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Impact of Irrigation and Decreased Light Level by Shade Crop on the Establishment of Cacao Plants

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ABSTRACT

The massive establishment of new plantations supported by the basic needs of a crop are technical approaches for an increased crop productivity. Water and decreased light levels by shade (i.e. intercropping) are considered basic needs of cacao plants, especially during the early vegetative growth stage. Thus, this study aimed to evaluate the influences of irrigation, intercropping, and intercrops on the performance of 39 cacao plantations at the establishment phase. The performance of each cacao plantation, after establishment, was evaluated and rated from 1 to 7 (1- poor; 3- satisfactory; 5- very good; and 7- outstanding) as a rating scale. In general, the results revealed that cacao plantations supplied with irrigation or under decreased light levels by intercrops (regardless of their nature), as well as a combination of these, made the plants perform better than those in plantations without irrigation and when plants were highly exposed to sunlight. The results suggested the importance of irrigation and decreased light levels by intercropping as prerequisites for a successful establishment of cacao plantations.

Introduction

The “Plant Plant Plant” program of the Department of Agriculture in the Philippines could help attain crop production targets. Recently, there was a massive establishment of new cacao plantations throughout the Philippines. This action is needed to meet the country’s 100,000 MT of dried beans target by the year 2022 (Department of Agriculture [DA], 2017). The National Seed Industry Council recommended high-yielding clones (grafted) that were provided as subsidy by some government agencies to interested farmers who wanted to venture on cacao production. However, it cannot be denied that this program will only succeed if aided with proper intercultural management practices. In the Bukidnon province, for example, several agencies, including the Philippine Council for Agriculture, Aquatic and Natural Resources, Research and Development (PCAARRD) supported the research, extension, and technology transfer on cacao through partnership with the academic sector to guide growers in employing proper intercultural management practices.

Knowing and providing crop requirements at optimum levels could lead to productive cacao farming. Cacao is a tree crop that can be cultivated as a monocrop and as an intercrop, but the latter is mostly employed by growers because of several advantages. Cacao requires proper shade management (decreased light levels) during the early vegetative growth (Acheampong et al., 2019) though some new hybrid clones can grow properly under direct exposure to sunlight as well. Essentially, the amount of light level that penetrates a cacao farm depends on the type of cultivar which is planted (Sonwa et al., 2018).

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Prolonged soil water limitation also tends to reduce yield significantly (Acheampong et al., 2019), although some hybrid clones can tolerate drought conditions (Ofori et al., 2014).

Water availability and reduced light levels are primary considerations in the establishment of new cacao plantations. Plant growth and development are influenced by different light intensities (Aliniaeifard et al., 2018). Also, light intensity changes under the plant canopy (Ghorbanzadeh et al., 2020). In most crops, especially those under protected cultivation, supplementary light is needed to improve quality (Asayesh et al., 2021). In contrast, reduced light levels or partial shade are needed by cacao plants, especially at early growth stages. Niether et al. (2018) stated the important role of shade trees in reducing ecophysiological stresses for cacao trees and maintaining photosynthesis at high temperatures. However, a study by Famuwagun et al. (2018) showed that irrigation is more essential than the amount of light, since it is a larger factor that influences the survival of cacao seedlings in the field. There is a small amount of local information on the classification of intercrops (i.e. plants that exist in the farm or are grown simultaneously with cacao seedlings) on the success of cacao plantations and their establishment.

This study evaluated the effects of irrigation, reduced light levels by intercrops, and classification of intercrops, while specifically zooming on how the performance of new cacao plantations were established in four municipalities within Bukidnon, Philippines.

Materials and Methods

This study was conducted in municipalities of Lantapan and Maramag, comprising two cities, i.e. Malaybalay and Valencia, in Bukidnon, Philippines, from August 2016 to July 2019. Thirty-nine newly-established cacao plantations, as reported by Valleser et al. (2020b), served as experimental units for this study.

Grafted cacao seedlings (UF 18 as rootstock) composed of at least three high-yielding clones which were either BR25, UF18, PBC123, K1, K2, USM1 or K9. Since they were registered and recommended by the National Seed Industry Council (NSIC), using them as planting materials was legal and safe. BR 25 and UF 18 are commonly-known clones in all plantations. These planting materials were produced by the Central Mindanao University-Science and Technology Community Based Farm (STCBF)- Cacao Nursery which is reachable and citable (http://bpi.da.gov.ph/bpi/index.php/sample-levels/crop-research-and-production-support-section/4075-certificate-of-accreditation-of-central-mindanao-university-as-plant-nursery-operator) in Musuan, Maramag, Bukidnon, Philippines. Each site (experimental unit) was planted with 250 grafted cacao seedlings (i.e. at least three compatible clones). Transplanting the cacao seedlings in each plantation depended on seedling availability and readiness of the site (while having planting holes based on a recommended farm layout). The farm layout was based on flat terrain and existing tree/crop vegetation in the area. Dimensions of planting holes (40 cm depth x 40 cm in diameter) were properly observed. Organic fertilizer (vermicast) together with complete (14-14-14) and dolomite (liming materials) were also applied during transplanting. Local recommended fertilizer management for cacao plants (Table 1) was used as a benchmark for fertilizer application. Other important intercultural management practices (e.g. pruning, field sanitation, etc.) were also employed for the cacao plants.

Availability of irrigation (natural bodies of water or small water impoundments) and reduced light levels by intercrops were the only factors not common to the new cacao plantations established in the region and in locations for the purpose of the experiment. Thus, we evaluated the effects of these factors on the performance of cacao plantations which were established in the locations intended for this research.

Data collection

The performance of each cacao plantation was evaluated and rated from 1 to 7 (1- poor; 3- satisfactory; 5- very good; and 7- outstanding). However, for the purpose of this study, we considered only the performance of cacao plantation during the completion of the project as influenced by irrigation and intercropping (Table 2).

An assessment of cacao plantations and their performance was mainly based on plant vigor (visual observation) and plant mortality. Plant vigor was scored using the following 1-7 rating with reference to the plant stand at CMU's high-yielding cacao varieties (HYV) clonal garden for a particular stage of growth: 1 = vigor is 25-100% lower compared to reference plants; 3 = vigor is 1-24% lower compared to reference plants; 5 = vigor is comparable to reference plants; and 7 = more vigorous than the reference plants. For plant mortality:

1 = 50-100% plant mortality; 3 = 25-49% plant mortality; 5 = 10-24% plant mortality; and 7 = less than 10% plant mortality.

Table 1. Fertilizer programs for cacao plantations adopted by farmers

Plant age (month(s) after transplanting)	Fertilizer material/ Soil amendment			
	Vermicast	Complete (14-14-14)	KCl (0-0-60)	Dolomite
	-----grams per tree-----			
0	500	100	0	100
1	0	45	0	0
4	0	60	0	0
8	0	60	0	0
12	0	92	0	0
18	0	121	0	0
24	0	192	19	30

Table 2. Information of the farm site per municipality/city in terms of irrigation availability and light level by shade crops with their respective performance rating (modified from a source by Valleser et al., 2020c)

Farm Site	Municipality/City	Planting Date	Irrigation Availability	Light Level	Nature of Shade Crop	Plantation Performance Rating*
LN-1	Lantapan	June 2017	With	Reduced	Newly grown	7
LN-2	Lantapan	June 2017	With	Reduced	Newly grown	3
LN-3	Lantapan	August 2017	With	Reduced	Existing	3
LN-4	Lantapan	June 2017	With	Reduced	Newly grown	7
LN-5	Lantapan	July 2017	Without	Reduced	Newly grown	3
LN-6	Lantapan	July 2017	With	Reduced	Existing	5
LN-7	Lantapan	August 2018	Without	Reduced	Existing	1
LN-8	Lantapan	November 2017	Without	Normal	Not applicable	1
LN-9	Lantapan	January 2018	Without	Normal	Not applicable	1
MC-1	Malaybalay City	July 2017	With	Reduced	Newly grown	7
MC-2	Malaybalay City	June 2017	With	Reduced	Newly grown	5
MC-3	Malaybalay City	June 2017	With	Normal	Not applicable	5
MC-4	Malaybalay City	September 2018	With	Reduced	Newly grown	3
MC-5	Malaybalay City	July 2017	With	Reduced	Newly grown	3
MC-6	Malaybalay City	September 2018	With	Reduced	Newly grown	3
MC-7	Malaybalay City	July 2017	Without	Normal	Not applicable	1
MC-8	Malaybalay City	October 2017	With	Reduced	Existing	5
MC-9	Malaybalay City	October 2017	With	Reduced	Existing	3
MC-10	Malaybalay City	October 2017	With	Reduced	Existing	3
MC-11	Malaybalay City	October 2017	With	Reduced	Existing	3
MC-12	Malaybalay City	November 2017	With	Reduced	Existing	5
MC-13	Malaybalay City	October 2017	With	Reduced	Existing	1
MC-14	Malaybalay City	February 2018	Without	Reduced	Existing	5
MC-15	Malaybalay City	November 2017	With	Normal	Not applicable	1
VC-1	Valencia City	September 2017	With	Normal	Not applicable	1
VC-2	Valencia City	June 28, 2017	With	Reduced	Existing	5
VC-3	Valencia City	June 28, 2017	With	Reduced	Existing	3
VC-4	Valencia City	September 2017	With	Reduced	Existing	5
VC-5	Valencia City	September 2017	Without	Normal	Not applicable	1
MR-1	Maramag	December 2017	With	Normal	Not applicable	5
MR-2	Maramag	June 2017	With	Reduced	Existing	7
MR-3	Maramag	May 2018	With	Reduced	Existing	3
MR-4	Maramag	May 2018	Without	Normal	Not applicable	1
MR-5	Maramag	May 2018	Without	Normal	Not applicable	1
MR-6	Maramag	May 2018	Without	Normal	Not applicable	1
MR-7	Maramag	May 2018	Without	Normal	Not applicable	1
MR-8	Maramag	May 2018	With	Reduced	Existing	3
MR-9	Maramag	May 2018	With	Reduced	Existing	3
MR-10	Maramag	May 2018	Without	Normal	Not applicable	1

The formula below was used for computing the cacao plantation performance and its rating for each farm:
Performance rating = (plant vigor score + plant mortality score)/2

Statistical analysis

Experimental units (plantations) were classified into two groups, based on irrigation availability (Group 1 = with and Group 2 = without irrigation). Those plantations with available water sources (e.g. water impoundment, pond, creek, river, irrigation canal, well of water, etc.), within 1 km radius of the research location, comprised Group 1. Meanwhile, Group 2 comprised plantations without nearby water resources (>1 km radius). These relied only on precipitation. Likewise, plantations were categorized into two groups in terms of the presence of intercrops (Group 1 = with and Group 2 = without intercrops). Plantations of which cacao seedlings were grown with other plants (intercrops) comprised Group 1. Plantations wherein cacao seedlings were grown under monocropping or sole cropping belonged to Group 2. The nature of shade crops (Group 1 = simultaneously grown and Group 2 = established) was also considered. Group 1 had plantations wherein intercrops were simultaneously grown with cacao seedlings. These intercrops were mostly annuals such as corn and high-valued vegetables (eggplant, lady's finger, etc.). Group 2 comprised plantations with established plants that provided shade to newly transplanted cacao seedlings. These plants were mostly biennial and/or perennial in nature, and included trees, banana, rubber, *Paraserianthes falcataria*, etc. Individual effects of irrigation availability, the presence of intercrops and the nature of intercrops on the performance of established cacao plantations were analyzed using a t-test.
To determine the combined effects of irrigation availability and reduced light levels or the presence of intercrops, the procedure was that cacao plantations (regardless of municipality/city) were classified into four groups, i.e. Group 1 = with irrigation + with intercrops; Group 2 = with irrigation + no intercrop; Group 3 = without irrigation + with intercrops; Group 4 = without irrigation + without intercrop. Each served as a treatment group, whereas farm sites were considered as experimental units. Data were then analyzed using Completely Randomized Design (CRD) in an unequal number of replications through Statistical Packages for Social Sciences (SPSS) 14.0 trial version.

Results

Impacts of irrigation availability on the performance of newly established cacao plantations

Regardless of the type of irrigation source, cacao plantations which were supplied with irrigation (3.96) performed better than those plantations without irrigation (1.5) based on the t-test (Fig. 1). From the results, it can be inferred that the importance of irrigation on the establishment of cacao plantations was noteworthy. Irrigation availability within the plantation site sustained cacao water requirement during periods with limited or near-zero rainfall. This should be seen as an important factor by farmers who aimed to venture on cacao production. Though the construction of irrigation facilities (e.g. water impoundment) is costly, this may in fact provide assurance for a successful cacao plantation establishment and, of course, assist with the increase in cocoa bean yield.

Impact of reduced light levels by shade crop on the performance of newly established cacao plantations

The existence of intercrops resulted in reduced light levels and was beneficial to the growth and survival of cacao at the establishment phase of the plantation. Those cacao fields with intercrops (shade crop) performed better (3.96) than those planted without intercrops (1.86) as shown in Figure 2. The results of this study suggested the importance of shade (reduced light levels), and indicated that shade should be implemented at an early vegetative growth of cacao plants. Farmers in the Philippines who aim to venture on cacao production must consider shade as an essential factor for a successful cacao plantation establishment.

Impact of the type of intercrop on the performance of newly established cacao plantations

According to Figure 3, the performances of newly established cacao plantations varied in response to the type of intercrop. Nonetheless, based on the t-test, the type of intercrop had no significant influence on the performance of newly established cacao plantations. This result indicated that the intercrop plants in this study had comparable effects and provided optimum growth for the newly transplanted cacao seedlings.

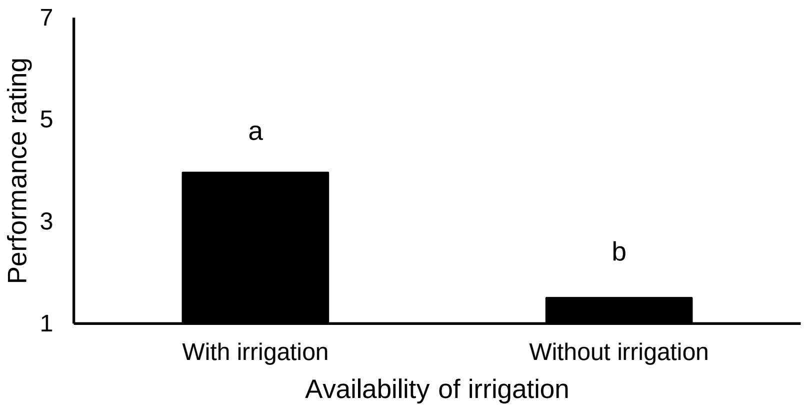

Fig. 1. Impact of irrigation availability on the performance of newly established cacao plantations

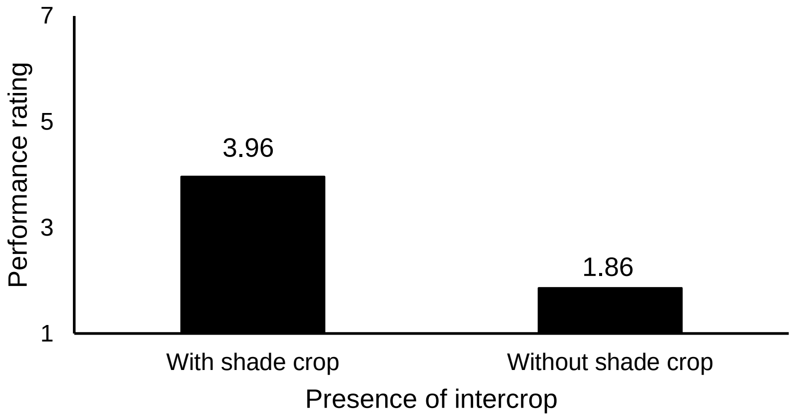

Fig. 2. Impact of intercrops on the performance of newly established cacao plantations

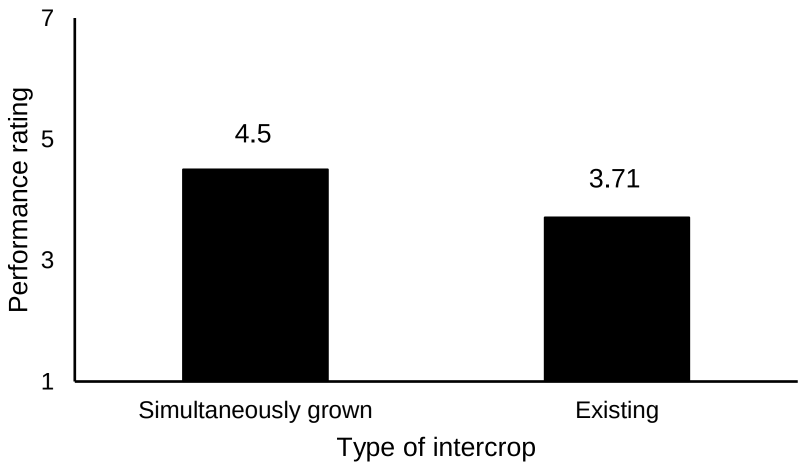

Fig. 3. Impact of the type of intercrop on the performance of newly established cacao plantations

Interaction effects of irrigation and reduced light levels by intercrop on the performance of new cacao plantations

Plantations under group 1 category (with irrigation and with intercrops) had a satisfactory to very good performance (4.04). This was followed and statistically comparable with the performances of plantations under Group 2 (with irrigation and intercrops) and then Group 3 (without irrigation but with intercrops) which had a performance rating of 3.00 and 2.20, respectively. The absence of irrigation and intercrops resulted in a poor performance (1.00) of newly established cacao plantations (Table 3).

Table 3. Performance of established cacao plantations as influenced by the presence of irrigation and reduced light levels by intercropping

Group/Category of cacao plantation	No. of farms	Plantation performance rating*	Descriptive performance rating
Group 1 (with irrigation; with intercrop)	23	4.04^{a}	Satisfactory to very good
Group 2 (with irrigation; without intercrop)	4	3.00^{ab}	Satisfactory
Group 3 (without irrigation; with intercrop)	5	2.20^{ab}	Poor to satisfactory
Group 4 (without irrigation; without intercrop)	7	1.00^{b}	Poor

*- highly significant based on Tukey's HSD test at the 0.01 level

The results obviously suggested the need of irrigation and reduced light levels, or the provision of shade, for an optimal establishment of a cacao plantation. However, it was also noted that the positive effect of irrigation on plantation performance was numerically higher than that of a given intercrop, although this was not statistically significant.

Discussion

Cacao is known as a shade-loving crop. It requires shade, especially during its early vegetative growth stage. However, cacao will also thrive even if shade is absent or very limited, as long as optimal amounts of water are provided (Valleser et al., 2020a). Growth of cacao can be greatly affected by climate changes and water availability (Santos et al., 2018). In the absence of natural water resources (e.g. lake, spring, river, etc.), small water impounding or rainwater harvesting would serve as an alternative. Naval (2016) reported that small water impounding projects located in the municipalities of Cabarroguis and Maddela, Quirino Province, Philippines, have shown a significant increase in annual yield and net income of the farmer-beneficiaries. But since water is a scarce, natural resource in some upland areas of Bukidnon, even with the presence of water impoundment, some efficient strategies are yet to be employed to conserve water or to minimize irrigation activities. One of these strategies, though not considered in this study, is mulching which improves the soil moisture status by reducing soil moisture evaporation (Acheampong et al., 2019) within the plantation.

Unlike other agricultural crops, cacao is a shade-loving crop. Reduced light levels are thus needed by young cacao plants. The intercrops used by the farmers provided shade or reduced light levels to the newly transplanted cacao plants, thereby resulting in better growth performance. This finding supports the recommendation of Asare et al. (2019) on the promotion of shade trees for a sustainable climate-smart cacao agenda. While intercrops and trees provide a positive impact on the growth of young cacao plants, conditions that prevail below the shade crop canopy (i.e. higher relative humidity, higher moisture, lower temperature) become favorable for pests and diseases. However, this concern was addressed by a report (Armengot et al., 2020) on cacao agroforestry systems which did not experience an increase in pest and disease incidence, as a result of the measures that were taken to tackle the risk of such incidences. The growth of cacao under agroforestry systems, herein, was comparable with monocultures, as long as good cultural management practices were employed. The same trend on pest and disease incidence was observed on a study that aimed at rehabilitating a 22-year-old degraded cacao plantation (Vanhove et al., 2016) and on cacao farms in the Peruvian Amazonia region (Kieck et al., 2016). Cacao agroforestry would encourage a build-up of soil microbial communities (Buyer et al., 2017) which could assist in managing pests and diseases.

The intercrop plants in this study had comparable effects and provided optimal growth for the newly transplanted cacao seedlings. However, it should be noted that the compatibility effects of these plants on cacao growth were specific only to the early vegetative stage of growth. The use of non-legume timber trees with an optimized spacing pattern can be used as dominant shade trees for cacao plants (Bai et al., 2017). Tree crops should only serve as temporary shade for cacao, however. As cacao trees approach a peak of their fruiting stage (i.e. 5 years after transplanting), there is a need to eliminate some of the shade crops to prevent the overlapping of plant canopies. At this stage, cacao monocropping can be considered as an ideal approach, compared to intercropping. Otherwise, the optimization of planting distances is needed. Koko et al. (2010) reported that cacao vigor and yield were positively correlated with the amount of light that was received by the cacao plants. Maximum light interception can be achieved under the monocropping scheme or if shade crops are planted within optimal patterns of distancing.

Some plants (e.g. *Nephelium lappaceum* and *Cola acuminata*) may also serve as alternate hosts of cacao pod borders where the incentives of shade cropping remain valuable for growth (https://www.plantwise.org/KnowledgeBank/datasheet/7017#HostPlantsSection). Thus, it is important to plant shade crops that are not an alternate host of cacao pests and diseases. Apart from reduced light levels, water is a critical factor for growth and development of young cacao plants. Young cacao plants require irrigation, especially during periods with no rainfall. Famuwagun et al. (2018) reported that irrigation was employed at intervals of 5-10 days which improved the field survival of cacao seedlings by 95%, with or without shade cropping. During the dry months, irrigation is essential for the survival of crops. Irrigation availability on a farm tends to compensate soil moisture loss which happens as a result of evapotranspiration.

In farming, it cannot be denied that some farmers are reluctant to employ irrigation and shade cropping on newly transplanted cacao seedlings. This situation might be widespread among traditional farmers, especially when transplanting tends to be scheduled during the onset of the rainy season (mid of May-July) in the general climate of Bukidnon, Philippines. However, as climate change is increasingly becoming prevalent, research cannot assure farmers that there will be enough rainfall during the rainy months. Thus, there is a need to provide optimal environmental conditions wherein the newly transplanted cacao seedlings can be managed for sustainable cacao production in Bukidnon, Philippines. Apart from the protection against high solar radiation, intercropping practice could alleviate water scarcity which would otherwise affect the growing crops. In rubber-based agroforestry systems, intercrops can improve surface water availability (Yang et al., 2020).

Conclusions

Irrigation and reduced light levels by intercropping played a vital role in causing a successful establishment of cacao plantation in Bukidnon, Philippines. The absence of one factor in the establishment of cacao plantation is more tolerable than the absence of both factors. Intercrops which were utilized in this study reduced the light level or provided partial shade to cacao seedlings. Thus, they can be used by farmers who aim to venture on cacao production. To ensure a successful establishment of new cacao plantation, it is highly recommended that farmers manage irrigation and/or apply a reduced level of sunlight by intercropping, so that newly transplanted seedlings could grow optimally.

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Conflict of interest

The authors indicate that there are no conflicts of interest.

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