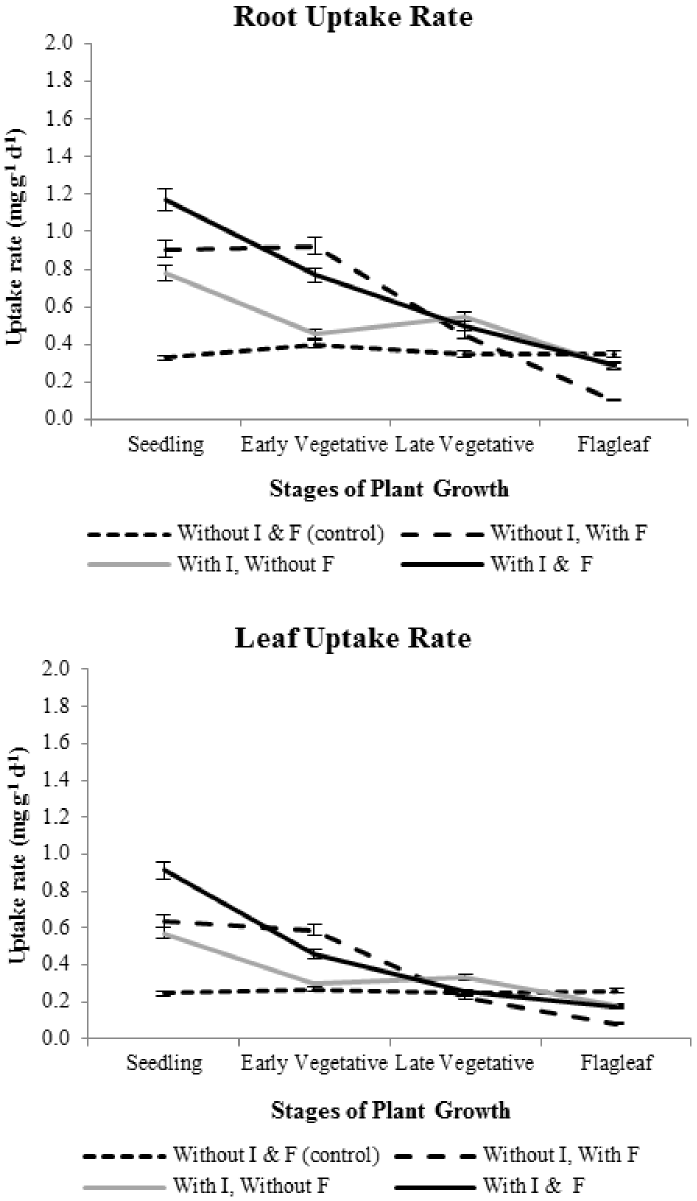

Fig. 2. Nitrogen root and leaf uptake rates of abaca (mg $g^{-1}_{dry\ matter}$ d^{-1}) at different developmental stages as affected by irrigation-fertilization across shade treatments

Effects of shade on P root and leaf uptake rates

Statistical analysis results showed that reducing light availability through shading had totally affected ($p \leq 0.01$) P root and leaf uptake rates of abaca at different developmental stages of the crop (Figure 3). The P root and leaf uptake rates in response to shade typically shows similar trend to what was observed on N root and leaf uptake rates, where both uptake rates decreases as the plant developmental stage progresses.

However, the usual pattern on P root and leaf uptake rates observed among sample plants grown under the shade treatments changed at late vegetative stage on abaca plants grown in 0% shade or full sunlight. This was due to the impact of high radiation on the leaves that negatively affected the P leaf uptake rate at seedling stage (probability=0.0001) and early vegetative (probability=0.0203) stage. Both P root (probability=0.0001) and leaf uptake rates were negatively affected at seedling stage due to photoinhibition. The affected plants fully recovered at early vegetative stage with an optimum response curve (P root and leaf uptake rate) at late vegetative stage. The significant increase in P root and leaf uptake rates was highly correlated to the amount of growth made at those particular developmental stages of the crop.

Effects of irrigation-fertilization on P root and leaf uptake rates

Analysis of variance results showed that irrigation and fertilizer application had nearly no effect on P root and leaf uptake rates of abaca, except during the flagleaf stage, which could be attributed to resorption or retranslocation of mobile nutrients (i.e., NPK) available to subsequent generation of suckers. As expected, high amount of P root and leaf uptake rates were recorded in fertilized abaca plants compared to those without NPK fertilization.

Furthermore, Figure 4 shows that irrigation and fertilizer application did not change the usual trend of P root and leaf uptake rates. The pattern of P root and leaf uptake rates on irrigation-fertilization treatments was similar to that recorded in shade treatments.

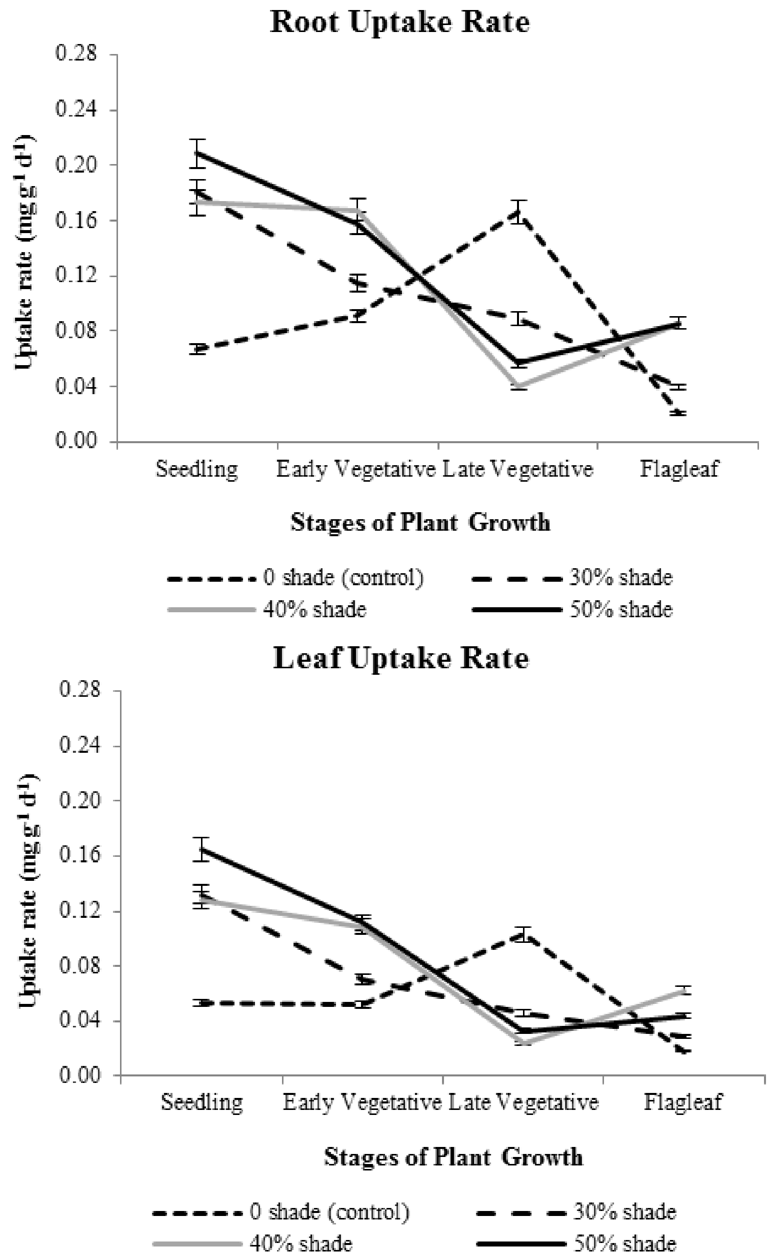

Fig. 3. Phosphorus root and leaf uptake rates of abaca (mg $g^{-1}_{dry\ matter}$ d^{-1}) at different developmental stages as affected by shade across irrigation-fertilization treatments

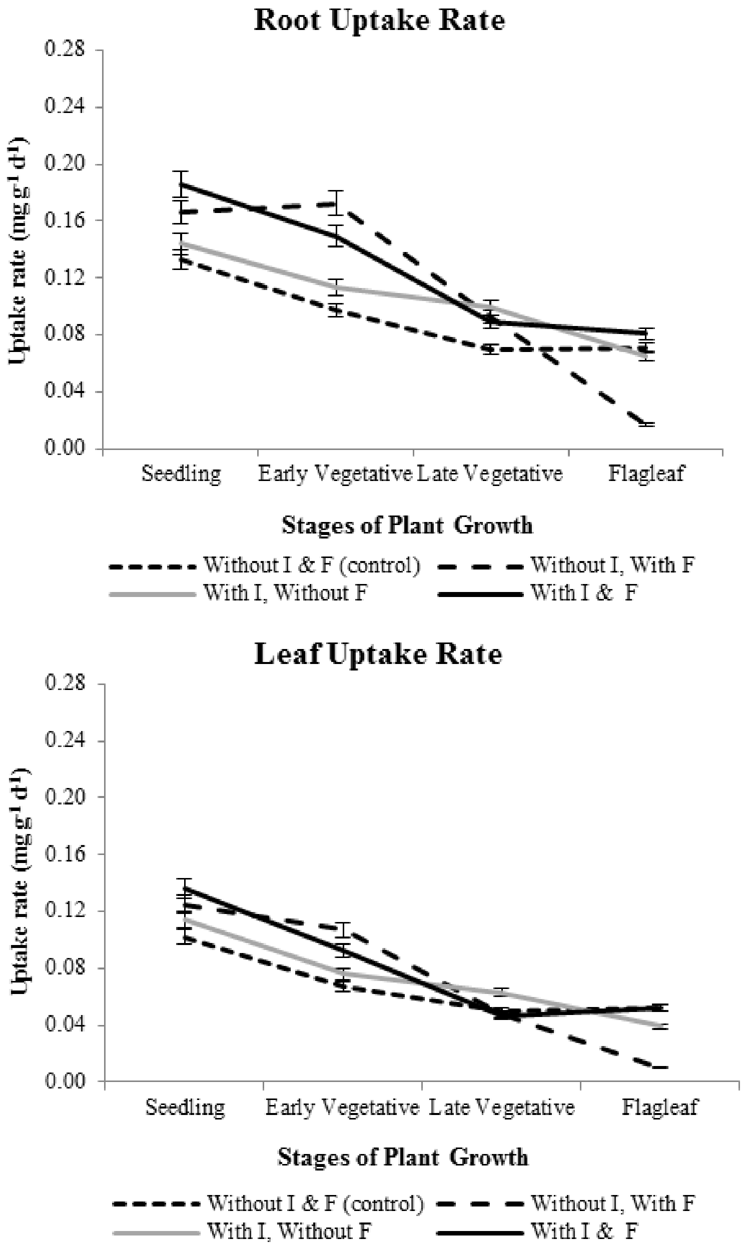

Fig. 4. Phosphorus root and leaf uptake rates of abaca (mg $g^{-1}_{dry\ matter}$ d^{-1}) at different developmental stages as affected by irrigation-fertilization across shade treatments

Effects of shade on K root and leaf uptake rates

The influence of shade on K root and leaf uptake rates was significant ($p \leq 0.01$) only at seedling and late vegetative stage of plant growth. However, Figure 5 shows a sharp decline in both K root and leaf uptake rates during the early vegetative stage, except on abaca sample plants grown in 0% sunlight. This substantiated the results presented in Table 2.

Effects of irrigation-fertilization on K root and leaf uptake rates

Abaca plants grown in the different irrigation and fertilizer application treatments showed an optimum response curve on both K root and leaf uptake rates at late vegetative stage and being low at early vegetative stage (Figure 6). This rapid decline in K root and leaf uptake rates corroborated the effect of the typhoon on NPK plant uptake (Table 3). Analysis of variance revealed that fertilizer application considerably enhanced ($p \leq 0.01$) K root and leaf uptake rates only during the seedling stage. Supplemental irrigation had no significant influence on K root and leaf uptake rates from seedling stage until flagleaf stage.

Fiber yield

Effects of shade on fiber yield

Statistical analysis results showed that shade significantly and positively ($p<0.01$) influenced total fiber yield of abaca. This was because abaca plants harvested under 50% shade produced longer (2.29±0.10 m), bigger (16.10±0.50 cm) and heavier (10.80±0.05 kg) pseudostem than those harvested in the open (0% shade) with pseudostem's length, base girth, and weight of 1.42±0.10 m, 13.18±0.50 cm, and 5.20±0.05 kg, respectively.

Table 4 shows that abaca planted in 50% shade had considerably higher fiber yield compared to other shade treatments. Analysis of variance revealed that fiber yield in 30% and 40% shade treatments were statistically similar but significantly lower than in the 50% shade and higher than those in 0% shade treatment.

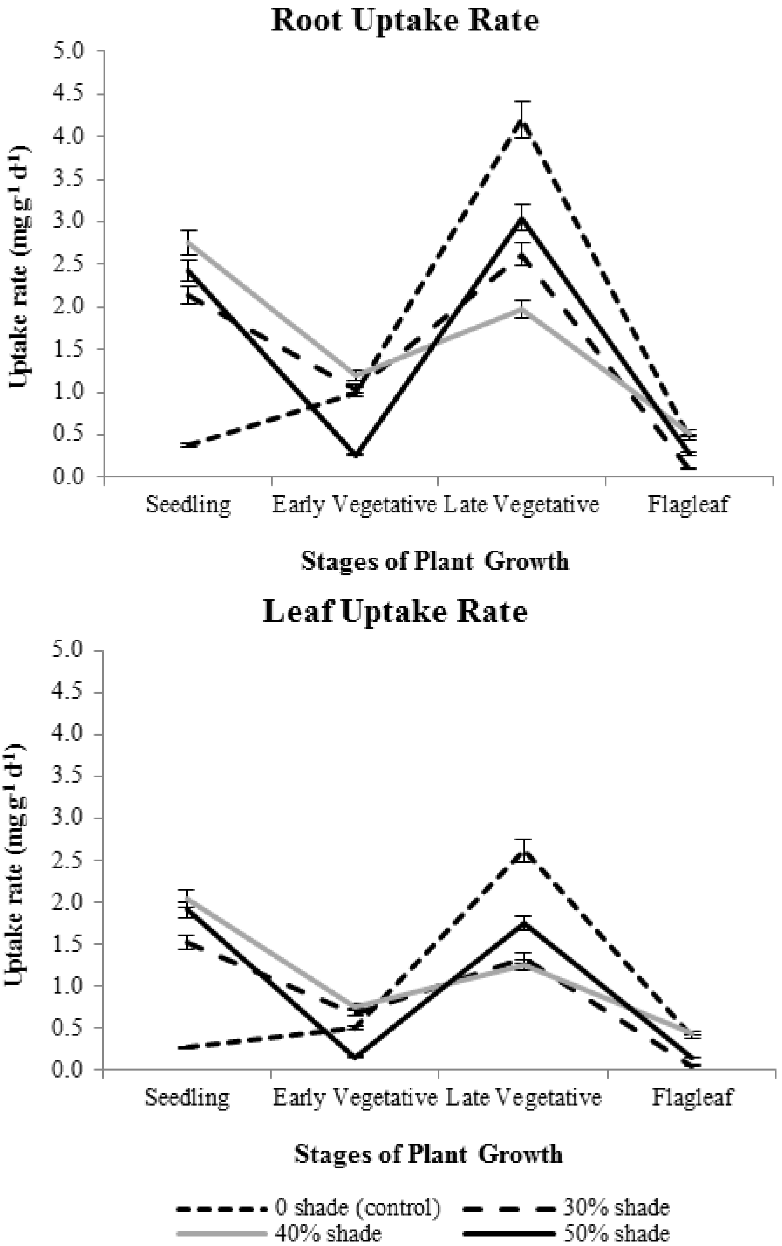

Fig. 5. Potassium root and leaf uptake rates of abaca (mg $g^{-1}_{dry\ matter}$ d^{-1}) at different developmental stages as affected by shade across irrigation-fertilization treatments

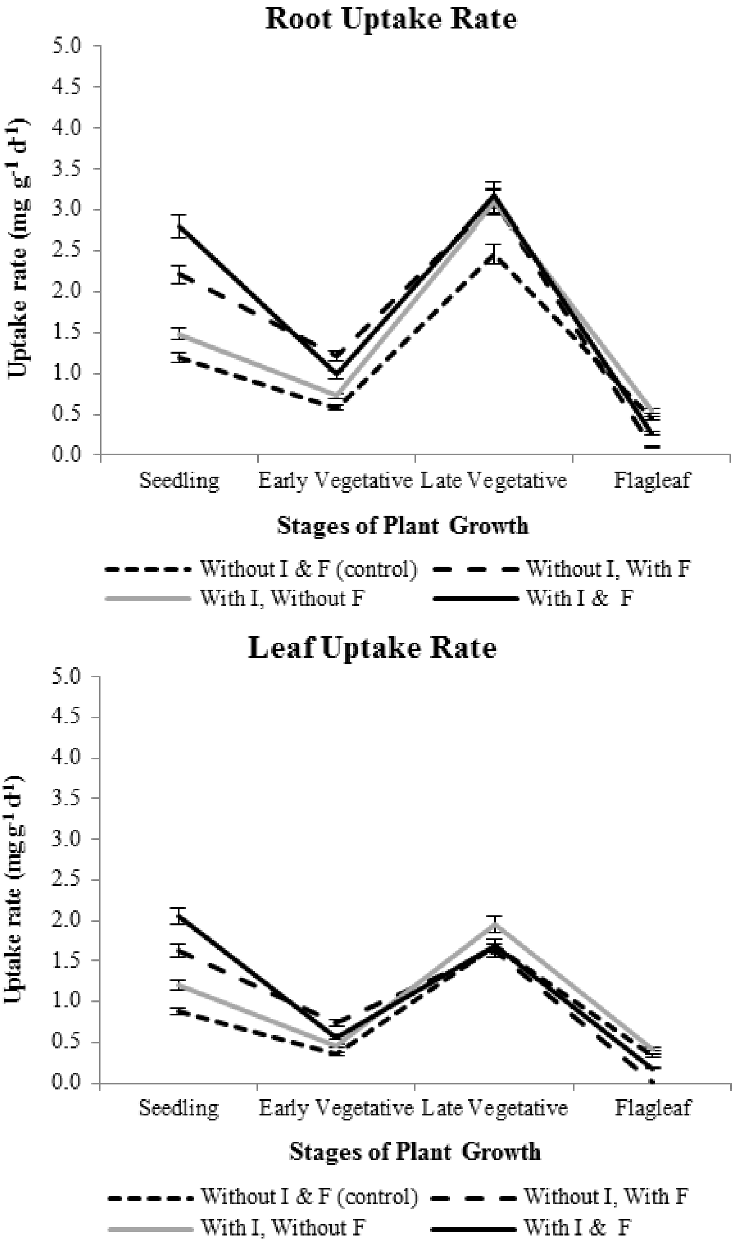

Fig. 6. Potassium root and leaf uptake rates of abaca (mg $g^{-1}_{dry\ matter}$ d^{-1}) at different developmental stages as affected by irrigation-fertilization across shade treatments

Table 4. Dried fiber yield of outer leaf sheaths, inner leaf sheaths and total fiber yield (g plant^{-1}) of abaca as affected by shade and irrigation-fertilization treatments

Treatments	**Dried Fiber Yield (g plant^{-1})**		
	Outer Leaf Sheaths' Fiber	Inner Leaf Sheaths' Fiber	Total Fiber Yield
Shade			
0% shade (control)	10.93±0.82^{c}	43.81±4.11^{c}	50.95±4.64^{c}
30% shade	16.76±0.68^{b}	78.76±3.92^{b}	92.95±4.43^{b}
40% shade	16.41±0.60^{b}	86.92±3.78^{b}	102.92±4.27^{b}
50% shade	19.39±0.60^{a}	115.87±3.82^{a}	135.04±4.31^{a}
Irrigation-Fertilization			
Without I and F (control)	14.83±0.75^{b}	65.79±4.07^{c}	78.57±4.60^{b}
Without I, with F	16.89±0.67^{a}	87.49±3.87^{ab}	102.40±4.37^{a}
With I, without F	14.33±0.65^{b}	77.35±3.87^{bc}	90.32±4.38^{b}
With I and F	17.44±0.65^{a}	94.73±3.82^{a}	110.57±4.32^{a}

Note: least square means in each cell within the column with different letter superscripts (a-c) are significantly different at $p<0.05$, $n=208$

Effects of irrigation-fertilization on fiber yield

The abaca plants treated with NPK fertilizer and/or combination of irrigation-fertilization had considerably higher fiber yield compared to sample plants without any irrigation and NPK fertilizer application (Table 4). The abaca harvested in plots with irrigation and fertilizer application had longer (2.02±0.10 m), bigger (15.59±0.50 cm) and heavier (9.40±0.05 kg) pseudostem compared to those plants harvested in plots without irrigation and NPK fertilization with pseudostems' length, base girth, and weight of 1.64±0.10 m, 13.29±0.50 cm, and 7.0±0.05 kg, respectively. Analysis of variance confirmed the effect of NPK fertilization on total fiber yield, where significant difference (probability<0.0001) was observed on abaca planted in plots with fertilizer application treatment. There was no significant effect on fiber yield in abaca grown in plot with supplemental irrigation compared to the control treatment. However, considerable effect (probability<0.0001) was documented in plot supplied with both irrigation and NPK fertilization.

DISCUSSION

Soil nutrient status. The results of soil profile examination showed that the soil was deep, porous, had good soil structure and excellent drainage indicating that the soil physical conditions were favourable for abaca production. On the other hand, soil analyses revealed that total N and available P were low (category A) while exchangeable K was high (category C) for plant nutrition according to Hoffmann's (1991) nutritional standard on agronomic crops. In this particular site, the soil was classified as a Haplic Alisol developed from alluvial sediments of volcanic origin according to FAO-World Reference Base (IUSS Working Group WRB, 2006), whose clay fraction is dominated by kaolinite and haloysite (Asio, 1996). The soil has more than 60% P retention capacity and contains significant amounts of goethite and hematite (Asio *et al.,* 1998).

NPK plant uptake. Growth is an important component of NPK plant uptake (Turner and Lahav, 1985). If NPK were in adequate supply in the field, then the amount of NPK absorbed is likely to be proportional to the amount of growth made (Turner and Lahav, 1986). Hence, if growth is reduced (by environmental or soil conditions) then the amount of nutrient absorbed will also be reduced. In this study, results showed that the amount of NPK plant uptake is highly correlated (r=0.98) to the amount of growth made at different stages of plant growth. Abaca absorbed high amount of potassium than nitrogen and phosphorus. This confirms that abaca plant is a heavy potash feeder (Halos, 2008; Armecin and Gabon, 2008). Marschner (1995) also reported that plants require 2-5% N of plant dry weight and 0.3-0.5% P of plant dry weight.

The growth of abaca planted in 0% shade was negatively affected by high radiation which caused photoinhibition and photooxidative damage of the crop at seedling and early vegetative stages that significantly affected N and P plant uptake (Table 2). On the other hand, K plant uptake of sample plants grown in 40% and 50% shade was significantly reduced at early vegetative stage due to the typhoon that severely damaged both roots and leaves of the crop. Lambers *et al.* (1998) reported that environment strongly affects plant nutrient concentration by changing both allocation among organs and the composition of individual tissues. This is true for nutrients associated with metabolism and more mobile elements (i.e., NPK) where temperature significantly influenced the concentration of these nutrients in leaves, pseudostem, corms and roots (Lahav and Turner, 1985). Furthermore, the differential leaf senescence among abaca plants grown in different treatments influenced NPK plant uptake at flagleaf stage. It is estimated that approximately half of the N and P content in the leaves is resorbed (Aerts, 1996; Killingbeck, 1996) or retranslocated to subsequent generations of suckers (*Turner* and *Lahav*, 1986) during senescence. According to Lambers *et al.* (1998), resorption is positively correlated with leaf mass loss during senescence, which suggests a role for source-sink interaction and phloem transport. The results of this study showed a considerable decline in leaf mass ratio at flagleaf stage that significantly affected NPK plant uptake. This indicates that the crop has already reached its maturity, switching from vegetative to generative growth stage.

NPK root and leaf uptake rate. Rates of nutrient uptake depend on the quantity of root surface and the uptake properties of this surface (Lambers *et al.*, 1998). Likewise, Turner and Lahav (1986) reported that the size of the root system will influence the ability of the plant to exploit the soil for nutrients and water. According to Lambers *et al.* (1998), the relative size is usually expressed as the root mass ratio (root mass as a fraction of total plant mass). The results on dry matter allocation among abaca organs showed that shade significantly affected (probability=0.0286) root mass ratio at late vegetative stage while irrigation-fertilization significantly influenced root mass ratio at late vegetative (probability=0.0110) and flagleaf (probability=0.0054) stages. It was recorded that abaca planted in 0% shade and in without irrigation-fertilization had higher root mass ratio compared to sample plants grown in other shade and irrigation-fertilization treatments. Brouwer (1962) found that root mass ratio is usually enhanced by growth at a low nutrient supply. Furthermore, Lambers *et al.* (1998) reported that plants have some capacity to acclimate to a range in soil conditions. One of these acclimations is morphological where a plant usually increase its root mass ratio when nitrogen is limited for its growth.

Meanwhile, the substantial shade effect on NPK root and leaf uptake rates at seedling and early vegetative stage could be attributed to the extensive effect of radiation (temperature) on the dry matter production of abaca grown in 0% shade. The study of Turner and Lahav (1986) on *Musa* (AAA group, Cavendish sub-group) grown in sunlit controlled-environment chamber showed that nutrients distribution among banana parts was influenced by the changing patterns of dry matter production and distribution brought by temperature.

Fiber yield. The major result of the study was the superior productivity of abaca in response to increasing shade. Horticultural measurements during harvest revealed that abaca plants grown under 50% shade were taller and had bigger, and heavier stalks (pseudostem) resulting in higher yield (g plant^{-1}) compared to abaca harvested from other light treatments. The results are in accordance with the findings of Batugal *et al.* (1977) on abaca (variety *Tinawagang puti*) where improved growth and yield were recorded in 66% light. Torquebiau and Akeampong (1994) and Senevirathna *et al.* (2008) studying edible banana (*Musa x paradisiaca*) under different irradiance documented the highest biomass and yield at 50% light. Meanwhile, Söndahl *et al.* (2005) recommended that overhead shade in arabica coffee (*Coffea arabica*) should not exceed 50% of total irradiance to attain optimum yield. Furthermore, Alcober (1986) reported that fiber yield depends on the number of harvestable stalks and the physical characters of the stalks at harvest. He found that there was a significant correlation between stalk weight, length and fiber yield. This was consistent with the result in this study where there were highly significant correlations between fiber yield and pseudostem or stalk weight (r=0.93) and length (r=0.87).

On the other hand, the higher yield of abaca grown in plots with NPK fertilizer application and/or combination of irrigation-fertilization across shade treatments could be attributed osmoregulation process. Osmoregulation is a process that affects water transport in the xylem that maintains high daily cell turgor pressure which in turn affects cell elongation for growth (Saifuddin *et al.*, 2010). Most importantly, it regulates the opening and closing of the stomata which effects transitional cooling and carbon dioxide uptake for photosynthesis (Yang and Zhang, 2006). Moreover, Lambers *et al.* (1998) reported that plants from nutrient-rich sites tend to produce more biomass per unit nutrient in the plant. Some published documents also revealed that low NPK nutrition on plants caused lower photosynthetic rates and slower leaf expansion (Evans, 1983; Field and Mooney, 1986; Gerik *et al.*, 1998; Zhao *et al.*, 2003). Thus, the application of NPK nutrients or combination of irrigation and fertilizer application consistently and positively improved the growth and NPK uptake of abaca leading to higher biomass production and fiber yield.

CONCLUSION

The study was conducted to investigate the effect of different shade conditions, irrigation, and fertilizer application on NPK plant uptake and fiber yield of abaca. Likewise, the study aimed to give a broad representation on the pattern of NPK root and leaf uptake rates at various stages of crop growth. Based on the results of the study, the following conclusions were drawn:

First, shade can fully prevent the negative effect of photoinhibition and photooxidative damage on the growth and NPK uptake of abaca planted in full sunlight at seedling and early vegetative stages which eventually lead to higher biomass production and fiber yield.

Second, irrigation and fertilizer application cannot offset or compensate the effect of shade on NPK uptake and fiber yield of abaca considering the present environmental and soil conditions of the site when the experiment was conducted.

Third, environmental (i.e., high radiation and/or temperature) and soil conditions (i.e., water and nutrient availability) can extremely affect NPK root and leaf uptake rates of abaca. However, the plant developed some capacity to acclimate by morphologically increasing its root mass ratio at late vegetative stage.

Fourth, the pattern on NPK leaf uptake rate was highly indicative of the trend on NPK root uptake rate as influenced by shade and irrigation-fertilization at different stages of crop growth.

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